# 2º ELAEE

## 2° Encuentro Latinoamericano de Economía de la Energía

**SEGURIDAD ENERGÉTICA, INTEGRACIÓN Y DESARROLLO EN AMÉRICA LATINA**

## 2nd LATIN AMERICAN MEETING ON ENERGY ECONOMICS

**ENERGY SECURITY, INTEGRATION AND DEVELOPMENT IN LATINA AMERICA**

AUSPICIA

EL MERCURIO

MPX

Colbún

ORGANIZA

INGENIERÍA DICTUC

COLABORAN

SOCHIEE

IAEE

B3E

Energías renovables

América economía

22 al 24 de marzo de 2009

March 22-24, 2009

Santiago, Chile

PONTIFICIA UNIVERSIDAD CATÓLICA DE CHILE
ESCUELA DE INGENIERÍA
DEPARTAMENTO DE INGENIERÍA INDUSTRIAL Y DE SISTEMAS

www.elaee.org

***Nº ISBN 978-956-14-1043-5***

# TITULO:

**ANALES DEL 2do ENCUENTRO LATINO AMERICANO DE ECONOMIA DE LA ENERGIA**

## SUBTITULO:

**SEGURIDAD ENERGÉTICA, INTEGRACIÓN Y DESARROLLO EN AMÉRICA LATINA**

SELLO EDITORIAL:
PONTIFICIA UNIVERSIDAD CATOLICA DE CHILE- EDICIÓN: 1

AUTOR: RICARDO RAINERI B.

# Contenido

## TITULO:

**ANALES DEL 2do ENCUENTRO LATINO AMERICANO DE ECONOMIA DE LA ENERGIA**

## SUBTITULO:

**SEGURIDAD ENERGÉTICA, INTEGRACIÓN Y DESARROLLO EN AMÉRICA LATINA**

*Nº ISBN  978-956-14-1043-5*

# 1. Globalization and Regionalization: Changing Patters of International Economic Activity

**Martinez-Garcia, Jaime**

Lecturer and Researcher

School of Economics, Authonomous University of San Luis Potosi, Mexico

Alvaro Obregon 64

San Luis Potosi, S. L. P. Mexico. 78000

Ph: +52-444-813-1238 ext. 116

Fax: +52-444-817-4705

jmartin@uaslp.mx

KEYWORDS: GLOBALIZATION, REGIONALIZATION, PLANNING

ABSTRACT: This paper is on the future collapse of globalization in its present form, and how its effects can be avoided following an adequate planning process. Economic globalization is based mainly in two elements: Information and Computer Technology (ICT), and cheap, massive, faster transportation. While ICT will continue its development, the increase in the cost of oil and its depletion, the strong future control on the emissions that cause global warming, and the difficulty of its substitution by alternative sources, will collapse the present model based in the location of production facilities based on comparative and competitive advantages. There is evidence that changes in prices due to fluctuations in oil markes have an impact equal to a tariff of 9%, and this tendency will continue. This paper shows that while technology and financial capital will maintain its international displacement and location, natural resources and human capital will be less mobile. Therefore, an alternative planning model is necessary. The Proposed model will consider not the political but the economic and geoghraphic limits and factor endowments, based on new

forms of international, regional and local cooperation, towards the regionalization of the economy, on a new role on the endogenous planning and regulation capacities of the state on the economic system, and on the principle of sustainability, from a global to a local perspective.

This paper is regarding the stages of the process of globalization, on the factors affecting its genesis and evolution, as well as on its impacts at the national and regional context for a sustainable development planning.

Globalization is multidimensional process, but this paper will be focused mainly on its economic aspects. At this moment, and according to the international trade theory, economic activity is is defined by the allocation of investment and production based on comparative and competitive advantages (Tugores Ques, 2005; Krugman y Obstfeld, 1995; Porter, 1990) as well as factor endowments and its relative prices. (Krugman y Obstfeld, 1995; Chalcholiades, 1990)

The prevailence of this model was confirmed by the changes occured in the international scenario between 1985 and 1995, when the world economic system was transformed from a bipolar scheme, based on ideologic and political differences, to one based on the free market economics, in which the state receded in its protagonic role by its reform to the private capital, in terms of investment, employment and contribution to economic growth

The process of economic reform started in the decade of 1980 in the industrialized countries, -mainly in the United States, with the government of Ronal reagan and in the United Kingdom with Margaret Thatcher- continued in the decade of 1990 in the countries of the former socialist block under the leadership of Mikhail Gorbachov (Martinussen, 1999) and latter in China. The prevailecense of this model in the world is almost absolut, with only two countries – North Korea and Cuba- still being centrally-planned, dirigiste economies

Globalization has been conduced by the countries of the Triad –North America, the Pacific Basin and the European Union- where is originated most of Foreign Direct Investment (FDI) in the form of Transnational Corporations (TNCs). An evidence of the fact that globalization is a process created for this entities is that they are responsible for most of FDI and the international trade of goods and servuices (Rugman and Hodgetts, 1997)

Another evidence ia the issue of the inclussion in the Former GATT of the TRIPs (Trade Ralated to Intellectual Property) and GATS (General Agreement on the Trade of Services) and its conversion into the World Trade Organization (WTO) given the fact that one of the main asses of TNCs are the patents resulting from its Research and Development (R and D) and that more than 50% of GDP of Industrialised countries is due to the services sector, in which

TNCs are main contributors (World Bank, 2007) In this sense, globalizatioon is perceived as a progresive, conmtinuous and linear process.

Among the existing theoretical approaches that could explain globalization is the Heckscher-Ohlin Model. Chalcholiades (1995) and Krugman and Obstfeld (1996) sumarise this model in terma of advantages for a country which specializes and export its production on the goods that are intensive in the abundant –and cheap- factor, and import those goods abundant in the that is scarce and expensive. In this form, as soon as a factor of production become scarce, exhausted and expensive -due to its exploitation- its relative price –as well as the good manufactured with it- will become expensive, and equal to that in other region of the world. Therefore, the abundant factor is exhausted, its relative price increases and those advantages disappear; consequently the trade of the produced good is reduced or suspended

In this sense, FDI has been located in those regions and countries where a factor is abundant, and tranform these in exports of manufactured goods. A sample of this is the case of China, in which the abundance of labour has moved firms with production facilities and porcess intensive in this factor to that country, along with a significant number of jobs from developed, industrialized countries.

Beside comparative advantages, another important issue on the success of globalization must be considered: Acording to several authors (Hoeckman and Kostecki, 2001; Held et al, 1999) the main two factors allowing globalization are the development of Telecommunications, and the increase in capacity and speed of transport, as well as the reduction in its costs, which along to the existence of comparative advantages have been translated in a raise in profits for TNCs.

In this paper an important remark is mabde on this issue: while telecommunicatios are showing a faster growth, due to research and development on information and electronics technology, transport sector is and will be affected by the availability and costs of energy sources. Among these, Oil (petroleum) is the most widely used fuel by this sector.

In the beggining of the Globalization process, during the decade between 1985 and 1995, this resource had a relative low price. Even considering market fluctuations, its price was around US$30 per barrel. This was the result of an increase in the world demand, the discovery of new oil fields, the improvement in exploration and extraction techniques and the growth in the infrastructure and vehicles of transport industry. All these facts were reflected in the reduction in price for this resource (IEA, 20078b)

Among the environmental consequences of world economic growth are the following: One is that the growth in the oil market do not reflect the future scarcity of this resource, which is one of the basic principles of sustainable development. Within the total demand for energy resources, the highest growth has occured in the transport sector, as well as the use of oil as its main fuel; amother is the fact that 80% of international trade is done using maritime and aerial transport, and these two sectors are not considered and regulated by international emmissions agreements ( IPCC, 2007; IEA, 2008a) In this sense, cheap transportation is a large contribution to the adoption of the model based on the allocation of production around the world, and its movement to other parts of the globe. In case of a sensible increase in costs, international transportation will be reserved to those goods with a high value-added

Following the operation principles of the oil maket, the fluctuations which reached its peak in july, 2008, could be the result of several factors: Oil reserves and its availability to satisfy a growing demand; the devaluaton of the US dollar –in which oil price is fixed- respect to other currencies; the switch of speculative investment to commodities, due to the reduction of returns in financial and stock markets (BBC, 2008) Due to the fact that its future exhaustion is certain, oil contribution to energy supllies is now more measured an element of national security as well as an strategic resource that is considered when establishing the international agenda.

It is important to note that the reduction in economic activity resulting from the international financial crisis, and not the uncertainty in its future availability and that of alternative energy technologies, is perceived as the cause of the fall in demand for oil resources (Mouawad, J.2008) A comment must be done in terms of the positive effects for the environment derived from this crisis

This last fact is reflected on the control of world oil suplies by TNCs, and therefore in the development of alternative energy technologies for its future replacement; its Research and Development is concentrated in the Most Developed Countries, and even with this, it has been slow and barely could replace oil at its current levels of energy contribution (Deutschland, 1992; Bundesministerium fur Bildung und Forschung, 2008) It has to be also considered the existent relationship between the of combustible fuels –oil and coal- as energy sources and the most serious environmental problems, such as global warming and climate change, and the reduction on food production. Therefore, the energy technologies necessary for the replacement of fossil fuels will not be available in the required volume (EU, 2008)

In the case of Mexico, Oil sales represents 37% of the total of Government income (World Bank, 2006) and that is the case of most oil export countries: a change in conditions of the international oil market has serious consequences on government programs and spending, on economic growth and development, and on income distribution and population welfare. In this sense is important to note that while most of the FDI to dveloping countries is provided by TNCs, more fo 70% of employment is provided by small and medium sized firms (PYMES) (World Bank, 2006) The quality and quantity of these posts depend on the availability of funding, in which goverment policies and resources play and important role.

Along with the sudden variations occured in the oil market during 2008, another factor affecting globalization is the drastic turmoil experienced by the international financial system. These two issues must have an effect on the curent conception of globalisation, and on the economic and public policies from governments of developing countries, in order to change the current economic and political models, to one model based on endogenous, local growth and development, moving to a regionalization of the economic activites, mainly production and consumption, not due to protectionist, (export-substitution) policies, but to a logical and necessary response to the problems of the globalised system and the future increase in costs of fossil fuels, the restrictions on its use for transportation on grounds of environmental preservation, and the lack of response on the availability of sustainable energy sources. Therefore, the most moving resources will be investment and technology, and the less will be labour and natural resources. It is necessary to note the fact that the conditions described in this paper will occur in the midium and long term, but the obligation of the state, though the governnment is to anticipate these, by a well designed and implemented planning process

The main purpose of this paper is to propose this alternative model as a form to overcome the effects of the near-collapse of globalisation. The elements of this Endogenous Developed Model are the following:

1. Design and Implement -within each of the developing countries, and the regions in which these are located- a system to identify the current state of energy sources and its markets, and how these will affect production and consumption in terms of impacts on manufacturing and transportion costs

2. Identify the degree of current and future research and development on alternative suistainable energy technologies, as well as its impact on the countries position on manufacturing and on international trade

3. Identify those activities necessary to substitute locally the goods formerly produced in other parts of the world, as well as the different local factor endowments and which are the factors required for the research and development of these production process

4. To design and implement public policies towards the development of effective tax and financial systems which can get and manage the resources requiered for this model, giving enphasis on the emergence of PYMES as partners,

replacement or complement of TNCs. And avoiding dependence on oil revenues

5. To focus planning process in the harmonisation of economic policies with those existing in the educative sector -especially in higher eduction- in order to achieve the levels of human capital formation required by this model

6. To design and implement all the resulting public policies in terms of its environmental impact, given the reduction in global economic activity and in the opportunity it represents to introduce new forms of production as well as new patterns of consumption favorable to sustainable development.

Bilbiografía:


Bundesministerium für Bildung und Forschung (2008) Skysails Project Germany, Hamburg

Bundesrepublik Deutschland (1994) Revista de la Republica Federal Alemana, Bonn

Chalcholiades, M. (1990) Economía Internacional, McGraw-Hill, Mexico

Environmental Audit Commitee/EU (2008) Report to the European Commission on Biofuels, European Union, Brussels

Fukuyama, F. (1992) The End of History and the Last Man, Perennial Books, New York

Hagaard, S. (2000) Interests, Institutions and Policy Reform, en Krueger, A. O. (ed) Economic Policy Reform, Chicago University Press

Held, D., McGrew, A., Goldblatt, D. Perraton, J. (1999) Global Transformations, Stanford University Press, Stanford

Hill, Ch, W. (2007) Negocios Internacionales, McGraw Hill, Mexico

Hoekman, B. M. y Kostecki, M. M. (2001) The Political Economy of the World Trade System, Oxford University Press, Oxford

Intergovernmental Panel on Climate Change (2007) Climate Change 2007: The Physical Science Basis, United Nations Environmental Program/World Meteorological Organization, Geneva

International Energy Agency (2008a) World Energy Outlook, OECD, Paris

International Energy Agency (2008b) IEA Statistics, Survey on Oil Prices , OECD, Paris

Krugman, P. R. y Obstfeld, M. (1995) Economía Internacional, McGraw Hill, Mexico

Martinussen, J. (1999) Society, State and Markets. Zed Books Limited, New York

Mouawad, J. (2208) Energy projects put on hold in response to lower prices, International Herlad Tribune, December 16, 2008

National Intelligence Council (2008) Global Trends 2025: A Transformed World. US Government Printing Office, Washington, D. C.

Porter, M. (1990) The Competitive Advantage of Nations, Free Press, New York

Rugman, A. M. y Hodgetts, R. M. (1997) Negocios Internacionales, Mc Graw Hill, Mexico

Trebilcock, M. J. y Howse, R (2005) The Regulation of International Trade, Routledge, London

Tugores Ques,J. (2005) Economía Internacional, McGrawHill, Mexico

World Bank (2007) World Development Report, Washington,D.C.

World Bank, (2006) World Development Indicators, Washington D. C.

Notes published on different dates in http://news.bbc.co.uk

# 2. The 21st Century First Oil War: The War on Iraq & Its Impact on the Oil Price & the Global Economy

**Dr Mamdouh G. Salameh**

Director International Oil Economist World Bank Consultant UNIDO Technical Expert

Oil Market Consultancy Service Spring Croft Sturt Avenue Haslemere Surrey GU27 3SJ United Kingdom

Introduction

With the global economy in the throes of recession and the world's banking system teetering on the brink of collapse, one could point out two major reasons behind these catastrophic developments. Both of them were caused by actions of the United States, namely, the Iraq war and the Bush Administration's policy to let the dollar slide steeply against other major currencies between 2003 and 2008.

By now it is very clear that the war on Iraq was not only a blunder of incalculable proportions but also a real disaster for the US economy and the global economy at large. In contrast with previous wars – where taxes were raised to pay for increased government spending – as America went into the current conflict, taxes were reduced. As a result, the war has been financed by borrowing, adding to the United States' already-enormous national debt. The cost to the US economy was calculated at $6.65 trillion, while the cost to the global economy as a whole was estimated at $14.34 trillion. These costs were instrumental in precipitating the global banking crisis and the current world recession.

The Bush administration has seen a steadily weakening dollar as an answer to its ever-widening current account deficit. After all, the dollar has depreciated about 25%-40% against a basket of currencies since 2002 without a peep from Washington. The United States has been pushing relentlessly for China and other Asian countries to revalue their currencies, thereby trying to make the dollar relatively weaker. Indeed, the US has been relying entirely on a depreciating dollar to increase exports and restrain imports. It has not encouraged domestic savings in order to reduce the need for massive inflows of foreign funds. It would be one thing if this lopsided policy was working, but the current account has continued to increase from its record-breaking $850 bn last year. In addition, the dollar cannot sink far enough to restrain imports without creating a panic. For example, while a softer dollar has benefited exporters, almost no conceivable dollar depreciation would be enough to significantly narrow the trade gap, simply because the value of the imports is twice that of exports. **1**

Because the United States needs to borrow more than $2 bn each day from

abroad to finance its imports and service its $3 trillion foreign debt, a dollar that plummets too fast would necessitate a rise in US interest rates to attract foreign funds. Thus the United States would end up with inflation, high interest rates and recession. Finally, a weakening dollar could lead to more acquisitions by the cash-rich countries – China and the Gulf states – that arouse political backlash in America. That could ignite more protectionist pressures and send Wall Street reeling and could also precipitate a global currency crisis. **2** This is exactly what happened with the collapse of the housing market and the bankruptcy of a number of leading investment banks in the United States. The world will need to spend about $4 trillion, or about 7% of global GDP to get back on track. **3**

The effect of easy credit was to flood commodity exchanges with liquidity, as liquidity fleeing risky securitized assets searched for a safe haven. This pushed up the prices of all commodities beyond what could be justified, sending premature signals of scarcity that attracted even more speculative investment. In this way a bubble was formed, but bubbles always burst, and when they do, the speculative money disappears very quickly, taking price support with it.

## The 21st Century's First Oil War

The war on Iraq was undoubtedly the 21st century's first oil war. The prize was Iraq's spectacular oil wealth estimated at 330 billion barrels of proven, semi-proven and probable oil reserves. **4** The value of these reserves is estimated at $42.9 trillion, more than three times the United States' gross domestic product (GDP). Even Alan Greenspan, the former chairman of the US Federal Reserve Bank for seventeen years, says the Iraq war is largely about oil. **5**

In the weeks before the war, Larry Lindsey, head of President Bush's National Economic Council, claimed that "the successful prosecution of the war would be good for the US economy". A key reason for this claim was the belief that it would keep oil prices low. The Wall Street Journal editorial that same day argued, "The best way to keep oil prices in check is a short, successful war on Iraq". **6**

Also in the lead-up to the war, Ahmad Chalabi who was once the Pentagon's choice to lead the "new" Iraq, promised to reopen the old British-built Iraq Petroleum Company (IPC) pipeline from Kirkuk in northern Iraq to the Israeli port of Haifa. This controversial plan impressed influential neoconservatives such as Richard Pearle, Paul Wolfowitz and Douglas Feith, thus influencing the Bush administration policy toward Iraq. Israel would get additional source of oil supply and could even export some of the Iraqi crude through Haifa. This has long been a goal not just of Israel itself, but also of pro-Israel factions in the United States. Under a 1975 memorandum of understanding, the United States guarantees virtually all Israel's oil needs in the event of a crisis – even if it means reducing the amount of oil available to the Americans. But to build the pipeline it would need a treaty with Iraq. Chalabi assured the neoconservatives that once he

assumed a position of influence in the new Iraqi government, Israel would get its treaty. As Chalabi's bubble burst so has his controversial plan. **7**

No wonder then that many people around the world, not just in the Middle East, believe oil has been at the centre of the war on Iraq from the outset. They believe the United States government went to war in Iraq because it wanted to get an assured supply of inexpensive oil for the US and its oil companies. Since the start of the war the US has been pushing for the legislation of a new Iraqi oil law under which the Iraqi Oil Industry would be privatised thus paving the way for awarding the lion's share in any future production-sharing contracts to US oil companies. The law will transform Iraq's oil industry from a nationalized model all-but-closed to US oil companies to a commercialized model that is all-but-fully privatized and open to US control. Naturally such a radical change is provoking strong emotions and reactions both inside and outside Iraq. **8** A response to the Iraqi draft oil law by 419 leading Iraqi academics, engineers and oil industry experts states, "it is clear that the Iraqi government is trying to implement one of the demands of the American occupation", and went on to argue that the law "lays the foundation for a fresh plundering of Iraq's strategic wealth and its squandering by foreigners, backed by those coveting power in the regions, and by gangs of thieves and pillagers". **9**

There are other reasons that have caused many around the world to conclude that oil was the underlying motive for the war. When America went into Iraq, it went to great efforts to protect the oil assets, even as it failed to protect Iraq's priceless antiquities, or (even more surprising from a military perspective) munitions supply. Moreover, while the weapons of mass destruction were put forward as the war's rationale, there was another country that was truly threatening to develop weapons of mass destruction: North Korea. But North Korea did not have oil and North Korea was not invaded. While America was focusing its attention on Iraq, North Korea became a nuclear power. **10**

The war's scenario was from the start to invade Iraq and seize its oilfields, pump oil like crazy and, in so doing, help solve the United States' energy crisis for a few decades and also destroy OPEC once for all.

The United States supported by "Big Oil", wanted to change the rules of the game. They wanted to regain influence over the great Middle East oilfields from which Western oil companies (the Seven Sisters) were expelled four decades ago. In a sense, they wanted to turn the clock back to a time before the great wave of nationalizations in the 1970s.

Under pressure from the US occupation, the Iraqi cabinet passed on 26 February 2007 a new national hydrocarbon law, which is yet to be approved by the Iraqi Parliament. Under the proposed draft law, 63 of Iraq's 80 known oilfields will be open to foreign multinationals, which in this case would be mostly American oil companies given the American occupation of Iraq while granting the Iraqi

National Oil Company (INOC), control over just 17 of the fields. **11** The new Iraqi system will stand in sharp contrast to neighbouring Kuwait, Iran and Saudi Arabia, who will maintain their national oil companies, having outlawed foreign control over oil development projects in their respective countries.

The foreign companies can take ownership of Iraq's oilfields without having to start operational work for at least two years. Potentially, this would allow the companies to take advantage of the weak negotiating position of the Iraqi government at a time of American occupation and civil unrest, while simultaneously being able to 'ride out' the current instability in Iraq. Furthermore, under the new law as currently drafted, foreign oil companies do not have to reinvest any of their earnings in the Iraqi economy, hire or train Iraqi workers, or transfer useful technology. **12**

America's war on Iraq is but one stage in the US quest to control dwindling global oil reserves and the routes of oil supplies because, in so doing, they will be in a position to control the global economy. **13** It is estimated that as much as 40% of the entire US military budget is spent protecting the global oil trade.

As available global oil reserves decline, the world's oil-hungry nations are tussling to grab as much as they can for themselves. The United States appears to be trying rapidly to monopolize the world's remaining oil reserves. In the 19$^{th}$ century the imperial adage was that "trade follows the flag". These days the flag follows the oil. Many of the shifts in US military deployment since the end of the Cold War have followed the oil. US forces in Europe have been drawn down, bases in the Arab Gulf built up. The war in Afghanistan took the US military into Central Asia, where the Pentagon hopes to keep access to bases close to current and likely future pipelines around the Caspian region. The United States has for sometime been funding a special army in Colombia in

Latin America to protect a pipeline partly owned by Occidental Petroleum of California. **14**

Moreover, the United States has created a new US strategic command for Africa (AFRICOM) and based it on the island of Sao Tome Principe (STP) in the Gulf of Guinea. This enables it to keep an eye on West Africa's major oil producers such as Nigeria and Angola and also to control West Africa's oil export routes. AFRICOM came into effect in September 2008. The US has followed such a strategy in the Middle East over the last 50 years in the guise of Central Command (CENTCOM), with bases at various times in the UAE, Kuwait, Qatar and Saudi Arabia. **15**

The Impact of the War on the Oil Price

Since the Iraq war began, oil prices have gone from about $25/barrel at the outset to more than $147/barrel by July 2008. Because of the knock-on secondary effects, higher oil prices affect almost every aspect of an economy. In oil-importing countries like the United States, higher oil prices lead to larger trade

deficits and inflationary pressures. Since governments then have to spend more on importing oil and on interest payments on outstanding debts, it becomes harder to balance budgets. Higher interest rates also lead to lower investment and consumer spending, declines in share prices, and a slowing of the economy. In America, the war has hurt the economy in other ways. I will try to identify the macroeconomic costs and, where possible, quantify them.

It is enough to say that if America went to war in the hope of securing cheap oil, it failed miserably. The war did however succeed in making the oil companies richer. **16** ExxonMobil and other oil companies have been among the few real beneficiaries of the war, as their profits and share prices soared. Meanwhile, the US economy as a whole has paid a high price.

To estimate how high a price, we need to answer three questions: How much of the increase in the price of oil can be attributed to the War? What have been the direct costs to the US economy from these price increases? And what have been the secondary effects – the effects on the overall macroeconomy.

The increase in the price immediately after the war can in part be directly attributed to the suspension of the UN Oil-for-Food programme which deprived the global oil market of some 2 mbd -2.5 mbd of Iraqi oil exports.

Oil prices started to soar just as the war began, and the longer it has dragged on, the higher prices have gone. This certainly suggests the war has something to do with the rising prices. On this, almost all oil experts agree. But what fraction of the total price increase is due to the war? To answer this, we need to ask: What would the price have been had there be no war?

Future markets – which summarize what buyers and sellers of oil contracts think prices will be in a year or more – provide some insight. Before the war, they thought prices would remain in the range that they had been, $20 to $30, for the next several years. Futures markets work on the basis of “business as usual,” that is, they assume nothing out of the ordinary is going to happen. The war in Iraq was the most notable out of the ordinary event at the time prices began to rise, and it is hard to identify any other disruption that could be given similar credit for the changes in demand or supply, especially in 2003 and 2004. Now, “business as usual” means that the turmoil that the Iraq war let loose will

| 2003 | | 2004 | 2005 | 2006 | 2007 | 2008 |
|---|---|---|---|---|---|---|
| The average oil price without war | 24.99 | 25.74 | 26.51 | 27.31 | 28.13 | 28.97 |
| The average oil price since | 35.63 | 45.88 | 75.20 | 85.69 | 90.52 | 147.00 |

continue, and futures markets are betting that prices will remain high for the next several years. **17**

We conclude, accordingly, that a significant proportion of the increase in the price of oil resulted from the war. Exactly how much the war increased prices cannot be gauged with precision. However, one pointer is that global oil prices had risen at an average annual rate of 3.0% during the period of 1992-2003. **18** One would safely assume that had the war not taken place, oil prices would have continued to rise at similar rates reaching $28/barrel in 2007 and $30/barrel in 2008. But since the war the prices have risen steeply from $25/barrel in 2003 to $91/barrel

in 2007 and $147/barrel in July 2008 (see Table 1). The war is unarguably the single most important factor contributing to the soaring price of oil and accounting

for some 66% of the rise in the oil price between 2003 and 2008.

Table 1 The Iraq War Contribution to the Rise in Oil Prices 2003-2008

Sources: Various sources including the US Department of Energy reports / BP Statistical Review of World Energy, June 2008 / Bloomberg / OPEC.

We can now calculate the direct cost to the US economy. The United States imports 5.11 billion barrels (bb) a year. Over the period 2003-2008, the extra expenditure to the US oil import bill resulting from oil price differences amounted to $1.64 trillion (see Table 2).

Table 2 The Cumulative Extra Expenditure on US Oil Imports, 2003-2008 ($ bn)

| 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | Total |
| --- | --- | --- | --- | --- | --- | --- |
| 64.37 | 102.92 | 248.81 | 298.32 | 318.81 | 603.13 | 1636.36 |

Sources: UD Department of Energy / BP Statistical Review of World Energy, June 2008.

The Full Macroeconomic Costs to the US

Higher oil prices mean people have less money to spend on everything else. American families have had to spend about 5% more of their income on gasoline and heating than before. **19** Even governments – especially those on the state and local level, which must limit spending to revenue – have had to cut back other spending to pay the higher prices of oil imports. Paying the oil exporters more for oil means that America is spending less on American goods. And, of course, this lower spending will cause the economy to produce less. While there is general agreement that spending an average of $272.7 bn more on oil every year (as has been the case since 2003) leads to a reduction in American GDP and incomes, there is some disagreement among economists on the size of the reduction. Economists call the extent to which a change in oil imports translates into a change in GDP the ***oil import multiplier***. A multiplier higher than 1 means that a $272.7 bn fall in demand for American goods, generates a decrease in GDP larger than that amount. **20** Standard estimates of

the multiplier are around 1.5. For our estimate, we assume that American GDP has gone down by $272.7x1.5, or $ 409 bn, for six years – a total of $2454 bn.

Higher oil prices have also depressed income in the United States' major trading partners, Europe and Japan, and that has meant that they imported less from the United States than they otherwise would have, which in turn has increased the impact of higher oil prices on the US economy. In Europe, inflationary pressures from higher energy prices most likely contributed to interest rates being higher than they otherwise would have been, especially given the European Central Bank's single-minded focus on inflation. This has further weakened their economies – with knock-on effects on America's.

By adding all the macroeconomic costs to the oil costs above, we can get a full tally of the costs of the war so far. The numbers are staggering. The numbers that best capture the US costs of the Iraq war, even without adding interest, are more than $6.63 trillion (see Table 3).

Table 3 The US Macroeconomic Costs of the War on Iraq

| Description | Cost in $ billions |
| --- | --- |

Oil Price Impact 2454 Budgetary Impact 1100

Subtotal Macroeconomic costs 3554

Plus Budgetary & Social Economic Costs Total Operations to date 646 Future operations 913 Future veterans' costs 717

| | | |
|---|---|---|
| The United States | 5.11 | 1636 |
| Europe | 4.91 | 1562 |
| Japan | 1.90 | 605 |
| China | 1.46 | 464 |
| Rest of the World | 7.40 | 2355 |
| Total | 20.78 | 6622 |

(Disability & social Security) Other military costs / adjustments 404

Subtotal Budgetary costs 2680 Social Costs total 415

Grand total 6649

Sources: Data from Prof. Joseph Stiglitz's Book: "The Three Trillion Dollar War"/ Dr Mamdouh Salameh's research into the oil price impact.

The Costs to the Global Economy

In global terms, the jump in oil prices since the start of the war dwarfs all other economic costs. The higher oil prices represent a direct cost to the global economy of $6.62 trillion (see Table 4). The cost to Iraq in lost oil export revenues is estimated at $171 bn during the period 2003-2008 not to mention the destruction of Iraq's economy and infrastructure.

Table 4 The Global Cumulative Extra Oil Expenditure, 2003-2008

Countries Oil Imports/year Extra Costs (bb) ($bn)

Sources: Energy Information Administration (EIA), "International Petroleum

Monthly", September 20, 2007 / BP Statistical Review of World Energy,

June, 2008 / Author's calculations.

The most direct global cost imposed on the rest of the world results from the increase in the price of oil, a price paid by all oil importers. Of course, the costs to some have been a benefit to others – namely the oil exporters. This has led to a redistribution of global economic power. The overall transfers from oil consumers to oil producers in 2007 alone were estimated at $1.3 trillion, or 3% of world GDP. **21**

The problem is that the increases in income generated to the oil-producing countries do not fully offset these depressing effects. Just as oil companies have done well by the war, so too have the oil-exporting countries. But, even with their profligate spending, these countries' "marginal propensity to consume" – the fraction of the income that is spent on goods and services – is lower, and hence global GDP is lower. Oil-producing countries know that prudence requires they set aside a large fraction of the bonanza for the future – one of the reasons that the world has been awash with liquidity.

We can now calculate the macroeconomic costs of the war so far to the United States, the global economy, the United Kingdom & Iraq (see Table 5).

Table 5 The Global Macroeconomic Costs of the War on Iraq 2003-2008, ($ bn)

Description USA UK Iraq Global Economy

Oil price impact 2454 7479* Budgetary costs 2232 31 Macroeconomic costs 1963 9 Loss of oil export revenue 171

Total Costs 6649 40** 171 7479

Sources: Data from Prof. Joseph Stiglitz's book, The Three Trillion Dollar War / Dr Mamdouh Salameh's calculations based on his research.

*Excluding the United States. ** Based on an exchange rate of $1.98 to the pound.

The Impact on the Global Oil Production Capacity

With oil this expensive, you would expect other oil-producing countries to start producing more. The anticipation of these supply-side responses would, in turn, drive down futures. The fact that there has not been the expected supply-side responses and that oil prices are still rising, needs explaining. We think the Iraq war is a key part of the explanation.

Had there been no war, and had the price of oil increased as a result of an unexpected rise in demand, the international community could have allowed Iraq to expand production, and this could have brought down the price.

In 2000, three years before the war, Iraq announced post-sanctions plans to implement a carefully-crafted timetable designed to increase its oil production capacity to 6 million barrels a day (mbd) by 2007, rising to 8 mbd by 2010 at an estimated cost of $21 bn. To achieve this, Iraq has set aside 10 giant oilfields in the south and west of the country for development by foreign companies on the basis of generous production-sharing contracts (see Table 6).

Table 6 Major Post-Sanctions Oilfield Development

Sources: Arab Oil & Gas Directory 2003 / Iraqi Oil Ministry / Centre for Global Energy Studies (CGES), London.

Had this development proceeded as planned, Iraq's export capacity could have risen to 5.2 mbd in 2007 and an impressive 7.1 mbd by 2010. **22** This could have

more than offset the current supply-demand deficit and could have kept the price of oil at an estimated range of $40 -$50 a barrel.

Even if this had not happened, it is likely that production elsewhere, especially in the Middle East, would have increased. But the instability resulting from the War there has increased the risk of investing in that region; and because costs of extraction are so much lower in the Middle East, there has not been a commensurate supply response elsewhere. If stability is restored, prices could be expected to fall, and these investments elsewhere would turn a loss.

There is a further aspect of oil price dynamics in which the war played a role. High oil prices sometimes induce oil producers to produce less and even to invest less in expanding production capacity. They realize that the demand elasticity is low (so that small reductions in supply can generate large increases in prices), and that means that they have a real incentive to restrict production, but it is often difficult for them to act as collusively as they should (from the

| **Oilfields -- ---------------- -** | **Operators ----- ----------------** | **Reserves (bb) -------- ----------** | **Cost ($ bn) ----- ---------** | **Planned Extra Capacity (b/d) -------------------------- ----------** |
|---|---|---|---|---|
| Majnoon | TotalFinaElf | 20-30 | 3.5 | 600,000 |
| West Qurna | Lukoil et al | 18 | 3.7 | 600,000 |
| Bin Umar | TotalFinaElf | 6 | 3.4 | 450,000 |
| Nassiriya | ENI, Repsol | 4 | 1.9 | 300,000 |
| N Rumaila | Machinoimport | 12 | 1.6 | 250,000 |
| Halfaya | CNPC, BHP | 5 | 2.0 | 225,000 |
| Ratawi | Petronas et al | 2 | 1.3 | 200,000 |
| Tuba | ONGC et al | 2 | 0.5 | 180,000 |
| Gharaf | CPC, Japex & Kriti | 2 | n/a | 150,000 |
| Rafidain --- -------------- | n/a -------------------- ------- | 2 ------- ---- | 0.5 ------ ------- | 150,000 --------------------- -------------- |
| **Total** | **73-83** | | **18.4** | **3,105,000** |

perspective of their own interests). When oil prices are high, they have less need for further government revenues; indeed, they often face difficulties spending what they have well. It makes more sense for them to keep their resources below the ground – which may appear as the "investment" with the highest rate of return.

Conclusions

The Iraq war and the Bush Administration's policy to let the US dollar slide steeply against other major currencies between 2003 and 2008 could be singled out as the two real reasons behind the current global economic recession and the world banking crisis.

By now it is very clear that the war on Iraq was not only a blunder of incalculable proportions but also a real disaster for the US economy and the global economy at large. The cost to the US economy was $6.65 trillion, while the cost to the global economy as a whole was estimated at $14.34 trillion. These costs were instrumental in precipitating the global banking crisis and the current world recession. The world will need to spend about $4 trillion, or about 7% of global GDP to get back on track.

The Iraq war is the 21st century's first oil war. It is unarguably the single most important factor contributing to the soaring price of oil and accounting for some 65% of the rise since 2003. Had the war not taken place, the oil prices could have been expected to settle around $40-$50/barrel range even with growing demand from China, India and other Asia-Pacific countries.

The cost to Iraq in lost oil export revenues is estimated at $171 bn for the period 2003-2008 not to mention the destruction of Iraq's economy and infrastructure and the suffering of the Iraqi people and their humiliation from the occupation.

If the intention of the war was to secure cheap oil supplies for the United States, the consequences have been the opposite: oil prices have soared. The war has also impacted on the global oil production capacity by creating instability in the Middle East and thus increasing the risk of investing in the region.

* Dr Mamdouh G. Salameh is an international oil economist, a consultant to the World Bank in Washington DC on oil & energy and a technical expert of the United Nations Industrial Development Organization (UNIDO) in Vienna. Dr Salameh is Director of the Oil Market Consultancy Service in the UK and a member of both the International Institute for Strategic Studies (IISS) in London and the Royal Institute of International Affairs. He is also a member of the Energy Institute in London.

Footnotes

1 Jeffrey E. Garten, **Beware the Weak Dollar**, Newsweek, September 10, 2007, p. 34.

2 Ibid., p. 34.

3 Jeffrey E. Garten, **Stop the Free-Fall**, Newsweek , December 22, 2008, p.

26. 4 Mamdouh G. Salameh, **Over a Barrel** (Haslemere, England: Salameh, June, 2004), p.194. 5 Alan Greenspan, **The Age of Turbulence** (London: Penguin Books Limited,

2007), p.463. 6 Joseph E. Stiglitz & Linda J. Bilmes, **The Three Trillion War** (New York:

W.W. Norton & Company, 2008), p. 218. 7 Susan Taylor Martin, **Israel Pipe Dream: Getting Oil from Iraq**, St

Petersburg Times Columns online, August 15, 2005.

8 Petroleum Review, April 2007, p.3.

9 Joseph E. Stiglitz & Linda J. Bilmes, **The Three Trillion War**, p. 220.

10 Ibid., pp. 218-219.

11 Antonia Juhasz, **Iraq's Proposed New National Oil Law**, Petroleum Review,

May 2007, p. 19. 12 Ibid., p. 19. 13 Mamdouh G. Salameh, **Over a Barrel**, p. 191. 14 Ibid., pp.211-212. 15 Mojgan Djamarani, **Scramble for Africa**, Petroleum Review, January 2008,

p. 30.

16 In 2007, five of the ten most profitable corporations in the world were oil & Gas companies – ExxonMobil, Royal Dutch Shell, BP, Chevron and Petro-China. In 2002, only one of the top ten most profitable corporations was from the oil & gas industry – Forbes magazine on-line.

17 Joseph E. Stiglitz & Linda J. Bilmes, **The Three Trillion Dollar War**, pp.116-

117. 18 BP Statistical Review of World Energy, June 2008, p.16. 19 In theory, households could dip into their savings to maintain other

expenditures. In reality, given the fact that America's saving rate was already zero or negative, the scope for doing so was limited.

20 Joseph E. Stiglitz & Linda J. Bilmes, **The Three Trillion Dollar War**, pp. 118-119.

21 Mamdouh G. Salameh, **Peak Oil: Myth or Reality** (a paper given at the invitation of the World Bank, Washington DC, 10 April, 2007), p. 11. The

calculation was based on projected oil exports of some 53 mbd in 2007 at an average price of $65/barrel and a global GDP of $42 trillion.

22 Mamdouh G. Salameh, **Over a Barrel**, pp. 192-193.

A Summarized Curriculum Vitae

Dr Mamdouh G. Salameh is an international oil expert, a consultant for the World Bank in Washington D.C. on energy and also a technical expert with the United Nations Industrial Development Organization (UNIDO) in Vienna. He specializes in the economics and geopolitics of oil and energy.

Dr Salameh has considerable experience and expertise spanning 30 years in the oil and chemical industries. He has held several senior management posts in the Middle East, Europe and the UK. He is currently Director of the Oil Market Consultancy Service in the UK.

Dr Salameh has presented papers to numerous international energy conferences on the economics and geopolitics of oil and energy and has been frequently invited to lecture on these topics at universities around the world. He has written three books on oil: **"Is a Third Oil Crisis Inevitable?"** (published in London in April 1990), **" Jordan's Energy Prospects & Needs to the Year 2010: The Economic Viability of Extracting Oil from Shale"** (published in London in October 1998) and " **Over a Barrel"** (Published in the UK in June 2004) as well as numerous research papers published in international Oil and Energy Journals. Dr Salameh has undertaken research assignments for the US Department of Energy, the World Bank, the Institute of Energy Economics in Japan, the Indian Government, OPEC, the Canadian Energy Research Institute, Boston University working on the Encyclopedia of Energy and the University of Jordan amongst others.

Dr Salameh has appeared frequently on BBC TV (English & Arabic), Aljazeera TV (English & Arabic), CNN, Jordan TV, CNBC (Dubai) TV, Canadian TV and Dubai TV discussing oil prices and other developments in the global oil market.

Dr Salameh has a doctorate in Economics specializing in the economics of oil and energy and a post-graduate Diploma in Industrial Management and Marketing. He is a member of the following International Institutes and Associations:

- Member of the Energy Institute, UK.
- Member of the British Institute of Energy Economics, London.
- Member of the International Association for Energy Economics, USA.

- Fellow of the International Energy Foundation, Canada.
- Member of the International Institute for Strategic Studies (IISS), London.
- Member of the Royal Institute of International Affairs, London.
- Fellow of the Chartered Institute of Marketing, UK.
- Member of the Institute of Directors, London.
- Member of the Chartered Management Institute, UK.
- Member of the Council for the Advancement of Arab-British Understanding (CAABU), London.
- Member of the Strategic & Combat Studies Institute, UK.
- Advisor to the Oil Depletion Analysis Centre (ODAC), London.

# 3. Analysis of the Global Natural Gas Market up to 2030 Scenario Analysis and Stochastic Modeling with the World Gas Model[1]

**Ruud Egging[a] and Franziska Holz[b]**

[a] Department of Civil and Environmental Engineering, University of Maryland,

College Park, Maryland 20742, USA, regging-at-umd.edu

[b] DIW Berlin, Mohrenstr. 58, 10117 Berlin, Germany

Presented at the 2nd ELAEE/IAEE Latin American Conference, Santiago, Chile, March 2009

Abstract

The World Gas Model (WGM) is a multi-period mixed complementarity model for the global natural gas market, allowing for endogenous capacity expansions in the liquefied natural gas, pipeline and storage sectors. The model contains over 80 countries and regions and covers 98% of world wide gas production and - seasonally and over the years varying – consumption for three demand sectors; as well as a detailed representation of border-crossing natural gas pipelines and contractual and spot trades in liquefied natural gas.

In the first part of this paper we present the WGM and analyze several scenarios and cases illustrative of contemporary and possible future developments in the global natural gas market. We will show the implications of different assumptions for the development of consumption levels and increased collusion between natural gas producers resulting in stronger strategic behavior at the supply side of the market. Presented results will address the impact on infrastructure investments, production and consumption levels; trade flows by pipeline and LNG; and prices.

[1] This paper is based upon work supported by the National Science Foundation Grant DMS 0408943 for co-author one.

In the second part of this paper, we address uncertainty of input parameters and its impact on model results. Although scenario analysis can provide a lot of insight in the consequences of different possible developments, to fully address the unpredictability of the future we should explicitly address the uncertainty in input parameters. Thereto we have developed a *stochastic* version of the WGM. We will present and discuss results of this stochastic version of the Multi-period World Gas Model.

Our results show that in a globalizing natural gas market the formazation of a gas cartel including the members of the Gas Exporting Countries Formum will have a large impact on consumption volumes and prices in importing regions, such as North America, Europe and Japan. A main result of the stochastic case is that especially the timing of investments is affected by the hedging behavior of market players deciding on capacity expansions.

Keywords: natural gas trade, World Gas Model, mixed complementary problem, stochastic modeling, hedging behavior, capacity investments

Introduction

December 23, 2008: the members of the Gas Exporting Countries Forum (GECF) establish and formalize a collaborating structure to coordinate their investments and supply strategies.[2]

January 1, 2009: Russia cuts off natural gas supplies – again – to Ukraine to reinforce its stance in a dispute over late payments and price negotiations. Several European countries suffer supply disruptions, and tens of thousands of consumers cannot rely on gas to heat their houses in one of the coldest winters in decades.[3]

The above are two illustrations of a world natural gas market in turmoil. On one side, high prices and the increasingly tight environmental constraints have diluted the perspectives of natural gas to become the 'transition' energy source on the way to a low-carbon world (e.g. hydrogen economy.) Thus, a large part of gas-fired power plants forecasted around the turn of the decade have been

---

[2] http://news.bbc.co.uk/2/hi/europe/7796806.stm
[3] www.reuters.com/article/topNews/idUSTRE4BN32B20090106?feedType=RSS&feedName=topNews

shelved because they turned out to be economically unviable (Stern, 2007.) But on the other side, natural gas still spurs various concerns about future reliable supplies, industry concentration, and supply security (Stern, 2007; Victor, Jaffe and Hayes, 2006.) It comes as no surprise to see diverging forecasts for natural gas supply, demand and prices even for the short-term future. Thus, the official forecast for natural gas demand in Europe, based on the Primes model, has been significantly reduced (European Commission, 2007.) Along these lines, the forecasts from the POLES model seem to be overoptimistic (European Commission, 2006.) The Energy Information Agency has also corrected its figures for US natural gas demand downwards (Energy Information Agency, 2007.)

In this paper, we provide a discussion about the perspective of the world natural gas market until 2040. In particular, we define and analyze a 'base case' which builds on business-as-usual assumptions based on forecasts of the world energy markets. The first part of the paper is devoted to presenting the World Gas Model (WGM) and a description of projections for developments in the world natural gas market, with some focus on the developments in South America. In the second part of the paper we develop an analysis in which we explicitly address uncertainty in future developments by incorporating four different future scenarios in a single stochastic modeling framework, provided by the stochastic extension of the world gas model. The main contributions of this work are: I. The multi-period, detailed, world-covering equilibrium modeling framework that has been developed to carry out in-depth analyses. II: the development of a stochastic extension of this model allowing for explicit consideration of input parameter uncertainty and thereby explicitly addresses hedging behavior of market participants in natural gas markets. And III the analysis of the impact of the establishment of a worldwide gas cartel.

The remainder of this paper is organized as follows: the next section introduces the World Gas Model (WGM) that has been used for the analysis presented in this paper. Section three presents the Base Case results. Section four introduces the Stochastic World Gas Model and clarifies some input data assumptions needed for the scenario analysis. Section five presents and discusses results of the stochastic case runs. The last section conclude and provide some directions for future research.

Model and Data

The World Gas Model

The World Gas Model (WGM) is a multi-period equilibrium model of the global natural gas market covering the next three decades. It includes more than 80 countries and over 98% of global natural gas production and consumption (in 2005, BP 2008.) WGM allows for endogenous investments in pipelines and storage capacities, as well as expansion of regasification and liquefaction capacities and considers demand growth, production capacity expansions and price and production costs increases over time. Taking into account the game-theoretic aspects of the natural gas market, the model includes market power à la Nash-Cournot for some players participating in natural gas trade (i.e., traders and regasifiers.) See Egging et al. (2008) for a detailed description of the model.

Modeled market players include producers (P), traders (T), liquefiers (L), regasifiers (R), storage operators (S), marketers (M) and consumers in three sectors CR (residential/commercial), CI (industrial), and CP (power generation.) Figure 1 illustrates some of the represented trade relations.

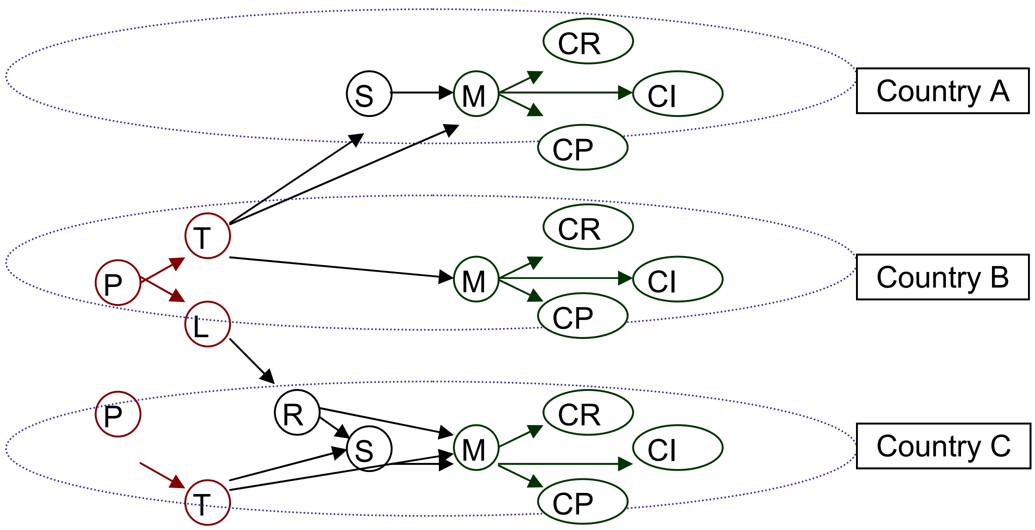



Figure 1: Illustration of typical gas supply chains in WGM

The consumers are present via their aggregate inverse demand function. All other players are modeled via their respective profit maximization problems under some player-specific operational and technical constraints. There is usually one producer and one trader per country; only the US, Canada, and Russia are divided into several regions due to their geographic scope and importance in the world market. Pipelines, liquefiers and regasifiers are included as of today (2008), but the model also allows for completely new pipelines and LNG capacities based on profit maximizing decisions of players in the model. While the role of producers, liquefiers, regasifiers and storage is intuitive, the traders are more specific: they act as the marketing arm of one or more producer(s) for trading via the pipeline grid. Depending on their origin and point of operation, traders may have market power; this means that they are in a position to withhold supplies in a respective market and thereby increase prices to maximize their profits.

WGM takes into account LNG contracts known as of today (2008.) Contracts are phased out based on their currently known end dates. Regasifiers, being the interface of the LNG supply chain with the downstream market, are modeled as Nash-Cournot players vis-à-vis the storage operators and marketers.

Storage operators act as arbitrageurs between the low demand and the high and peak demand seasons in the model. Pipeline operators are agents that assign pipeline capacity to traders. The minimum transport costs are set by a regulated tariff; an endogenously determined congestion fee ensures that the scarce pipeline capacities are allocated optimally.

The base year of the WGM is 2005; investment projects already under construction at the time of writing have been included in the 2010 and other future capacities. Model runs include the period until 2040 in five year intervals, but results are only reported up to 2030.

Data and calibration

The model has been calibrated to projections of the future energy markets, namely PRIMES forecasts for Europe (European Commission, 2007) and POLES forecasts for the rest of the world (European Commission, 2006.) These sources are used to determine the (exogenous) production capacities and the reference consumption quantities and prices of the demand function. POLES projections reflect a worldwide increase in natural gas production and consumption of 70% in 2030 relative to 2005. Generally, demand stagnates or even declines in some countries in the projections after 2025.

The calibrated worldwide base case consumption (production)[4] in 2005 is 2368 (2435), and 3757 (3905) bcm[5] in 2030, and an average wholesale price of $375 per 1000 m³. An average yearly price increase of 3%, in accordance with POLES projections, is used. For infrastructure capacities, project and company information from various sources (e.g., Oil and Gas Journal, GSE database at www.gte.be, Energy Information Agency [6]) has been employed. This information was used to include existing additional capacities since 2005 and also considered when assessing the maximum allowable capacity expansions per period for the base case.

Base Case Results

The base case (BC) follows business as usual assumptions as described in the previous section 0. Figure 2 shows a steady increase of world wide natural gas production and consumption over the whole forecasting period up to a level of about 3,900 bcm/y in 2030.

---

[4] WGM model accounts for losses in liquefaction, regasification, storage and pipelines. Consumption in WGM is corrected for 'own consumption' in the energy sector, IEA: www.iea.org/Textbase/stats/prodresult.asp?PRODUCT=Natural%20Gas

[5] bcm: billion cubic meter. bcm/y: bcm per year, which can also be written as: bcma, bcm per annum

[6] We thank the Energy Information Agency, in particular Justine Barden, for sharing data regarding seasonality of consumption, and likely future pipeline capacity expansions.

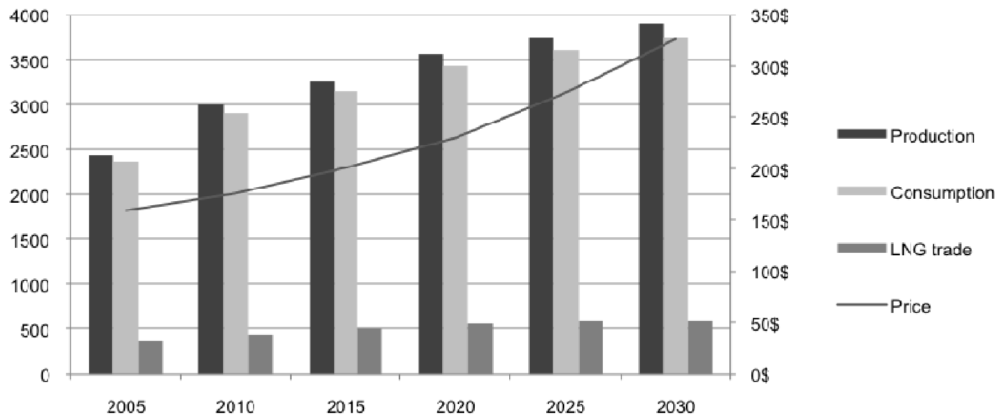



Figure 2: World consumption and production and world average wholesale price; in bcm/y and $/kcm

LNG trade grows until 2020 and then plateaus around 525 bcm/y. By 2020 approximately 15% of total natural gas production is traded as LNG. The share of natural gas consumed domestically in production countries drops from 60% to close to 50% of total consumption by the end of the time horizon, while the share of natural gas exported by pipeline remains relatively stable (30%.)

Figure 3 shows global trade flows in 2030. The Middle East, Russia and the Caspian region split their sales between Europe and Asia, and small volumes of LNG are exported to North America. Total consumption in Europe in 2030 amounts to 667 bcm/y; of which 27 bcm/y are LNG imports, (4% of total consumption), and 200 bcm/y are produced within Europe. The lion's share of consumption, however, is imported from Russia and the Caspian region.

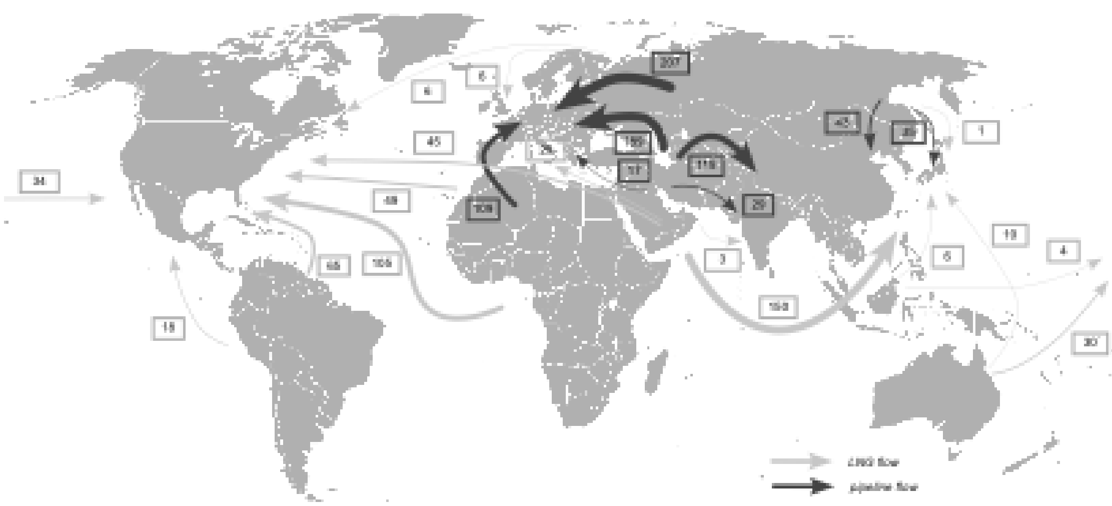


Figure 3: Natural gas flows in 2030 by region; in bcm/y, base case

In the base case, Asia consumes almost 850 bcm/y in 2030. Looking at the country level reveals a very differentiated picture: while Japan and Taiwan continue to rely to a large extent on LNG imports, China and India each produce half of their consumption domestically and import another 40% by pipeline from Russia, Burma, the Caspian region and the Middle East. LNG imports fulfill only a minor part of domestic demand. North America produces about 60% of its consumption regionally with the remaining 40% is satisfied by LNG imports.

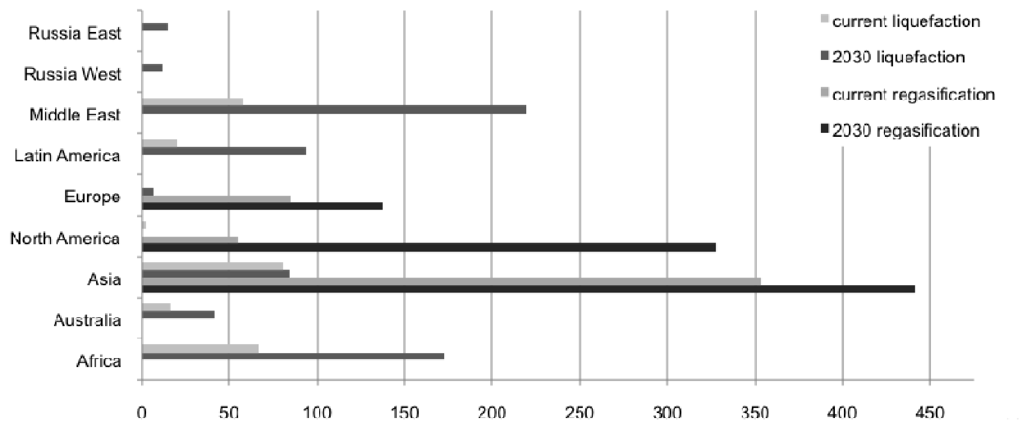



Figure 4: Base case liquefaction and regasification capacities (bcm/y)

Investments in liquefaction and regasification capacities are presented in Figure 4. While liquefaction capacities almost triple, from 242 to 652 bcm/y, regasification capacities roughly double from 491 to 945 bcm/y. Ample spare capacities remain allowing to address seasonal demand fluctuations. Investment is strongest at the beginning of the time horizon, with another boost in 2020; after that, investments decrease due to the assumption of demand stagnation in many developed markets in the long run.

Base Case Projections for South American countries

Figure 5 shows the South American countries that are included in the data set of the WGM: Argentina (ARG), Bolivia (BOL), Brazil (BRA), Chile (CHL), Ecuador (ECU), Peru (PER), Trinidad and Tobago (TRI) and Venezuela (VEN.) Another Latin American country, Mexico, is included as part of the North American gas system.


Figure 5 South American countries in WGM[7]

Table 1 shows the base case production, consumption, LNG and pipeline values for 2005 in bcm[8]. We see that Argentina is both the largest producer and consumer, and that the second largest producer, Trinidad and Tobago is the largest exporter. Bolivia is the second largest exporter, and Brazil is the largest importer of pipeline gas, (indicated with a minus sign) [9].

Table 1 Base case volumes South America 2005 (bcma)

| Country | Production | Consumption | LNG exports | Pipe exports |
|---|---|---|---|---|
| ARG | 37.5 | 33.5 | 0.0 | 4.0 |
| BOL | 10.8 | 1.3 | 0.0 | 9.5 |
| BRA | 7.5 | 15.3 | 0.0 | -7.8 |
| CHL | 2.0 | 7.4 | 0.0 | -5.4 |

[7] http://en.wikipedia.org/wiki/Wikipedia:Blank_maps

[8] Production and consumption values calibrated to data of BP Statistical review of the World 2008. LNG and pipeline volumes are model outcomes, but match the production – consumption balance on a country level.

[9] The aggregate imports are slightly lower than the aggregate exports. This is due to the explicit incorporation of pipeline compression losses.

| Country | Production | Consumption | LNG exports | Pipe exports |
|---|---|---|---|---|
| ECU | 0.5 | 0.5 | 0.0 | 0.0 |
| PER | 1.2 | 1.2 | 0.0 | 0.0 |
| TRI | 25.4 | 11.6 | 13.8 | 0.0 |
| VEN | 18.8 | 18.8 | 0.0 | 0.0 |

Figure 6 shows the development of seasonal consumption levels over time[10]. The figure shows large seasonal variation in gas consumption, most notably in Argentina. According to these projections Argentina will remain the largest consumer of natural gas in South America in the period up to 2030, however that is largely due to the underlying demand growth assumptions and it is very well possible that the demand growth of countries that have only started using gas in recent years will outpace the growth in more mature markets such as Argentina.

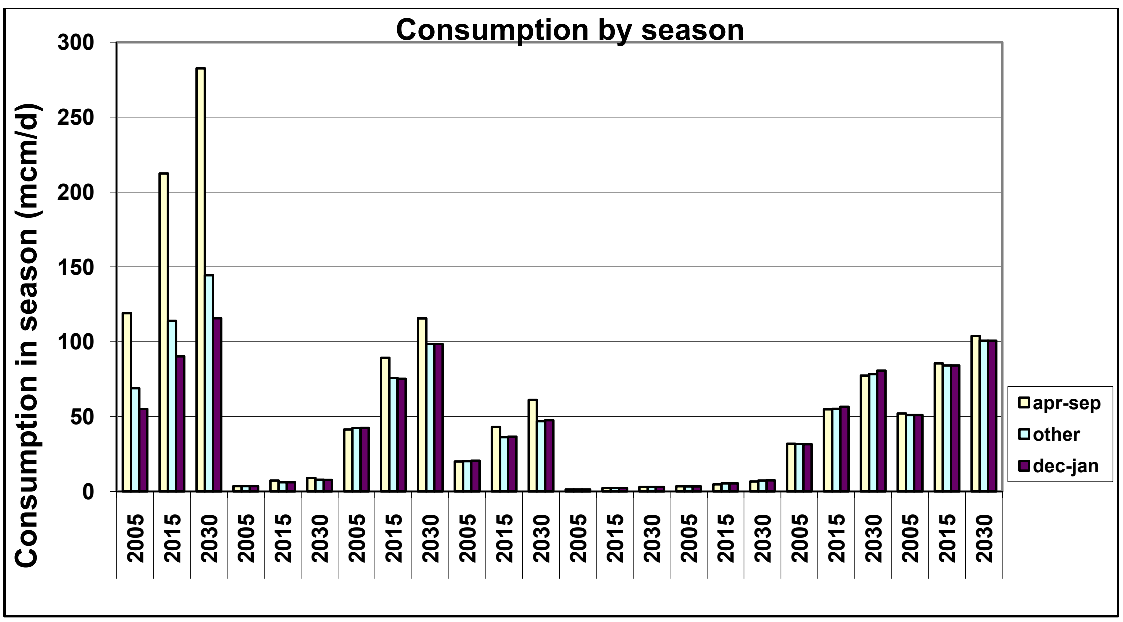



Figure 6 Seasonal consumption values for 2005, 2015, 2030

Figure 7 presents the projected values for LNG exports for four countries that have, or are considering to invest in, liquefaction capacity. Especially for Bolivia we see large variation in LNG exports by season. This may be explained by

[10] Seasonality of South American countries is opposite to that of countries in the Northern Hemisphere Therefore the model's seasonal definitions of low, high and peak demand periods for the periods {mar-sep}, {apr,may,oct,nov} and {dec-jan} respectively, are somewhat misleading.

demand seasonality in the pipeline export markets, which allows for fewer LNG exports in the mid-year period apr-sept, and seasonality of LNG importing markets, with higher demand in the northern hemisphere winter period.

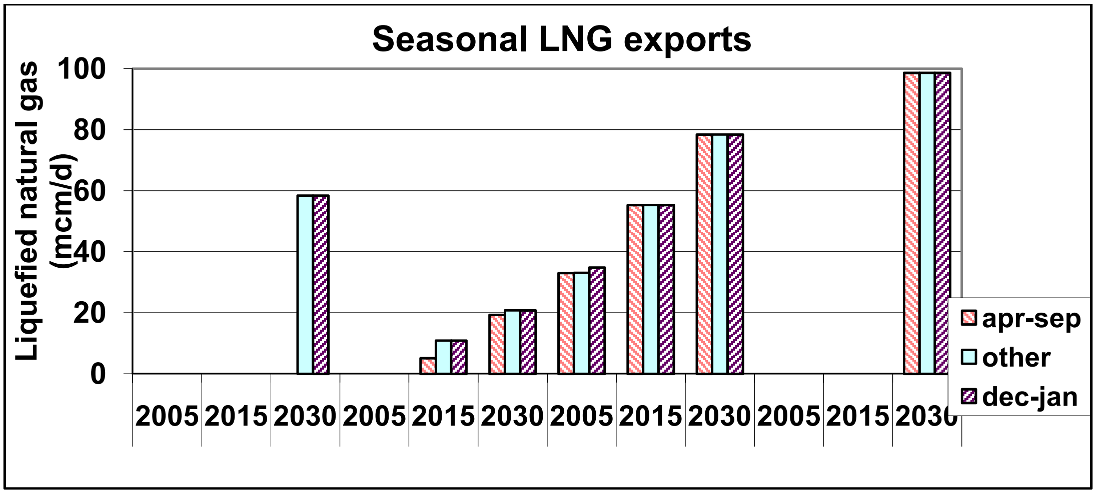



Figure 7 Seasonal LNG exports for 2005, 2015, 2030

Generally one would not not expect that the very capital intensive liquefaction terminals be used half of the year only, but another interpretation of these model results is that there are price pressures in south american countries with LNG exports and seasonality in consumption. We can conclude that there is a need for the development of seasonal swing in production and gas storage facilities.

At least two south american countries, Chile and Brasil are considering to invest in regasification terminals. By assumption, Chile can build regasifiers, starting 2010, and Brazil starting 2015. However, our in base case neither country will invests in re-gasification capacity. The promixity of countries that can supply gas via pipelines allows for relatively low-cost pipeline imports. We note that the model does not take into account policies that could favor diversification and alternative supply sources to enhance supply security at the expense of to higher costs.

Table 2 presents the South American pipeline flows in two seasons in three years. The table shows that regional pipeline gas trade increases dramatically over the time horizon. Most notably is the increase in exports from Bolivia to Argentina, which could amount to 114 mcm/d in the high demand period in 2030, equivalent to an annualized 40 bcm. The seasonal variation in pipeline trade confirms the observation made previously about the availability of natural gas for LNG exports.

Table 2 Base case pipeline trade volumes South America 2005 (bcma)

| | Country To: | ARG | | BRA | | CHL | |
|---|---|---|---|---|---|---|---|
| Cntry from: | Year | apr-sep | dec-jan | apr-sep | dec-jan | apr-sep | dec-jan |
| | 2005 | | | 0 | 11 | 7 | 8 |
| ARG | 2015 | | | 0 | 6 | 0 | 8 |
| | 2030 | | | 0 | 4 | 0 | 8 |
| | 2005 | 3 | 0 | 19 | 13 | 8 | 7 |
| BOL | 2015 | 44 | 8 | 28 | 19 | 10 | 12 |
| | 2030 | 114 | 9 | 25 | 20 | 19 | 13 |
| | 2005 | | | 0 | 0 | 0 | 0 |
| PER | 2015 | | | 0 | 2 | 22 | 7 |
| | 2030 | | | 8 | 8 | 28 | 14 |

Summarizing, we see that South America develops into a large LNG exporter; that there seems to be an increasing need for swing supply to local markets and LNG exports; and that there is no purely economic rationale for the development of re-gasification capacity. (Although there may be policy reasons.)

After having outlined the Base Case results in this section using a detailed deterministic version of the WGM, the next sections will present a description and analysis of a stochastic case developed with the World Gas Model.

Stochastic case – some introductory comments

This section provides a clarification of the stochastic model and analysis performed with the WGM.

In the stochastic case we will consider uncertainty in two aspects. The first aspect is the establishment of a gas cartel[11] in 2010 and the second is a faster depletion of natural gas reserves in North America, Europe and some Asian importing countries from 2020. This leads to four – partially overlapping – scenarios, that each have been assigned a probability of 25%.

Stochastic scenario tree

Figure 8 shows the scenario tree that is implemented for the stochastic case run. The scenario tree contains 31 nodes. One node, 01, to represent the first year 2005. In years 2010 through 2020 there are two scenario nodes. Each year after 2020 is represented by four different scenario nodes.

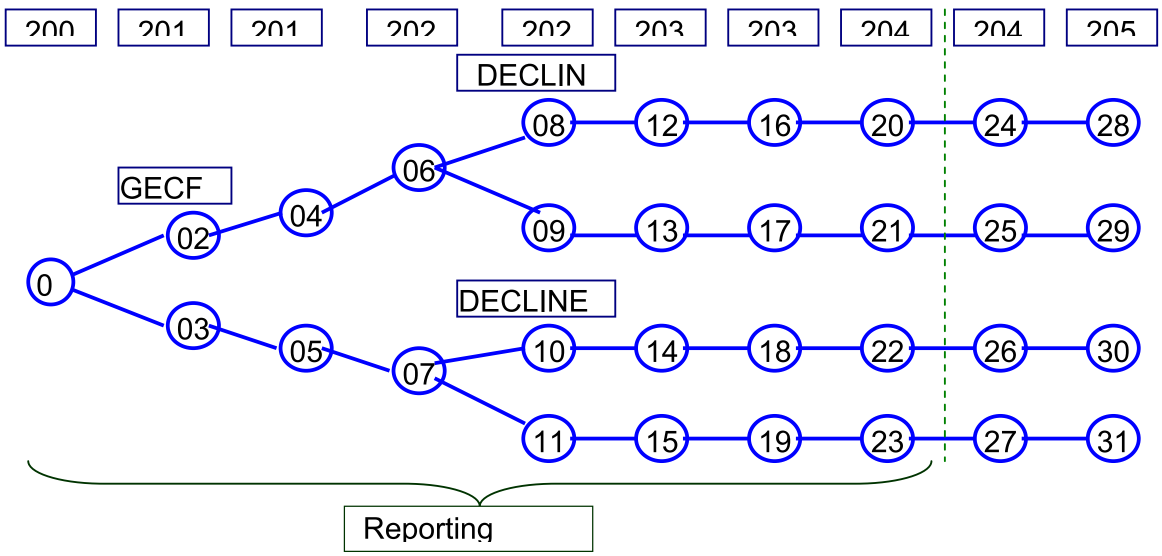



Figure 8 Scenario tree for case STOCH

Each scenario node has its own set of input parameters. These input parameters differ in market power assumptions and production capacities. Each scenario node also has its own set of decision variables. So for example the investment level in a pipeline in 2035 depends on the scenario, and may assume different levels among nodes 16, 17, 18 and 19. The market agents maximize their expected profits, having perfect information about all possible scenarios. Decisions, notably investment levels, will be optimal 'on average' among the different scenarios of which the relevant scenario node is a part. E.g., in early periods, before 2025, the optimal decisions hedge against the outcomes of different futures. The decisions taken in 2005 have consequences for all future periods, to the contrary a decisions taken in scenario node 08 in

[11] Both *cartel* and *GECF* are used to refer to the group of cartel members.

year 2025 will only have consequences for its succeeding nodes in a single scenario, nodes: 12, 16, 20, 24 and 28.

Since investments in capacity expansions need some time to earn a return, investment decision outcomes in the last model periods tend to be distorted. We deal with that issue by including scenario nodes for the last two periods in every scenario, but not reporting any outcomes for them.

Model size and calculation times

The multi-period determinist WGM for which results have been discussed in previous sections needs about 3½ hours of run time.[12] Empirically we have seen that a doubling of the model size induces an about tenfold increase in run time. Running a four scenario stochastic model, using the scenario tree in Figure 8, results in an about threefold increase in model size, with dramatic impact on the calculation time[13]. Long run times are undesired for several reasons and therefore we have chosen to reduce the model size by aggregating the over 80 countries of the deterministic WGM into nineteen geographical regions (Appendix 0.)

Stochastic input data and assumptions

The input data for consumption, production, pipeline and storage capacities are aggregated to these regional levels as well. To allow a valid implementation of the market power assumptions for the gas cartel case we transform the LNG data into pipeline data with adequate costs and loss rates. Figure 9 illustrates the logistical supply chain as it is represented in the model.

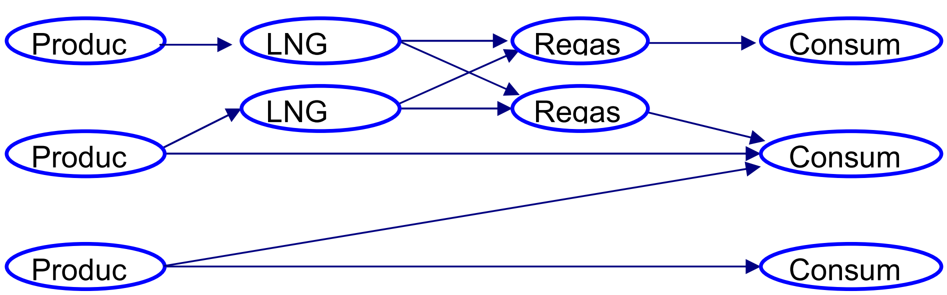



Figure 9 Natural gas international transport network

[12] using GAMS version 22.7.2, on a 2GB dual core 2 x 1.2 GHz computer
[13] Estimated to be about 1 to 1 ½ weeks for running the full scale model with four scenarios.

The gas producing countries that will possibly take part in the gas cartel are included as separate production entities, however their gas trade is executed by a single trading company. That trading company maximizes its total profit, given the production and transport costs and losses and the assumptions for market power. Section 0 gives an overview of the input data used.

Figure 10 illustrates the structure of the natural gas market in the model. Traders buy gas from producers and sell it to final consumers and storage operators (in the low demand season.) Storage operators inject the purchased gas into storage and sell it to final consumers in the high and peak demand seasons.

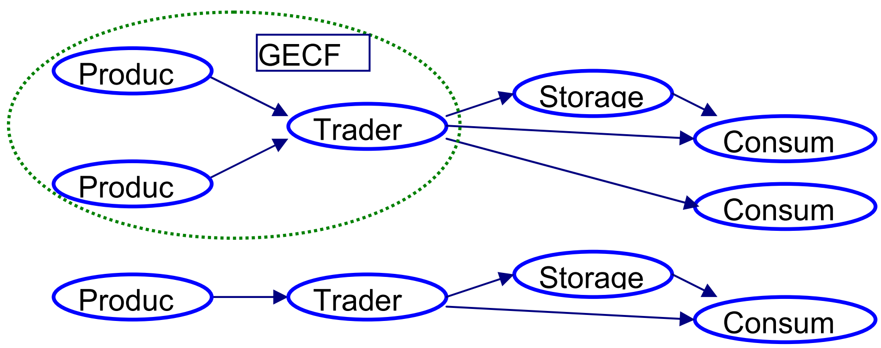



Figure 10 Natural gas market structure

To evaluate the stochastic model runs, we compare the stochastic outcomes with the results of three other runs that are all deterministic but contain some aspects of the stochastic case. A BASE case provides the reference case for the deterministic model. A GECF case, that shows the coming into existence of a gas cartel in 2010; and a DECLINE case that shows a faster depletion of natural gas reserves in North America, Europe and some Asian countries from 2020[14]. The STOCH case is the stochastic case as described previously. The regions that take part in the gas cartel are indicated in the table in section 0 at page 54. Table 3 summarizes the main differences in assumptions among the cases.

Table 3 Main differences in assumptions

| Assumption | BASE | GECF | DECLINE | STOCH |
|---|---|---|---|---|
| Market | All traders in all periods 0.25, | Starting 2010 GECF trader | Same as | Scen 1 and 2: |

[14] Implemented by assuming a linear decrease from 2020 values in 2020 to zero in 2070 for regions: CHN, JAP, GER, NED, SPA, CAN, USA

| | | | | |
|---|---|---|---|---|
| Power | except for North America: 0 | full market power | BASE | GECF<br>Scen 3 and 4: BASE |
| Production rates | Aggregates based on WGM | Same as BASE | Faster depletion in importing regions[14] | Scen 1 and 3: DECLINE<br>Scen 2 and 4: BASE |

Stochastic Results and Discussion

The main means to influence prices of a cartel is to withhold supplies from the consumption markets. An anticipated effect of a gas cartel would therefor be lower supply and production levels by members of the cartel. To the contrary, suppliers that do not take part in the cartel may respond to higher prevailing market prices by bringing more gas to the markets, and thereby possibly reaping high benefits. Figure 11 shows the production levels by GECF (left) and other countries (right), in the three deterministic cases BASE, GECF and DECLINE, the four scenarios in the STOCH case, and the Expect values (the probability weighted averages) of the scenario outcomes labeled as Exp Stoch.

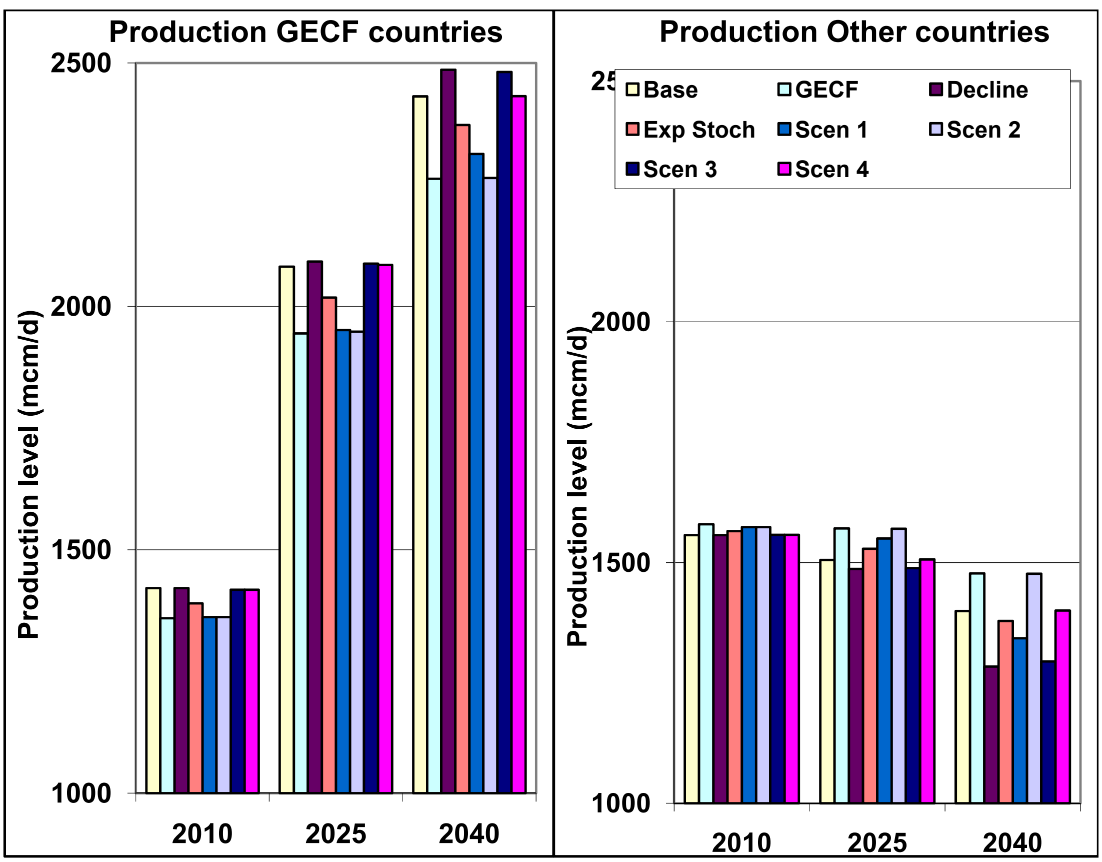


Figure 11 Production levels by case, region and cartel and non-cartel members

Relative to 2010, the GECF countries production levels in the Base - non-cartel - Case, increase with 661 bcma[15], from 1421 to 2082 bcma (+47%) in 2025 and 1010 bcma (+71%, to 2431) in 2040. Production levels in the cartel case are 62 bcm lower in 2010 (-4.4%), 138 lower in 2025 (-6.6%) and 169 lower in 2040 (-7.0%.) In the Decline case, the production level is the same in 2010, in 2025 10 bcma higher (+0.5%) and 55 bcma higher in 2040 (+2.3%.) The difference in the 2040 production levels between the GECF case and the DECLINE case is 10%.

In 2010 the non-cartel countries still have a small overhand at the supply side, with a market share of 52% and a production level of 1557 bcm. However as a group, in the Base Case the aggregate production decreases over time. Total production in 2025 amounts to 1505 (-3% relative to 2010), and in 2040 1399 bcma (-10%.) The non-cartel marketshare in 2040 is only 36½% in the base case.

Production levels of non-cartel members in the GECF case are slightly higher than in the base case, but not nearly enough to offset the by the cartel countries' withheld supplies. The added volumes of 66 and 79 bcm in 2025 and 2040 respectively, replace less than 50% of the GECF production. Since consumption levels in GECF countries actually rise due to lower domestic gas prices (results not shown), the impact on the supply to non-GECF countries is even harsher than this analysis might suggest.

In the DECLINE case, the 2025 production is 1487 bcma (-4.5% relative to 2010, and -1.2% relative to BASE) and 1284 bcma (-17.5% wrt 2010, and -8.2% relative to BASE.) The absolute differences with the BASE case are -18 and -115 bcm, and we saw before that the GECF countries only supply 10 resp. 55 bcma more, compensating only about 50%, resulting in higher prices and higher profits.

One could expect the results of the stochastic scenarios to be within the range of the *extreme* deterministic cases, the cases with the mildest and harshest assumptions. For instance since having to anticipate different scenarios will probably result in more moderate investment decisions and one would not

[15] bcma: billion cubic meter per annum

expect that relatively low (high) expansions would be completelty compensated with higher (lower) expansions in later periods, due to cost recovery limitations or physical limitations on construction activities.

For GECF countries the production levels in all four scenarios are within the deterministic GECF case (at the lower end of the range of values) and the DECLINE case (at the higher end of the range of values. Scenario 2, which follows the same input assumptions as the GECF case[16], results indeed in slightly higher production levels of GECF countries in scenario 2 (between 2 and 4 bcma) than the deterministic GECF case. When we look at scenario 3, for which the same input assumptions apply as for case DECLINE[16], has 3 to 5 bcma lower production levels of GECF countries as that latter case. In scenario 4, the scenario closest to the BASE case, the GECF production levels are a bit lower (-3 bcma) in 2010, and a bit higher (+3 and +1 bcma) in the other two reported years. In scenario 3, the lower own production levels of non-cartel members induce higher supplies by GECF countries. An analysis of cartel profits or price levels in affected countries would give more insight on the impact, but is excluded due to page size limitations. An analysis of price levels, giving a similar although less detailed insight, will follow in a later paragraph.

For the non-cartel countries we see similar results among the cases and scenarios, with the roles of the GECF and DECLINE cases reversed. As expected, the non-cartel countries produce at higher levels in the GECF case and scenarios, and at lower levels in the DECLINE case and scenarios.

The following paragraphs will analyze the expansion of transport capacities over time. We focus on liquefaction capacities in cartel countries. Since there are no LNG importers among the cartel countries, all LNG exports will be received by non-cartel countries and we can use the expansions of LNG export capacity as a proxy for the willingness to supply by cartel countries.

Figure 12 shows the expansion of liquefaction capacity in GECF countries over time. We see that the aggregate investment levels in the cartel case and scenario are less than half relative to the DECLINE scenario, and about 40% lower than in the BASE case. Results of Scenarios 2,3 and 4 are close to their deterministic counter parts – GECF,  DECLINE and BASE – however the timing of some of the expansions differs significantly. For instance if we look at scenario 4 we see that there are virtually no capacity expansions in the first year[17], whereas in the base case there are some. In following periods the

---

[16] except for the initial years having to anticipate multiple futures
[17] The actual value, 0.1, is too small to show in the Figure

expansions in scenario four are higher (2010) or constrained by expansion limitations (2015) and it takes until 2020 for the total LNG export capacity to overtake Base Case levels. In periods 2025 and 2030 the expansions are higher in the deterministic scenario, and after 2040 the total liquefaction capacities in GECF countries are virtually the same in both cases.

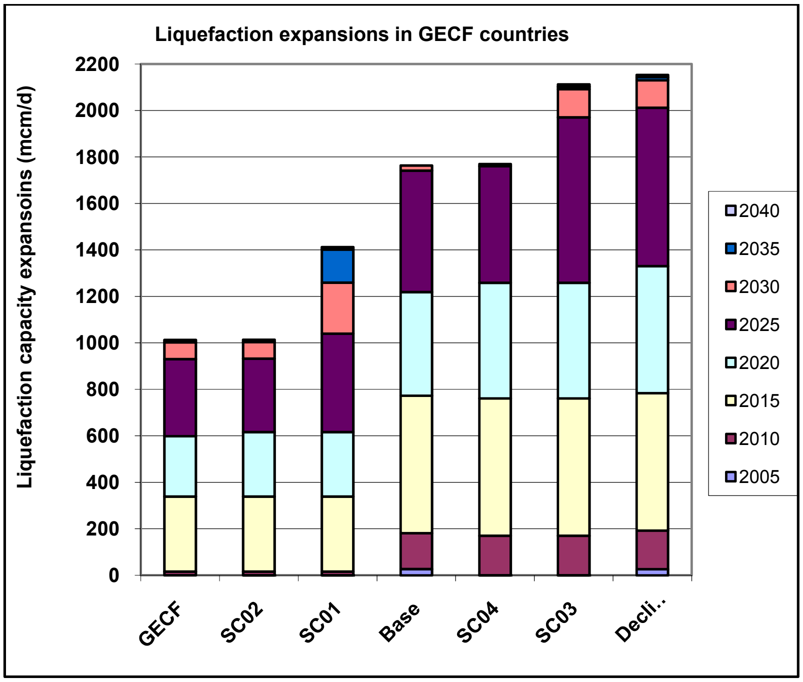



Figure 12 Liquefaction capacity expansions by cartel members

Similar observations can be made for scenarios 2 and 3, but are omitted from this paper. We will however briefly discuss Scenario 1 outcomes. Scenario 1 has no deterministic counterpart. Until 2015 it overlaps with Scenario 2, which closely follows the deterministic GECF scenario. However from 2020 the declining production rates in several non-cartel countries start playing a role. In all years after 2020 the capacity expansions in scenario 1 are significantly higher than in scenario 2. In 2030 and 2035 the expansions are even higher than in any other case, although never nearly enough to get to similar total capacities by the end of the time horizon.

The last results that we will discuss are price results for regions GER, JAP and USA, three of the regions that face harsher decline in production levels in case DECLINE.

Figure 13 shows the development of volume weighted average wholesale prices in region ‘GER” for all cases relative to the prices in the Base Case. The prices in the different scenarios rather closely follow the prices in their deterministic counterparts. In the cases and scenarios that the gas cartel is established in 2010, we see higher prices immediately. In the cases with declining production rates in several importing countries, among which is GER, we see (another) price relative increase starting 2025, the first year that production capacities are affected. The combined impact of a gas cartel and declining production rates in later years, e.g. the +30% in 2040 in Scenario 1 is higher than the aggregate of the separate impacts. Notably, the prices in Scenario 4 in years after 2025 are exactly the same as in the Base Case.

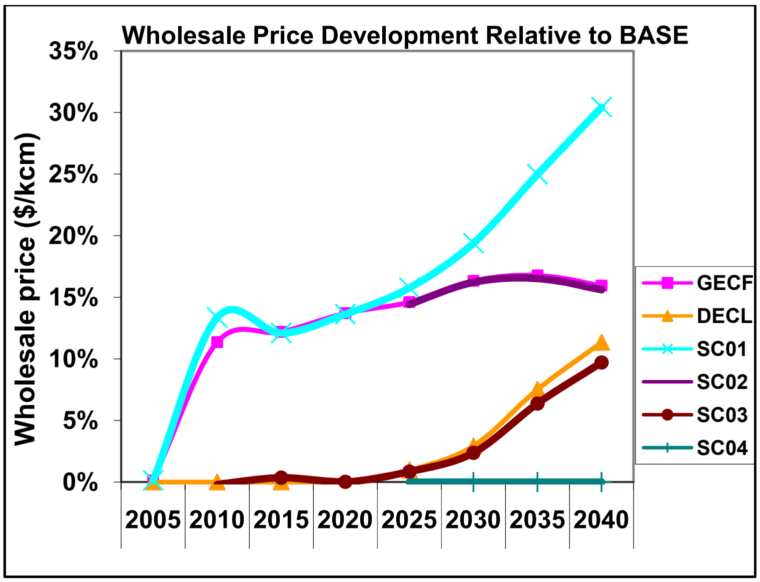



Figure 13 Price development relative to Base Case for Central and East Europe.

Similar to the previous figure, Figure 14 shows the development of prices in all cases in the region Japan/South Korea, relative to the prices in the Base Case. In this region the relative impact of the gas cartel is felt most immediately after establishment of cartel, with a relative price hike of 18-20%. We suspect that the proximity of Japan and South Korea to non-GECF LNG exporter Australia softens the effects in the long term as Australia would bring more LNG export capacity on stream.

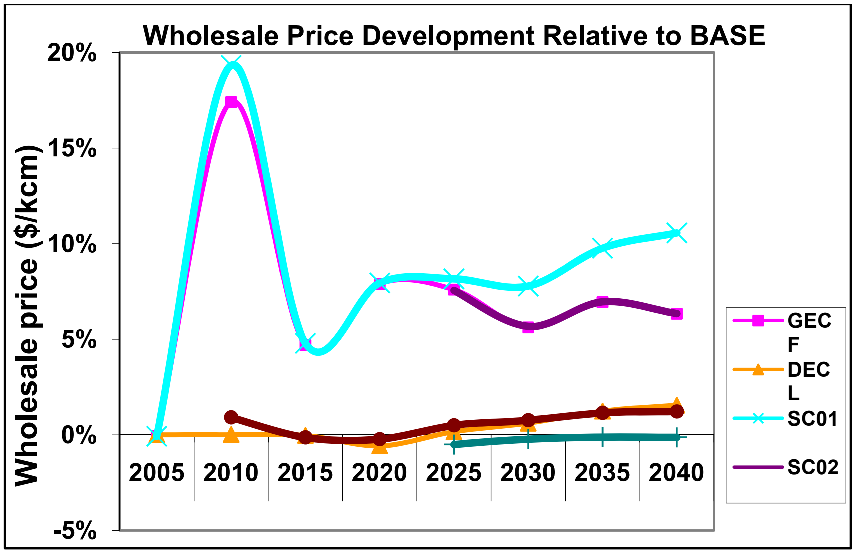



Figure 14 Price development relative to Base Case for Japan and South Korea.

Lastly, Figure 15 shows the development of prices in all cases relative to the prices in the base case for the USA and Mexico.

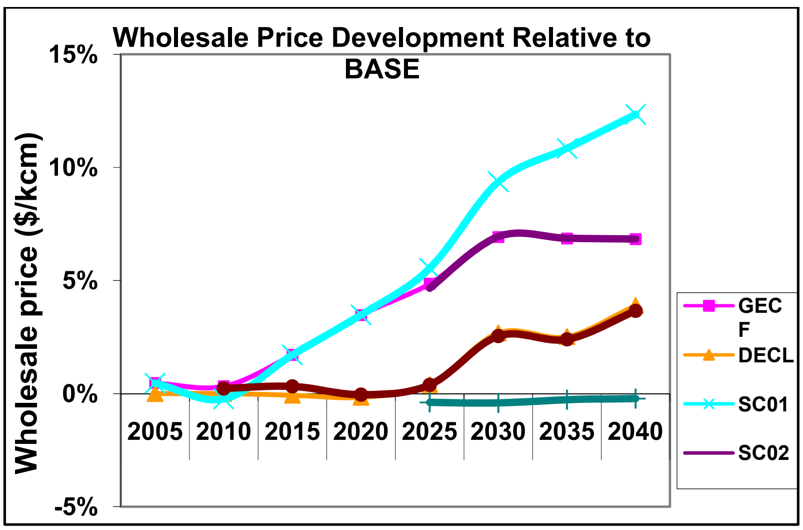



Figure 15 Price development relative to Base Case for USA and Mexico.

The felt impact on prices in North America due to the cartel establishment and the declining production rates is much more modest in the short run relative to the other two regions, but increases over time. This can be explained by the different dependencies on imports from cartel members, which is low early on in the time horizon, but increases rather rapidly in later years for USA.

Summarizing, although early on region JAP suffers most from a cartel, and for region USA the impact becomes bigger over time, overall we see the harshest impact on price levels for the GER region.

## Conclusions and Future Directions

This paper presents and analyzes deterministic and stochastic scenario results for developments in the global natural gas market in the next four decades, using the World Gas Model. Results for a Base Case are presented for production and consumption levels, trade flows, capacity expansions and wholesale prices, based on business-as-usual assumptions. Results for South America have been presented in more detail.

We also have introduced a Stochastic variant of the World Gas Model, with which we have analyzed a case with four scenarios in a single modeling framework. In these four scenarios different assumptions apply for the exercised market power by members of the Gas Exporting Countries Forum, as well as for the domestic production capacities of some regions that rely on imports to cover significant parts of their domestic natural gas demand.

We have seen that different assumptions greatly affect model outcomes. Some infrastructural consequences resulting from market power assumptions include that LNG export expansions by cartel members would be about 50% lower than the expansions in a more competitive market structure. In the stochastic scenarios we see that the consideration of several possible futures has large impact on the timing of investments, however less on the installed total capacity at the end of the time horizon.

Generally the relative impact of different assumptions on prices and consumption volumes seems rather modest. However regionally the impact of a gas cartel may be an up to a 30% price increase relative to a business as usual situation. Although in a globalizing competitive gas market consequences of changing local supply situations may smooth out over the globe, the establishment of a gas cartel, especially with dwindling reserves in importing regions, should be a matter of concern to policy makers.

In future research we will address the explicit consideration of natural reserves in countries as well as limitations in scalability of Stochastic Mixed Complementarity Problems by developing time-effective solution methods for large-scale mixed complementarity problems.

## Acknowledgement

We thank Daniel Huppmann, Christian von Hirschhausen, Steven Gabriel and Sophia Rüster for their contributions to the development of the World Gas Model.

References

BP (2008): Statistical Review of World Energy.

Egging, Ruud, Steven A. Gabriel, Franziska Holz, and Jifang Zhuang (2008): A Complementarity Model for the European Natural Gas Market. *Energy Policy*, Vol. 36, No. 7, pp. 2385-414.

Egging, Ruud, Franziska Holz, Christian von Hirschhausen, and Steven A. Gabriel (2008): Representing Gaspec with the World Gas Model. Accepted for publication, the *Energy Journal*.

Energy Information Administration (2007): International Energy Outlook.

Energy Information Administration (2008): Country Energy Data and Analysis; http://tonto.eia.doe.gov/country/index.cfm.

European Commission (2006): World Energy Technology Outlook – 2050 – WETO-$H_2$.

European Commission (2007): European Energy and Transport – Trends to 2030 – Update 2007.

Stern, Jonathan (2007): The New Security Environment for European Gas: Worsening Geopolitics and Increasing Global Competition for LNG. *CESSA* Working Paper Nr. 14.

Victor, David G., Amy M. Jaffe and Mark H. Hayes (2006): Natural Gas and Geopolitics: Introduction to the Study. In: Natural Gas and Geopolitics: From 1970 to 2040. Cambridge and New York, Cambridge University Press; pp. 3-24.

Appendix: Input data for nineteen regions

This appendix provides input data that is used in the Stochastic scenario case.

Regions, used abbreviations and GECF membership

| Region | Node | GECF member |
|---|---|---|
| North Africa | ALG | yes |
| West Africa | NIG | yes |
| Australia | AUS | no |
| Asia other | CHN | no |
| South East Asian LNG exporters | IDO | yes |
| Japan and South Korea | JAP | no |
| Caspian region | KZK | yes |
| Central Europe | GER | no |
| Norway and Netherlands | NED | no |
| South/West Europe | SPA | no |
| Brazil and Argentina | BRA | no |
| Venezuela, Bolivia, Trinidad | VEN | yes |
| Chile, Peru, Ecuador | CHL | no |
| Middle East GECF | QAT | yes |
| Middle East non GECF | YMN | no |
| Canada | CAN | no |
| USA and Mexico | USA | no |
| East Russia | RUE | yes |
| West Russia | RUW | yes |

General data

The model is calibrated for base year 2005, with the GECF countries operating via a single trader. All traders are assigned a market power indicator with value

0.25, except for the traders of USA and CAN, that operate perfectly competitive in the North American market. The outcome for the average worldwide wholesale price was $166/1000 m$^3$. All costs and prices are in $2005, the (real) discount rate used in the model runs is 10%.

Production and Consumption levels 2005 (bcma)

The following table presents production capacities, and reference values and model outcomes for production and consumption in the (calibrated) base case in bcm.

| | | Production | | | Consumption | |
|---|---|---|---|---|---|---|
| region | node | Capacity | Model outcome | Reference | Model outcome | Reference |
| Africa | ALG | 233 | 145 | 145 | 59 | 58 |
| | NIG | 36 | 17 | 17 | 5 | 5 |
| Asia Pacific | AUS | 43 | 36 | 36 | 23 | 22 |
| | CHN | 124 | 118 | 116 | 130 | 130 |
| | IDO | 137 | 119 | 120 | 41 | 41 |
| | JAP | 2 | 2 | 2 | 113 | 113 |
| Caspian | KZK | 167 | 134 | 135 | 79 | 78 |
| Europe | GER | 70 | 62 | 62 | 314 | 313 |
| | NED | 188 | 153 | 154 | 40 | 39 |
| | SPA | 98 | 94 | 94 | 254 | 253 |
| South America | BRA | 52 | 44 | 44 | 49 | 49 |
| | CHL | 4 | 4 | 4 | 9 | 9 |
| | VEN | 81 | 55 | 55 | 32 | 32 |
| Middle East | QAT | 167 | 122 | 122 | 97 | 96 |
| | YMN | 147 | 115 | 115 | 95 | 95 |
| North America | CAN | 172 | 155 | 156 | 67 | 67 |

<table>
<tr><td></td><td>USA</td><td>542</td><td>472</td><td>471</td><td>578</td><td>577</td></tr>
<tr><td rowspan="2">Russia</td><td>RUE</td><td>12</td><td>10</td><td rowspan="2">574</td><td>10</td><td rowspan="2">377</td></tr>
<tr><td>RUW</td><td>617</td><td>564</td><td>370</td></tr>
</table>

Liquefaction

The following table contains the liquefaction capacities, per unit costs and allowed capacity expansions in each future period. Note that a expansions occur with a five year delay, so an investment in a capacity expansion in a certain year will lead to a higher capacity in the following period.

| Liquefaction | Capacity 2005 (mcmd) | Calibrated cost ($/1000m$^3$) | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| YMN | 61.1 | 60 | 27.4 | 49.3 | 49.3 | 49.3 | 41.1 | 41.1 | 32.9 | 32.9 | 16.4 |
| VEN | 55.3 | 47 | 16.4 | 16.4 | 49.3 | 74.0 | 74.0 | 74.0 | 41.1 | 41.1 | 16.4 |
| RUW | | 55 | - | - | 32.9 | 32.9 | 16.4 | 16.4 | 16.4 | 16.4 | 16.4 |
| RUE | | 55 | 35.6 | 21.9 | 21.9 | 21.9 | 8.2 | 8.2 | 8.2 | 8.2 | - |
| QAT | 97.0 | 47 | 164.4 | 82.2 | 98.6 | 115.1 | 115.1 | 115.1 | 98.6 | 98.6 | 32.9 |
| NIG | 52.1 | 48 | 30.1 | 49.3 | 98.6 | 82.2 | 82.2 | 65.8 | - | - | - |
| IDO | 220.3 | 43 | 30.1 | 41.1 | 65.8 | 49.3 | 32.9 | 32.9 | 16.4 | - | - |
| AUS | 43.8 | 45 | 38.4 | 101.4 | 32.9 | 32.9 | 32.9 | 16.4 | 16.4 | 16.4 | 16.4 |
| ALG | 130.5 | 53 | 35.6 | 115.1 | 65.8 | 65.8 | 49.3 | 49.3 | 32.9 | 32.9 | 32.9 |

The loss rate of natural gas in the liquefaction process is set at 12%. The investment costs for expansions of and new liquefaction capacity are assumed to be $160,000 per mcm/[18]d.

Re-gasification

The needed data for the regasifiers are very similar to that for liquefaction.

---

[18] million cubic meter

| Regasifier | Capacity 2005 (mcmd) | Calibrated costs ($/kcm) | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| BRA | - | 25 | - | 32.9 | 32.9 | 16.4 | 16.4 | 16.4 | 16.4 | 16.4 | 16.4 |
| CHL | - | 25 | 11.0 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 | 8.2 |
| CHN | 97.0 | 4 | 41.1 | 84.9 | 131.5 | 139.7 | 139.7 | 106.8 | 65.8 | 57.5 | 41.1 |
| BEL | 15.1 | 21 | 11.0 | 150.7 | 90.4 | 41.1 | 32.9 | 24.7 | 24.7 | 24.7 | 8.2 |
| GRC | 21.6 | 21 | 27.4 | 16.4 | 32.9 | 32.9 | 32.9 | 32.9 | 16.4 | 16.4 | - |
| JAP | 869.3 | 30 | 65.8 | 49.3 | 49.3 | 32.9 | 32.9 | 32.9 | 24.7 | 16.4 | 16.4 |
| ITL | 90.7 | 17 | 112.3 | 74.0 | 57.5 | 32.9 | 32.9 | 24.7 | - | - | - |
| UKD | 104.3 | 33 | 117.8 | 153.4 | 82.2 | 49.3 | 49.3 | 41.1 | 16.4 | 16.4 | - |
| USE | 129.6 | 30 | 43.8 | 65.8 | 65.8 | 98.6 | 98.6 | 82.2 | 82.2 | 82.2 | 16.4 |
| USG | 18.9 | 30 | 76.7 | 98.6 | 131.5 | 131.5 | 131.5 | 131.5 | 98.6 | 32.9 | 32.9 |
| USW | - | 25 | 8.2 | 98.6 | 164.4 | 164.4 | 164.4 | 98.6 | 90.4 | 90.4 | 32.9 |

The loss rate of natural gas in the regasification process is set at 1.5%. The investment costs for expansions of and new regasification capacity are assumed to be $50,000 per mcmd.

Pipeline data

For an explanation of the pipeline input data in the following table see the comments before the table with Liquefaction data.

| Pipeline | Investment Cost Adjustment Factor | Capacity 2005 (mcmd) | Loss Rate (%) | Regulated fee | 2005 | 2010 | 2015 | 2020 | 2025 - 2045 |
|---|---|---|---|---|---|---|---|---|---|
| ALG.SP | 2 | 134.5 | 2.8 | 20 | 75 | 105 | 90 | 60 | 10 |

| Pipeline | Investment Cost Adjustment Factor | Capacity 2005 (mcmd) | Loss Rate (%) | Regulated fee | 2005 | 2010 | 2015 | 2020 | 2025 - 2045 |
|---|---|---|---|---|---|---|---|---|---|
| A | | | | | | | | | |
| BRA.CHL | 2 | 41.1 | 1.3 | 10 | 15 | 30 | 30 | 30 | 30 |
| CAN.USA | 2 | 534.5 | 2.5 | 20 | - | 50 | 100 | 75 | 75 |
| CHL.BRA | 4 | - | 3.1 | 20 | 30 | 60 | 60 | 60 | 60 |
| CHN.JAP | 4 | - | 2.5 | 20 | - | - | 30 | 30 | 30 |
| GER.SPA | 1 | 313.6 | 1.6 | 13 | - | 30 | 30 | 30 | 30 |
| IDO.CHN | 8 | 24.1 | 1.6 | 15 | 60 | 120 | 120 | 120 | 120 |
| KZK.CHN | 6 | - | 4.4 | 20 | - | 90 | 90 | 70 | 70 |
| KZK.GER | 3 | 18.1 | 2.5 | 19 | 30 | 30 | 30 | 30 | 30 |
| KZK.QAT | 4 | 21.9 | 1.3 | 20 | 60 | 60 | 60 | 60 | 60 |
| KZK.RUW | 3 | 150.7 | 3.8 | 31 | 60 | 60 | 60 | 60 | 60 |
| NIG.ALG | 6 | - | 5.0 | 30 | - | 60 | 60 | 60 | 60 |
| NED.GER | 2 | 454.3 | 1.8 | 8 | - | 20 | 20 | 20 | 20 |
| NED.SPA | 2 | 110.9 | 1.9 | 18 | - | 10 | 6 | 6 | 6 |
| QAT.CHN | 6 | - | 3.8 | 20 | - | - | 50 | 50 | 50 |

| Pipeline | Investment Cost Adjustment Factor | Capacity 2005 (mcmd) | Loss Rate (%) | Regulated fee | 2005 | 2010 | 2015 | 2020 | 2025 - 2045 |
|---|---|---|---|---|---|---|---|---|---|
| QAT.GER | 3 | 27.4 | 2.5 | 10 | - | 30 | 30 | 30 | 30 |
| QAT.KZK | 4 | - | 2.5 | 10 | - | 60 | 60 | 60 | 60 |
| QAT.YMN | 2 | - | 2.1 | 20 | - | 80 | 110 | 110 | 110 |
| RUE.CHN | 4 | - | 4.4 | 35 | - | - | 100 | 200 | 200 |
| RUE.JAP | 8 | - | 2.5 | 30 | - | - | 50 | 50 | 50 |
| RUW.GER | 8 | 676.8 | 4.7 | 33 | 40 | 300 | 300 | 400 | 400 |
| RUW.KZK | 3 | 35.6 | 5.0 | 10 | - | - | - | - | - |
| SPA.GER | 2 | 93.1 | 1.6 | 13 | - | 50 | 50 | 50 | 50 |
| VEN.BRA | 4 | 40.4 | 3.1 | 10 | 30 | 60 | 60 | 60 | 60 |

The investment costs for pipeline capacity are $50,000/mcmd times the factors in the table above, in column Investment Cost Adjustment Factor. The factors are based on characteristics as: is it a new pipeline or expansion of an existing one, is the pipeline onshore or offshore, and the length of the pipeline.

LNG Shipping distances (1000s of sea miles)

For virtual pipelines that represent LNG shipping routes, the loss rates and costs are based on the shipping distances.

| | CHN | JAP | CHL | USW | USE | USG | BRA | GER (BEL/GRC)[19] | UKD | ITL |
|---|---|---|---|---|---|---|---|---|---|---|
| RUW | 11.2 | 12.7 | 08.3 | 08.6 | 04.4 | 05.8 | 06.7 | | 01.8 | 03.7 |
| ALG | 08.1 | 09.6 | 07.2 | 07.5 | 03.7 | 05.0 | 04.4 | | 01.4 | 00.7 |
| NIG | 09.3 | 10.8 | 06.7 | 10.1 | 05.2 | 06.1 | 03.3 | | 04.1 | 04.2 |
| QAT | 05.1 | 06.5 | 10.6 | 11.3 | 08.4 | 09.7 | 08.2 | | 06.1 | 04.5 |
| YMN | 04.8 | 06.3 | 09.3 | 11.1 | 07.1 | 08.3 | 08.0 | | 04.7 | 03.1 |
| IDO | 01.5 | 02.6 | 09.6 | 07.9 | 11.6 | 11.9 | 08.4 | | 08.3 | 07.6 |
| RUE | 02.1 | 00.9 | 09.6 | 04.8 | 11.0 | 10.0 | 11.6 | | 11.5 | 09.8 |
| AUS | 02.7 | 03.7 | 08.7 | 07.9 | 12.1 | 11.7 | 08.4 | | 09.1 | 07.5 |
| VEN | 12.0 | 04.4 | 05.7 | 06.3 | 01.9 | 02.1 | 02.1 | | 03.8 | 04.5 |

Shipping costs are equal to $9 times the shipping distances in 1000s of miles. Loss rates are equal to 0.3% of these distances.

[19] Just before sending out the paper we found an omission in the data set resulting in zero losses and zero transport costs to the regasification terminals in Central and South East Europe (node GER). Since the model was calibrated using these zero values, and the transport routes from the most likely suppliers: Western Russia and North Africa to Europe are rather short, the impact on the model outcomes is very modest.

# 4. Latin America Oil Demand: An Econometric and Economic Historical Approach

**Francisco Ebeling Barros[1], Mariana Iootty de Paiva Dias**

1 - Economist at the IBP (Instituto Brasileiro de Petróleo, Gás e Biocombustíveis) and former research assistant at the IE-UFRJ Energy Economics Group

francisco.ebeling@ibp.org.br

Oil demand; Johansen Co-integration; Heterodox Economics

Abstract: Foreign economic dependence is one of the keywords most used to describe Latin America's insertion in the world economy. This dependence finds its roots in the very way latin american nations interacted in the global economic scenario as primary exporting countries. In this context, foreign demand for agricultural or mining products had great impact, positive or negative, on the social and economic indicators of those countries. Even though a path of industrialization and economic diversification has been trailed in the region, many of those countries are still very dependent on foreign demand for primary goods. Oil as an exporting good revealed itself as a very special case, as some countries such as Mexico and Venezuela managed to receive much more higher revenues than any other latin american exporting goods in any other country of the region. Unfortunately, those colossal revenues lead to economic distortions such as the "dutch disease", induced by poor government administration of the oil rents. Nevertheless, some recent political developments and geological findings have defied the traditional role of oil as an exporting good in countries like Venezuela or Brazil. It is the opportunity to introduce a new debate, in which oil exporting revenues could finance a wholly new phase of economic growth. As foreign oil demand is the one factor which helped to reinforce economic dependence and, paradoxically, at the same time can be seen as a new tool to slow down the same dependence, it is especially important to understand how oil demand is structured in latin american countries. This paper uses Johansen co-integration to estimate the oil demand function for four countries of the region: Argentina, Brazil, Mexico and Venezuela. Results show that all countries are or tend to become net oil exporters. Even though solid foreign oil demand elasticity assures that a country might receive oil revenues from the world, it is necessary that those oil revenues are properly spent. Using a historical and heterodox approach based on Chang (2002), this paper analyses if the four countries have adequate political and economic institutions in order to properly use the oil revenues they receive. It is believed that diverse possible institutional arrangements can lead to sucess or failure in the delicate balance between oil industry and national economy. The focus, in this sense, should be placed at the local and regional premises one country is faced with while structuring its oil industry.

## 1.- Introdução

A dependência em relação aos principais países do mundo (em termos econômicos) sempre foi, historicamente, um dos traços marcantes das economias dos países da América Latina. Essa se originou, em grandes linhas, na especialização daqueles países em produzir e exportar bens de exportação primária. Segundo Prebisch (1962), ao priorizar esse tipo de atividade, os países sistematicamente obtiveram taxas de crescimento econômico inferiores a media dos demais países do mundo. Para romper com esse ciclo, surgiu a idéia de introduzir um processo de substituição de importações, representado pela criação de uma indústria mais sólida, apta a ajudar a romper com esse ciclo de subdesenvolvimento.

O petróleo, nesse contexto, representa um caso bastante singular. Embora seja um produto de exportação primária, seu elevado conteúdo tecnológico o qualifica enquanto setor industrial que pode ter impactos gigantescos sobre o conjunto da economia, em proporções que transcenderiam o velho padrão econômico de dependência. Entretanto, esses impactos podem ser bons ou ruins. Predominaram, na América Latina, os impactos negativos, com o surgimento da "doença holandesa" principalmente no México e na Venezuela.

Na contramão disso, aqui se argumenta que o petróleo pode impactar positivamente sobre a economia de um país, desde que os instrumentos institucionais - políticos e econômicos - sejam bem geridos para, ao mesmo tempo, aplacar os vícios que o petróleo introduz numa economia nacional e também explorar as boas potencialidades que sua cadeia de produção e as rendas petrolíferas trazem consigo.

Usando a co integração de Johansen estima-se uma função de demanda por petróleo de quatro países da América Latina, tomados isoladamente. Argentina, Brasil, México e Venezuela são os casos analisados. Se os coeficientes relativos à elasticidade-renda por parte do mundo são elevados, isso significa que aumentos da renda mundial podem representar grandes influxos de rendas petrolíferas para aqueles países.

No entanto, segundo o que foi argumentado acima, essa não é uma condição suficiente para o que desenvolvimento econômico seja atingido. Para avaliar se as instituições políticas e econômicas desses países estão aptas a transformar rendas petrolíferas no tão sonhado desenvolvimento, é usado um instrumental analítico baseado em Chang (2002). O autor argumentou que os padrões históricos de desenvolvimento dos países mais ricos não são compatíveis com o que o *main stream* classifica como a “receita de bolo” para atingir esse fim. Por essas razões, a análise é considerada heterodoxa e ao mesmo tempo histórica.

O artigo divide-se em quatro partes, além da introdução. A primeira parte analisa o debate que considera que o petróleo, a despeito do seu caráter de produto primário exportador, pode levar os países a rumos que nada tem a ver com sub desenvolvimento. Na segunda parte é feita a estimação da função de demanda por petróleo. Essa parte se divide nos seguintes subtópicos: a) resenha da literatura; b) modelo teórico; c) metodologia; d) dados usados; e) resultados e f) observações finais. Na terceira seção é feita a análise baseada em Chang (2002). Por fim, são feitas algumas observações finais na conclusão.

## 2.- Da dependência externa em economias primário-exportadoras ao novo debate na economia do petróleo

As economias dos países latino-americanos tradicionalmente especializaram-se em atividades primário-exportadoras. Esse padrão foi adotado em decorrência da estrutura política que se estabeleceu naqueles países desde a chegada dos colonizadores, que usaram as colônias latino-americanas como plataformas de exportação de bens primários para sustentar suas economias metropolitanas. A emancipação política dos países no século XIX não foi capaz de romper com tal paradigma, de tal sorte que a estrutura primário-exportadora se aprofundou mesmo no século XX. Na maioria dos casos, excluindo-se principalmente a Argentina do começo do mesmo século, esse sistema econômico teve como conseqüência para as nações latino-americanas um forte grau de dependência econômica em relação aos países mais desenvolvidos e um elevado grau de subdesenvolvimento econômico e social. Pode-se ressaltar aqui, em grandes traços, que a demanda por produtos latino-americanos por parte dos países mais ricos moldou o sistema econômico que se instaurou na região e determinou os rumos, bons ou ruins, que essas economias seguiram. Em geral, a tendência à perda predominou.

Essa tendência histórica foi bem sintetizada por Eduardo Galeano (1970):

"La división internacional del trabajo consiste em que unos países se especializan em ganar y otros en perder. Nuestra comarca del mundo, que hoy llamamos América Latina, fue precoz: se especializó em perder desde los remotos tiempos em que los europeeos del renacimiento se abalanzaron a través del mar y le hundieron los dientes en la garganta. Pasaron los siglos y América Latina perfeccionó sus funciones. Este ya no es el reino de las maravillas donde la realidad derrotaba a la fábula y la imaginación era humillada por trofeos de la conquista, los yacimientos de oro y montañas de plata. Pero la región sigue trabajando de sirvienta. Contínua existiendo al servicio de las necesidades ajenas, como fuente y reserva del petróleo y el hierro, el cobre y la carne, las frutas y el café, las matérias primas y los alimentos con destino a los países ricos que ganan, consumiéndolos, mucho más de que América Latina gana produciéndolos...." (Galeano, E., 1970)

Tendo como pano de fundo a estrutura desigual de poder econômico e, consequentemente, o subdesenvolvimento e a pobreza, surgiu nos anos 40, 50 e 60 toda uma linhagem de pensadores que procuraram pensar soluções para os problemas latino-americanos. Esses pensadores tiveram também como inspiração a experiência nacionalista que se praticou em alguns países da América Latina nos anos 30, 40 e 50. Nessa época deu-se início, ainda que num estágio embrionário, uma política de substituição de importações por parte dos governos nacionalistas. Nesse contexto, os autores, dentre os quais se destacaram Raul Prebisch, Celso Furtado, Maria da Conceição Tavares e Fernando Henrique Cardoso, construíram o edifício teórico da escola estruturalista.

Uma das principais idéias que se destacam aqui neste trabalho a respeito da escola estruturalista é de Raul Prebisch (1962), que sugeriu que se as economias latino-americanas continuassem se especializando em exportar produtos agrícolas de baixa elasticidade-renda, estas continuariam a ter taxas de crescimento sistematicamente inferiores às dos países desenvolvidos. Para romper com esse ciclo, as rendas obtidas nas atividades primário-exportadoras deveriam ser revertidas para a criação de uma indústria que produzisse bens de elasticidade-renda maior e fornecesse ao país a possibilidade de crescer a taxas superiores e assim realizar algo como um *catching-up*.

No contexto do pensamento estruturalista e das decisões políticas praticadas pelos governos dos paises latino-americanos, foram postas em prática rígidas políticas que visavam a mitigação dos efeitos adversos do subdesenvolvimento e que lograssem alcançar o tão almejado *catching-up*. Esse modelo teve seu auge nos anos 70. Entretanto, como a industrialização era financiada por forte endividamento externo, a crise econômica dos anos 70, que cortou boa parte dos fluxos de financiamento, culminou naquilo que ficou conhecido, em muitos dos países latino-americanos, como "a crise da dívida". Mais à frente, em especial nos anos 90, foram postas em prática políticas neoliberais como alternativa ao modelo desenvolvimentista que até então era praticado e que não parecia mais ter sucesso. Sistematicamente os países da região praticaram profundas reformas que não alcançaram, principalmente na última década, os resultados desejados.

Na contramão disso, nos últimos anos tem surgido um novo debate em torno da possibilidade de se adotar um novo desenvolvimentismo, uma via que admita a importância estatal por rechaçar a idéia neoliberal do estado mínimo, mas que não renegue o importante papel do capitalismo enquanto fonte de inovações e de acumulação.

Nos últimos anos, a economia do petróleo em países latino-americanos surge como um dos principais pontos a serem esclarecidos na agenda do novo desenvolvimentismo. A razão disso é que o nacionalismo energético voltou à pauta no continente, já que alguns países trouxeram ou visam trazer de volta em maior grau o Estado à atividade petrolífera. Como a agenda novo desenvolvimentista se propõe a discutir a otimização da participação estatal na economia, o nacionalismo energético surge como tema crucial a ser discutido.

Outra razão pela qual o petróleo tenha se deslocado para o centro das atuais discussões, principalmente numa época em que seus preços estão em alta, é o reconhecimento de que o energético poderia se configurar uma das principais fontes de desenvolvimento econômico na América Latina, a despeito do passado sombrio em que a doença holandesa assolou alguns dos países exportadores de petróleo. Para isso, alguns fatos estilizados precisam ser esclarecidos.

De fato, pela má gestão dos recursos petrolíferos, alguns países como a Venezuela ou o México padeceram das mazelas da doença holandesa, em que a apreciação cambial decorrente da priorização do setor petrolífero tornou os demais setores da economia pouco competitivos. Poucos investimentos em agricultura e nas indústrias não-petroleiras completaram um quadro em que as rendas petrolíferas, a despeito de sua estrondosa magnitude, não foram capazes de alterar a estrutura econômica de dependência que é tradicionalmente conhecida na América Latina e que foi bem analiticamente descrita pela escola cepalina.

No entanto, é preciso ressaltar que a posse de recursos minerais como o petróleo não necessariamente constitui uma desgraça tal como a descreveu Furtado (2008) em seu estudo sobre a Venezuela. Bresser-Pereira (2007) analisa a possibilidade de reverter os malefícios da doença holandesa, ao ressaltar que os recursos advindos da renda petrolífera devem ser adequadamente geridos e que deve haver um planejamento que contemple em que medida as variáveis econômicas são negativamente afetadas pela atividade petrolífera e quais as possíveis medidas de saneamento desses problemas. O autor sugere como uma das principais medidas para impedir a aparição ou o alastramento desse fenômeno a criação de um imposto sobre a *commodity,* que tenha como magnitude exata a diferença entre um câmbio que seja favorável ao setor industrial não-petroleiro e aquele que normalmente vigoraria caso não existisse o imposto. Nesse sentido, a própria *commodity* financiaria, via câmbio, a competitividade dos demais setores da economia. Além disso, existe a possibilidade de criar fundos setoriais para realizar investimentos diretos em infra-estrutura, P&D entre outras aplicações que restaurem ou potencializem a competitividade relativa dos demais setores.

Outro aspecto importante que sustenta a esperança de que o petróleo possa vir a financiar o desenvolvimento econômico de alguns países latino-americanos é a idéia de que o energético, a despeito de ser primário-exportador, tem uma estrutura industrial com grande conteúdo tecnológico. Para que as atividades de E&P sejam realizadas é necessário um grande aporte de bens de capital com grande sofisticação e de custos muito elevados. A instalação de uma indústria tão sofisticada como a petrolífera pode significar um grande efeito multiplicador em outros setores industriais, tais como aqueles de apoio a ela mesma.

Argumenta-se aqui que o petróleo é uma *commodity* com grande elasticidade-renda, apesar de ser um produto de exportação primária, e por isso enquadra-se no perfil que a análise estruturalista de Prebisch qualifica como produto que poderia romper com o ciclo de subdesenvolvimento e, conseqüentemente, compatibilizar as taxas de crescimento de um país atrasado com a de países com PIBs per capita elevados. Quando a demanda global está aquecida, essa grande elasticidade renda do produto faz aportar grandes somas de divisas nas economias que produzem o mineral. No entanto, ser um produto de grande elasticidade-renda não é condição suficiente para que uma economia petrolífera por si só seja propulsora do desenvolvimento econômico de uma nação. É preciso que as rendas petrolíferas sejam bem administradas e bem investidas e que seus efeitos macroeconômicos adversos sejam controlados.

Pelas razões supra citadas, a indústria petrolífera de um país como o Brasil, que se encontra numa época de “euforia petroleira”, poderia dar início a um processo de *catching-up* assim como o descreveu Prebisch, a despeito dos fatos estilizados que indicam o contrário. Se esse processo ocorrer, um aparente paradoxo entrará em cena. A demanda externa por bens primário-exportadores, que no passado foi a força motriz do subdesenvolvimento e da dependência externa, passaria a ser a força motriz do desenvolvimento econômico e da atenuação da dependência externa. Evidentemente, a pauta de exportação, o momento histórico e político e a complexidade das atividades econômicas relacionadas a cada época atenuam e dão dimensão muito mais complexa a esse aparente paradoxo.

## 3.- A análise econométrica

### 3.1- Resenha da literatura

Existem dois tipos de estudos que modelam a demanda por petróleo e de outros energéticos: aqueles que contemplam a demanda por petróleo a nível nacional ou ao nível de grupos de nações e aqueles que procuraram modelar a demanda mundial por petróleo. Embora o foco deste trabalho esteja na estimação ao nível da nação, é importante ressaltar que os trabalhos que abordaram o tema sob a ótica mundial também trouxeram importantes contribuições para o seu avanço e conseqüente sofisticação dos instrumentais econométricos envolvidos.

Entre os principais trabalhos que abordaram o tema ao nível das nações, estão os de Balestra e Nerlove (1966), Pindyck (1979), Pesaran et al. (1998) e o de Gately e Huntington (2002).

Os autores Balestra e Nerlove (1966) foram alguns dos pioneiros na aplicação de um modelo dinâmico com o uso de uma série de tempo em *cross section*s para a estimação de uma função de demanda por energéticos em diferentes grupos de uso (residencial e comercial).

Em seu estudo clássico, Pindyck (1979) analisou procedimentos econométricos para a modelagem da demanda por petróleo, aplicando esse referencial para a estimação da demanda por alguns derivados do petróleo para os mercados somados do Brasil e do México, que foram depois comparados com os dados anteriormente obtidos para um conjunto de países OECD.

Nesse sentido, o autor usou um modelo log-linear com um lag de Koyck para explicar os ajustes dinâmicos da demanda ao preço e à renda, aplicado aos mercados de óleos combustíveis, gasolina, querosene e GLP. O autor, ressalta-se, usou também um modelo dinâmico. A variável dependente do seu modelo era o consumo per capita de um determinado combustível, sendo as variáveis independentes o PIB per capita no país e o preço do combustível no mesmo. A partir dessas variáveis, obteve duas elasticidades: as elasticidades renda e preço da demanda de longo prazo. Admitiu, adicionalmente, a possibilidade de incluir outras variáveis para enriquecer o modelo, como preço de combustíveis substitutos e também preços agregados significativos de energia nos países. Os dados utilizados foram fornecidos pelo UN World Energy Supply, com a série 1954 a 1974, no Brasil, e 1960 a 1974 no México. Para estimar o modelo, Pindyck (1979) utilizou o modelo de mínimos quadrados. A Tabela 1 mostra os resultados obtidos pelo autor (1979).

Tabela 1

| Principais Resultados do Estudo de 1979 de Pindyck | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Variável dependente | Preço | PIB | Lag dependente | Constantes<br>BR / Mex | Elasticidades LP<br>Preço / Renda | Lag mediano | $R^2$ | F |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Óleos combustíveis | -0,84 (-1,87) | 0,126 (1,53) | 0,777 (5,2) | 1,69 (3,83) / 0,22 (3,21) | -0,38 / 0,57 | 2,75 | 0,97 | 232 |
| Gasolina | -0,118 (-1,72) | 0,26 (2,41) | 0,787 (6,21) | 1,48 (2,35) / 0,603 (1,13) | -0,55 / 1,22 | 2,89 | 0,986 | 482 |
| Querosene | -0,129 (-2,14) | 0,1 (1,44) | 0,349 (5,09) | 3,53 (5,09) / 4,47 (2,29) | -0,2 / 0,15 | 0,66 | 0992, | 912 |
| GLP | -(0,762) (-3,45) | 1,72 (6,21) | - | 4,97 (2,87 / -0,81 (2,41) | -0,76 / 1,72 | - | 0,931 | 103 |
| Fonte: Pindyck (1979) | | | | | | | | |

Pyndick (1979) concluiu, através de sua estimação, que as elasticidades preço e renda de longo prazo da demanda pelos energéticos são, respectivamente, sempre negativas e positivas. Dessa forma, aumentos em preço tendem a repercutir negativamente na demanda, enquanto aumentos da renda tendem a impactar positivamente sobre esta.

Gately e Huntington (2002) estimaram os efeitos assimétricos das mudanças de preço e renda sobre a demanda por petróleo numa visão comparativa entre os 96 maiores países do mundo em termos de renda per capita. O artigo concluiu que aumentos dos preços tem efeitos diferentes do que diminuições dos mesmos sobre a demanda por petróleo em países OECD, enquanto que essa assimetria se mostrou em termos de renda nos países que não fazem parte do OECD. Ainda, a elasticidade-renda de longo prazo da demanda por petróleo no segundo grupo de países, unitária, é praticamente o dobro daquela observada no primeiro grupo.

O outro grupo de trabalhos que modelou a demanda por petróleo o fez a nível mundial. Dentre eles, destacam-se os dos autores Adams e Miovic (1968), Darmstadter (1971), Kennedy (1976) e Krichene (2007). Para os três primeiros trabalhos pode ser traçada uma tendência comum, que é o tratamento dado à elasticidade-preço da demanda por energia. Já o último artigo resume a orientação metodológica deste artigo.

Kennedy, em seu artigo publicado no livro “Econometric Studies of U.S. Energy Policy” (1976), procurou explicitar a importância do comportamento de preços sobre a demanda mundial por petróleo. O artigo foi escrito num contexto de preocupações com o abastecimento de petróleo, então afetado pelo primeiro choque de petróleo de 1973. Essa preocupação suscitaria então a realização de estudos econométricos que modelassem a demanda por energia, ajudando a determinar qual comportamento os agentes deveriam adotar diante de um cenário adverso.

O autor argumentou que seus antecessores Adams e Miovic (1968) e Darmstadter (1971) não tinham dado importância ao papel dos preços. A elasticidade-renda que ambos autores tinham achado, da ordem de 1, estaria superestimada, já que o papel dos preços sobre a demanda por petróleo não teria sido considerada.

O autor, nesse sentido, montou um modelo log linear considerando tanto as elasticidades preço e renda de longo prazo da demanda por petróleo como também as de curto prazo. As elasticidades de longo prazo estimadas foram de 1,3 para a renda e -0,82 para o preço. Tais resultados fizeram o autor concluir que o preço é sim um fator impactante sobre a demanda por petróleo mundial.

Krichene (2007) estimou um modelo mundial da demanda e oferta de petróleo e gás natural. No caso da demanda por petróleo, as variáveis consideradas no modelo foram a quantidade de óleo extraída no mundo, o preço do petróleo, a renda do mundo, a taxa LIBOR (London Inter-Bank Interest Rate) e a taxa nominal de câmbio do dólar, assim como um termo de erro. O autor utilizou dados anuais (1970 e 2006) e quadrimestrais (1984 a 2006). A Tabela 2 sintetiza os resultados da estimação da demanda mundial por petróleo (curto prazo).

Tabela 2

| Principais Resultados Obtidos por Krichene (2007) | | | | |
|---|---|---|---|---|
| Variável | 1970 a 2006 Coeficiente | 1970 a 2006 Estatística T | 1984 a 2006 Coeficiente | 1984 a 2006 Estatística T |
| Lag | 0,54 | 5,08 | 0,04 | 0,32 |
| Preço do petróleo | -0,01 | -1,28 | -0,02 | -2,17 |
| Renda do Mundo | 0,12 | 3,12 | 0,44 | 6,48 |
| Taxa de Juros | -0,006 | -2,55 | 0,003 | 1,7 |

| | | | | |
|---|---|---|---|---|
| Câmbio | -0,023 | -0,19 | -0,17 | -3,12 |
| $R^2$ | 0,96 | | 0,99 | |
| DW | 1,93 | | 1,78 | |
| Fonte: Elaboração própria a partir de Krichene (2007) | | | | |

O autor, baseando-se nos resultados, demonstrou que a demanda por petróleo é relativamente inelástica com relação ao preço no curto prazo. Já em relação à renda, ela é ligeiramente positivamente elástica. Em relação à taxa de juros, que no primeiro momento tinha impacto negativo no curto prazo em relação à demanda petróleo, ela passou a ter um impacto positivo a partir de 1984. Isso reflete, segundo o autor, a possibilidade de manipular o consumo de petróleo através da política monetária. Por fim, a taxa de câmbio, como era esperado pelo autor, teve uma elasticidade negativa em relação à demanda por petróleo. Uma depreciação do dólar, por essa razão, estimularia o aquecimento do mercado mundial do petróleo, fenômeno que se observa atualmente com a baixa do dólar e o aumento espetacular do preço do petróleo observado ao longo dos últimos anos, a pesar da recente queda.

3.2- O modelo teórico

O modelo teórico deste trabalho inspira-se naquele aplicado no artigo de Krichene (2007). A modelagem da demanda por petróleo feita pelo autor teve como antecedentes metodológicos as obras clássicas de Working (1927) e de Pindyck (1979). O primeiro autor estabeleceu os antecedentes teóricos para que dados estatísticos refletissem efetivamente uma relação de demanda e de oferta. Já o segundo consolidou a prática de modelar a demanda por petróleo em função de seu preço e de sua renda.

Neste trabalho, similarmente ao artigo de Krichene (2007), a demanda de petróleo de um país, ou a sua produção, que é entendida como a soma do que é consumido internamente e o que é exportado, pode ser modelada pela seguinte função:

Demanda de petróleo do país i = f(PIB nacional real em USD; PIB mundial real em USD; taxa de câmbio USD nominal efetiva; preço do petróleo em USD; taxa de câmbio LIBOR)

A diferença central em relação ao de Krichene (2007), é que neste trabalho é considerada também a variável PIB nacional real em USD, uma vez que a estimação será feita a nível nacional. Além disso, uma outra diferença é que o foco analítico deste trabalho é de longo prazo.

Através dessa equação, espera-se captar a sensibilidade da demanda de petróleo produzida por um dos quatro países da amostra (Argentina, Brasil, México e Venezuela) ao nível de atividade econômica do próprio país e do mundo, ao preço e à variação cambial. A taxa de juros aparece como variável de controle, não tendo sua elasticidade estimada.

Observa-se que, a despeito da teoria econométrica tradicional, a renda não é exógena ao modelo, já que o PIB mundial ou nacional é sempre influenciado pelos preços do petróleo. Da mesma maneira, a taxa de juros também não é exógena, por que é um instrumento de política monetária necessário para controle da inflação, que é, em grande parte, influenciado pelos preços do petróleo, fenômeno que se observa com força nos últimos dois anos. Apesar da endogeneidade das duas variáveis, é importante incluí-las no modelo para efeito de simplificação.

No que diz respeito à taxa de câmbio, é válido que ela entre no modelo, por que mudanças no seu patamar afetam os preços domésticos tanto do petróleo quanto de ativos financeiros, e, portanto a demanda relativa entre estes bens. Ela serve, ainda, para captar uma parte do efeito que experienciamos hoje: a corrida para o mercado do petróleo como fonte alternativa de investimento em virtude da queda do dólar, o que tem efeito importante sobre o nível da produção de petróleo.

As variáveis devem ser tomadas em seu logaritmo, com exceção da taxa de juros, que entra no modelo como variável de controle. Dessa forma, tem-se o seguinte modelo:

$$\text{Ln}C_t = \alpha \text{Ln}P_t + \beta \text{Ln}Yi_t + \zeta \text{Ln}Ym_t + \delta \text{Ln}E_t + \text{R}_{t} + \text{Ln}k, \quad (1)$$

em que $C_t$ representa a demanda por petróleo do país i em t, $P_t$ indica o preço do petróleo de um país no tempo t, $Yi_t$ é o PIB do país i no período t, $Ye_t$ é o PIB do mundo no período t, $E_t$ representa o preço do câmbio do país i em relação ao dólar no período te $R_t$ o preço da taxa de juros LIBOR (London Inter-Bank Interest Rate) no período t.

Por sua vez, os coeficientes $\alpha$, $\beta$, $\zeta$ e $\delta$ representam, respectivamente, a elasticidade-preço (variação da demanda por petróleo em função da variação do seu preço), a elasticidade-renda (variação da demanda por petróleo em função da variação do PIB do país i), a elasticidade-renda (variação da demanda por petróleo em função da variação do PIB do mundo) e elasticidade da taxa de câmbio em relação ao petróleo (variação da demanda por petróleo em função da variação do câmbio nominal ao dólar). Por fim, $k$ é uma constante.

O comportamento dessas variáveis obedece a um padrão que é definido como premissa para que a função escolhida seja tomada como logarítmica. Os antecedentes teóricos deste trabalho, a teoria econômica e a experiência estatística apontam o sinal que as variáveis provavelmente terão. Segundo Kmenta (1994):

"A teoria econômica diz-nos que relações compõem o modelo, que variáveis devem ser incluídas em cada uma das relações e qual o sinal de algumas derivadas parciais."

Em razão disso, é possível fazer hipóteses acerca do comportamento das elasticidades, sendo que $\alpha$ deveria ser menor do que zero, $\beta$ maior do que zero, $\zeta$ maior do que zero e $\delta$ menor do que zero.

O $\alpha$ é pressuposto como sendo menor do que zero por que se entende que quando o preço do petróleo aumenta, sua quantidade demandada deve diminuir, principalmente no longo prazo.

O $\beta$, que representa a elasticidade-renda em relação ao PIB do país, deve ser maior do que zero por que supõe-se que aumentos da renda de um país induzem positivamente a sua demanda por petróleo.

Já o $\zeta$ (elasticidade-renda da demanda por petróleo em relação ao PIB do mundo) deve também ser maior do que zero, pela mesma razão da elasticidade-renda em relação ao PIB do país.

E por fim o $\delta$, que indica a elasticidade da demanda por petróleo em relação às variações do câmbio, é suposto como sendo inferior a zero por que quando este muda, a demanda relativa entre o petróleo e outros ativos financeiros muda, induzindo, além disso, mudanças também no nível de produção de petróleo.

O foco analítico deste trabalho é o longo prazo, pois nesse horizonte de tempo é possível desconsiderar o fator aleatório dos movimentos realizados pelos agentes no curto prazo diante dos choques que podem ocorrer em pequenos horizontes de tempo. Como são aleatórios, podem não ter significância estatística e podem não oferecer material sólido para interpretação econômica posterior. Os efeitos mais relevantes são, claramente, os de longo prazo.

A escolha de uma função de demanda a ser estimada traz consigo a missão de estimar elasticidades, renda e preço e também para o câmbio, de longo prazo, bem como a possibilidade de formular hipóteses de como os coeficientes deverão comportar-se se o modelo estimado estiver correto. Tem-se, desta forma, um modelo econométrico pronto para ser estimado. Ainda em Kmenta (1994):

"O resultado final é um modelo econométrico pronto para a estimação ou para o teste. Esse modelo representa um resumo do conhecimento apriorístico do pesquisador, referente ao fenômeno em questão."

Em relação ao fenômeno em questão (delimitado e especificado em modelo), a demanda por petróleo do país, formula-se a seguinte hipótese:

Hipótese: $\alpha$ menor do que zero, $\beta$ maior do que zero, $\zeta$ maior do que zero e $\delta$ menor do que zero.

3.3 – Metodologia

O método de cointegração, desenvolvido por Johansen (1988, 1995) e Johansen e Juselius (1990), foi escolhido para resolver o problema que foi formulado, já que o foco analítico do trabalho, assim como do método de cointegração, é o longo prazo.

A metodologia do método de cointegração propõe a utilização de uma modelagem de vetores auto-regressivos (VAR) para estimar os vetores de cointegração, cujos parâmetros já indicam as elasticidades de longo prazo, sem a necessidade de procedimentos adicionais.

O método, que analisa a existência e a forma da relação de longo prazo entre algumas variáveis, pode ser organizado em três etapas:

Análise de estacionaridade das séries individuais;

Verificação da existência de cointegração entre as séries;

Identificação dos coeficientes da relação de cointegração.

A primeira etapa diz respeito à análise de estacionaridade das séries individuais, isto é, é um procedimento preliminar do modelo, já que se pretende verificar quantas observações poderão ser efetivamente usadas.

A estacionaridade reflete se a distribuição de probabilidade de uma série não muda ao longo do tempo. Em Gujarati (2006):

"(...) se uma série temporal é estacionária, sua média, variância e autocovariância (em diferentes defasagens) permanecem as mesmas, não importa qual seja o ponto em que as medimos: isto é, elas não variam com o tempo." (p. 639)

As séries que têm essa característica têm a tendência a retornar a uma média, e as flutuações em torno dessa média serão suaves. Dessa maneira, existe a possibilidade de prever o futuro usando como base o passado.

Séries em nível são séries temporais como PIB ou consumo de petróleo ao longo do tempo. Para elas é ideal encontrar não-estacionaridade

Séries em primeira diferença são aquelas em que se subtrai da segunda observação a primeira, de tal maneira que exista a possibilidade de que uma esteja relacionada à outra, possibilitando a previsão do futuro através do passado. Assim, é ideal para séries em diferença encontrar estacionaridade.

Na etapa da verificação da existência de cointegração entre as séries reside a parte central do método da cointegração. Depois de verificadas quantas observações podem ser usadas para serem usadas no método, analisa-se se há cointegração entre as séries. Isto é, se é possível, através dos dados da amostra, estabelecer uma relação funcional, um vetor de cointegração comum aos dados coletados.

Quando duas ou mais séries são cointegradas, elas apresentam uma tendência estocástica comum. Um processo estocástico ocorre quando um conjunto de variáveis aleatórias ordena-se no tempo (Gujarati, 2006). Se isso ocorre, a análise de sua regressão pode revelar se há uma relação de longo prazo entre elas, o que seria um vetor de cointegração comum entre as variáveis independentes do modelo.

Nessa etapa, verifica-se quantas relações de cointegração existem, partindo-se do pressuposto que, se há n séries, podem haver m<n relações de cointegração. É ideal, contudo, que haja somente um vetor de cointegração.

A terceira e última etapa do método que aqui será usado, representa a efetiva identificação dos parâmetros (elasticidades) que o modelo se propõe a achar. Se há um vetor de cointegração, os coeficientes normalizados deste vetor são as elasticidades de longo prazo.

Reescritos sob a forma funcional correta, estes fornecem os parâmetros da função de demanda por petróleo que o modelo quer estimar.

3.4 – Dados

Os dados usados neste trabalho foram coletados em diferentes fontes. Como havia uma grande discrepância entre as periodicidades das mesmas, o período da análise limitou-se de 1986 a 2006. Devido ao foco analítico de longo prazo, optou-se pela utilização de dados anuais.

A Tabela 3 organiza as fontes dos dados utilizados no modelo econométrico deste trabalho.

Tabela 3

| Síntese das Fontes dos Dados Utilizados | |
|---|---|
| Dados | Fonte |
| Produção de petróleo ou demanda | BP Statistical Review |
| Preço do petróleo Brent Spot | BP Statistical Review |
| Renda dos países | FMI |
| Renda do mundo | FMI |
| Câmbio argentino em relação ao dólar | BCRA |
| Câmbio brasileiro em relação ao dólar | BCB |
| Câmbio mexicano em relação ao dólar | Banco de Mexico |
| Câmbio venezuelano em relação ao dólar | BCV |
| Taxa de juros LIBOR | British Banker's Association |
| Fonte: Elaboração própria | |

3.5 – Resultados

A Tabela 4 apresenta os resultados do teste de traço de Johansen, que determina se há um ou mais vetores de cointegração para as variáveis utilizadas no modelo, isto é, se elas têm ou não uma tendência estocástica comum.

Tabela 4

| Resultados do Teste de Traço de Johansen | | | | |
|---|---|---|---|---|
| | Argentina | Brasil | México | Venezuela |
| LR | 74,05 | 90,06 | 71,38 | 85,57 |

| | | | | |
|---|---|---|---|---|
| 90% | 72,74 | 84,27 | 72,74 | 72,74 |
| 95% | 76,81 | 88,55 | 76,81 | 76,81 |
| 99% | 84,84 | 96,97 | 84,84 | 84,84 |
| Fonte: Elaboração própria | | | | |

A forma de ler a tabela acima é que há um vetor de cointegração quando há um nível de significância de 90%, de 95% ou de 99%. Os valores indicados em amarelo são superiores aos valores de LR, indicados em vermelho. Os resultados são muito robustos para Argentina, Brasil e México. Vale ressaltar que este trabalho reproduz a metodologia proposta por Krichene (2007) e que em muitas situações os dados não são muito confiáveis e também que a série é curta.

Para a Argentina, Brasil e México há um único vetor de cointegração. Já para a para a Venezuela, há mais de um vetor de cointegração. Em todos os casos, todavia, assumiu-se apenas um vetor de cointegração para efeito de estimação dos coeficientes normalizados, sendo os resultados apresentados abaixo.

Tabela 5

| Resultados da Estimação | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | Argentina | | Brasil | | México | | Venezuela | |
| | coef | p-valor | coef | p-valor | coef | p-valor | coef | p-valor |
| e | -0,07 | 0,00 | -0,02 | 0,00 | -0,13 | 0,00 | -0,20 | 0,00 |
| r | -0,05 | 0,00 | -0,05 | 0,00 | -0,01 | 0,00 | -0,00 | 0,00 |
| Rex | 3,04 | 0,00 | 0,91 | 0,00 | 0,14 | 0,00 | 2,01 | 0,00 |
| Rin | 0,69 | 0,00 | 0,45 | 0,00 | 0,03 | 0,00 | 0,49 | 0,00 |
| P | 1,14 | 0,00 | 0,29 | 0,00 | 0,05 | 0,00 | 0,70 | 0,00 |
| const | 27,57 | 0,00 | 2,55 | 0,00 | 15,81 | 0,00 | 22,96 | 0,00 |
| trend | 0,003 | 0,00 | 0,09 | 0,00 | - | - | - | - |
| Fonte: Elaboração própria | | | | | | | | |

Legenda: coef = coeficiente, e = taxa de câmbio, r = taxa de juros, Rex = renda externa, Rin = renda interna, P = preço, const = constante e trend = tendêcncia

Sensibilidade à Taxa de Câmbio

Nota-se que, em todos os casos, a demanda por petróleo reage negativamente à taxa de câmbio de cada país em relação ao dólar. Isto é, toda vez que ocorre uma depreciação do dólar, os agentes econômicos tendem a correr para o mercado de petróleo. No entanto, quando o dólar se aprecia, ocorre um movimento contrário. Os agentes preferem deter dólares a comprar petróleo. Esse tipo de raciocínio é mais condizente com a realidade de países exportadores, mais integrados com a dinâmica do mercado mundial de petróleo, nos quais a demanda pelo produto é muito sensível às variações do mercado mundial. No caso, os países que exportaram mais petróleo, notadamente para os Estados Unidos, foram os países no qual esse coeficiente foi mais negativo. É o caso de Venezuela e México, cujos coeficientes foram, respectivamente, -0,202 e -0,13. Já Brasil e Argentina, que exportam menos para o mercado americano, tiveram coeficientes mais baixos, da ordem de -0,026 e -0,0704, respectivamente. Nestes dois últimos casos, as variações do mercado de câmbio tiveram efeitos menos significativos sobre o mercado do petróleo. No caso argentino, vale ainda ressaltar que de 1994 a 2001 o câmbio era fixado em um para um, de forma que a possibilidade da transmissão de choques do mercado de câmbio para o mercado de petróleo parece uma hipótese pouco provável.

Sensibilidade à Taxa de Juros

A sensibilidade negativa da demanda por petróleo às variações da taxa de juros obedece a uma dinâmica similar àquela observada para a sensibilidade negativa da demanda por petróleo ao câmbio. Quando a taxa de juros sobe muito, há uma tendência de saída dos agentes do mercado de petróleo para o mercado de ações ou de títulos governamentais. Por essa razão, a apreciação da taxa de juros tende a impactar negativamente sobre a demanda por petróleo. No caso, todos os países da amostra apresentaram coeficientes negativos: -0,056, -0,053, -0,018 e -0,005, respectivamente para Argentina, Brasil, México e Venezuela.

Sensibilidade às Variações da Renda

Tanto a renda do mundo como a renda de cada um dos países tendem a impactar negativamente sobre a demanda pelo petróleo internamente produzido em cada um desses países. Numa visão comparativa, no entanto, é uma tarefa complexa analisar como se comporta cada uma dessas elasticidades para cada caso e o porquê das magnitudes.

No caso argentino, a sensibilidade da demanda por petróleo às variações de renda foi maior para o caso da renda do mundo, com um coeficiente de 3,043.

Já a renda do país teve como coeficiente 0,694. Segundo a teoria econômica, isso representa que aumentos da renda do mundo estimulam mais a demanda pelo petróleo argentino do que aumentos da renda daquele país. Uma interpretação que pode ser feita é que, como a Argentina tende a basear sua matriz energética no gás natural, o país procura exportar mais petróleo. As políticas neoliberais dos anos 90 contaram com as divisas petrolíferas para o funcionamento da política econômica implementada na época, de sorte que a demanda por petróleo no país esteve bastante atrelada ao consumo externo.

No Brasil, observou-se uma tendência similar dos coeficientes. O coeficiente relativo à renda externa foi de 0,916, enquanto aquele relacionado à renda interna foi de 0,451. Uma possível explicação para esses valores que, em tese, não estão de acordo com a tendência brasileira de ter sua demanda por petróleo "puxada" pelo mercado interno, é que esse quadro tem se revertido nos últimos anos. Em outras palavras, as exportações brasileiras de petróleo têm crescido.

No México, o coeficiente relativo à renda externa foi de 0,148 e o relativo à renda interna, 0,031. Tais resultados estiveram plenamente de acordo com o papel do México na indústria mundial de petróleo enquanto país exportador do produto. A renda do mundo tende a "puxar" mais a demanda pelo petróleo mexicano do que a renda daquele país, o que configura um caso clássico.

Por fim, o mesmo observou-se na Venezuela. Um coeficiente de 2,01 para a renda do mundo e um de 0,498 para a renda venezuelana. Como no México, os resultados estiveram alinhados ao que era esperado para um caso clássico de país exportador. Na Venezuela, entretanto, a renda do mundo teria maior importância ainda sobre a demanda por petróleo venezuelano do que no México com relação ao mexicano.

Sensibilidade aos Preços

Segundo a teoria econômica, espera-se que a produção petrolífera seja estimulada nas épocas em que o preço do petróleo esteja em alta. Como o mercado petrolífero mundial tem preços de referências globais, é interessante para países exportadores produzir mais quando esses são mais elevados, já que poderão realizar uma renda petrolífera especial também mais elevada.

No caso dos cinco países da amostra, percebe-se que em todos eles os preços tendem a estimular a produção petrolífera local. Dá-se especial ênfase ao caso colombiano, no qual a elasticidade-preço da demanda pelo petróleo interno é de 2,722. Na Argentina, ela é da ordem de 1,14, enquanto na Venezuela é de 0,7. Por fim, Brasil e México têm, respectivamente, elasticidades-preço da demanda pelo petróleo interno de 0,298 e 0,055. O que se observa aqui é que, obedecendo à lógica do modelo, os resultados foram na direção correta.

### 3.6 – Observações finais

Os resultados da estimação foram bastante robustos de uma forma geral. No caso da Venezuela não foi possível encontrar um só vetor de cointegração. No entanto, em todos os casos os resultados estiveram de acordo com a teoria econômica. Isto é, corroboraram as hipóteses estabelecidas a partir do modelo de Krichene (2007), que foi reproduzido neste artigo. Verificou-se que, os países da amostra, assim como foi ressaltado na introdução deste trabalho, têm a tendência a serem exportadores de petróleo. Isto se revelou nos resultados encontrados para elasticidade renda em relação à demanda do mundo e elasticidade renda em relação à demanda interna pelo petróleo produzido em cada um dos países. Em geral a primeira teve magnitudes maiores.

É necessário ressaltar que, em muitas situações, os dados estatísticos utilizados nem sempre foram muito robustos, principalmente em virtude de sua periodicidade anual. Na operação de converter dados mensais ou semestrais em anuais pode-se perder boa parte da qualidade dos dados, deixando, por exemplo, de poder refletir sazonalidades. Um passo a ser recomendado para um futuro estudo é aumentar o número de anos da amostra ou, por exemplo, incluir outras variáveis que captem as especificidades regionais bem como as tendências sazonais.

## 4.- A análise econômica histórica heterodoxa

Os resultados obtidos na estimação demonstram que as indústrias petrolíferas dos países da amostra têm sensibilidade significativa aos estímulos dados pela demanda global por petróleo, em especial em relação à renda do mundo e ao preço do petróleo. Isto é, quando a demanda petrolífera mundial está aquecida, em todos os países a produção e o conseqüente consumo do petróleo internamente produzido em cada um desses países são estimulados. Demonstrou-se, dessa forma, que as elasticidades-renda, em especial em relação à renda do mundo, são positivas. O mesmo ocorre com a elasticidade-renda preço. Variações para baixo ou para cima dessa variável tendem a impactar, em menor ou maior grau, na mesma demanda pelo petróleo produzido nos países da amostra.

Embora todos os países aqui considerados produzam petróleo para exportação ou tenderão a fazê-lo, a proporção entre o quanto exportam e o quanto consomem diverge muito. A Tabela 6 relaciona consumo interno e produção interna de petróleo dos países aqui considerados.

Tabela 6

| Relação entre consumo e produção internos | | | | | |
|---|---|---|---|---|---|
| Argentina | 2003 | 2004 | 2005 | 2006 | 2007 |
| Produção | 806 | 754 | 725 | 716 | 698 |
| Consumo | 372 | 394 | 421 | 442 | 492 |
| % Óleo Internamente Consumido | 46,1% | 52,3% | 58,1% | 61,8% | 70,4% |
| Brasil | 2003 | 2004 | 2005 | 2006 | 2007 |
| Produção | 1555 | 1542 | 1715 | 1809 | 1833 |
| Consumo | 1985 | 1999 | 2047 | 2097 | 2192 |
| % Óleo Internamente Consumido | 127,7% | 129,6% | 119,4% | 115,9% | 119,6% |
| México | 2003 | 2004 | 2005 | 2006 | 2007 |
| Produção | 3789 | 3824 | 3760 | 3683 | 3477 |
| Consumo | 1885 | 1919 | 1973 | 1972 | 2024 |
| % Óleo Internamente Consumido | 49,7% | 50,2% | 52,5% | 53,6% | 58,2% |
| Venezuela | 2003 | 2004 | 2005 | 2006 | 2007 |
| Produção | 2554 | 2907 | 2937 | 2824 | 2613 |
| Consumo | 479 | 518 | 547 | 565 | 596 |
| % Óleo Internamente Consumido | 18,8% | 17,8% | 18,6% | 20,0% | 22,8% |
| Fonte: Elaboração própria a partir de BP Statistical Review 2008 | | | | | |

Observa-se na tabela acima que, na maioria dos países, o índice de petróleo internamente consumido é crescente. Na Argentina, na qual o consumo interno cresceu 32% em apenas 5 anos, essa informação é preocupante, considerando o índice RP, que foi da ordem de 10,2 anos em 2007. Já no Brasil, onde o consumo nacional ainda extrapola a produção aqui realizada, essa informação é um problema menor, já que o RP de 18,9 tenderá a crescer com o ritmo de novas descobertas do pré-sal. Algo similar à Argentina ocorre no México, onde o consumo interno cresce, ao passo que o RP é baixo, da ordem de 9,6 anos. Por fim, a Venezuela encontra-se numa fase confortável, com um RP de 90,3 anos bastante elevado. As informações acima expostas demonstram, grosso modo, que os países se encontram em momentos bastante distintos das suas trajetórias enquanto economias exportadoras e/ou potencialmente exportadoras de petróleo. Para a Venezuela e o Brasil, dependendo do comportamento futuro do mercado mundial de petróleo, as perspectivas, inclusive em termos de desenvolvimento econômico, são favoráveis, o que não se observa tanto na Argentina e no México, dadas as atuais perspectivas de E&P naqueles países.

Para fazer uma análise mais completa do que representa para um país ser exportador de petróleo e sobre como ele deve moldar sua indústria petrolífera para atender à demanda forânea e, consequentemente, dela fazer possível fonte de desenvolvimento econômico sustentável, optou-se por um instrumental analítico econômico histórico heterodoxo. Partiu-se da premissa anteriormente apresentada de que não basta apenas que existam elasticidades-renda elevadas para que um processo de desenvolvimento econômico seja facilitado. O foco está na correta administração dos recursos e do abrandamento dos efeitos adversos que uma economia petrolífera possa ter sobre o restante da economia de um país. A análise proposta aqui tem como objetivo verificar em que medida as instituições econômicas, políticas e governamentais de um país estão aptas a lidar com as rendas petrolíferas.

Esse instrumental foi encontrado no livro “Chutando a Escada”, de Ha-Joon Chang (2002). O autor sustenta a tese de que os países desenvolvidos tendem a “vender” estratégias para alcançar taxas de crescimento econômico mais favoráveis e assim realizar o chamado *catching-up,* que nada tem a ver com as estratégias de desenvolvimento que eles mesmos adotaram. Em geral, segundo o autor, essas estratégias podem ser encontradas na cartilha neoliberal que, se seguida à risca, manterá os países que querem crescer acoplados aos interesses dos países que já cresceram e têm poder político no cenário global. Por isso a metáfora da escada sendo chutada, já que o aqueles países pretenderiam seria conscientemente manter os menos desenvolvidos à margem e atrelados aos seus mercados.

O caráter histórico e heterodoxo da análise advém do fato que bons *insights* sobre como os países realmente se desenvolveram podem ser obtidos em análises minuciosas da história, deixando um pouco de lado modelos econômicos tradicionais demasiadamente rígidos.

Nesse contexto, Chang (2002) analisou em que grau as economias de nações se desenvolveram, desmascarando alguns mitos muito comuns. O foco de sua análise está na muito difundida defesa do livre comércio, prática que os principais países da economia global não adotaram no estágio inicial de suas economias. Em outras palavras, existiu de fato proteção à indústria nascente. Além disso, o autor observou que há também um descompasso, em termos de melhores práticas institucionais, entre o que é pregado como a fórmula mágica do crescimento econômico e aquilo que realmente foi praticado nas nações que conseguiram atingir essa meta. Seguem abaixo os principais pontos da análise histórica de Chang (2002) acerca das melhores práticas institucionais pregadas pelos países desenvolvidos que “chutam a escada”:

Proteção ao comércio;

Democracia;

Burocracia e Judiciário;

Os regimes de direito de propriedade;

A governança empresarial (sociedade por cotas de ação, a lei da falência, auditoria e transparência de informação, a lei da concorrência);

As instituições financeiras (o sistema bancário e sua regulamentação, o banco central, a regulamentação dos títulos, instituições financeiras públicas);

O bem-estar social e as instituições trabalhistas;

Neste trabalho é feito um exercício de abstração que considera que alguns desses pontos podem ser também pensados como as possíveis melhores práticas institucionais para uma indústria como a petroleira. Isto é, a partir dessa premissa se analisa em que medida os quatro países analisados nesse artigo seguiram, em suas respectivas indústrias petroleiras, a “receita de bolo” do crescimento econômico, nesse caso restrito ao setor petróleo. A proposta é observar se há algum tipo de interligação entre determinadas práticas institucionais num país e o sucesso do modelo petrolífero escolhido. A título de simplificação, optou-se por três dos sete itens acima citados, a saber: proteção ao comércio, instituições democráticas e regimes de direito de propriedade.

A proteção ao comércio, ou à indústria nascente, fica representada pela decisão governamental de um país de não expor a sua indústria petroleira, desde os seus primórdios ou em algum estágio mais recente, à concorrência externa.

No que diz respeito às instituições democráticas, se quer observar em qual ambiente político a economia petrolífera de um determinado país opera ou operou em sua melhor ou pior época e quais as conseqüências práticas disso.

Por fim, a análise dos direitos de propriedade da indústria petrolífera de um dos países que serão observados tem como objetivo observar em que medida os mecanismos de distribuição de áreas de concessão impactaram positiva ou negativamente sobre os rumos das indústrias petrolíferas dos países, e, consequentemente, sobre a economia local.

Feita essa análise, ter-se-á obtido três indicadores das possíveis razões de sucesso ou de fracasso dos caminhos adotados pelas respectivas indústrias petrolíferas dos países. A utilidade dos mesmos poderia ser, então, auxiliar no debate sobre a descoberta de melhores rumos para as indústrias petrolíferas. O aprimoramento desses caminhos certamente terá impactos significativos sobre os nossos principais problemas econômicos se considerarmos as boas perspectivas que a indústria petroleira terá em alguns países da América Latina. Ademais, poderá auxiliar enquanto instrumental analítico no urgente contexto das discussões sobre os caminhos do novo desenvolvimentismo latino-americano.

## 4.1- Argentina

### A proteção ao comércio

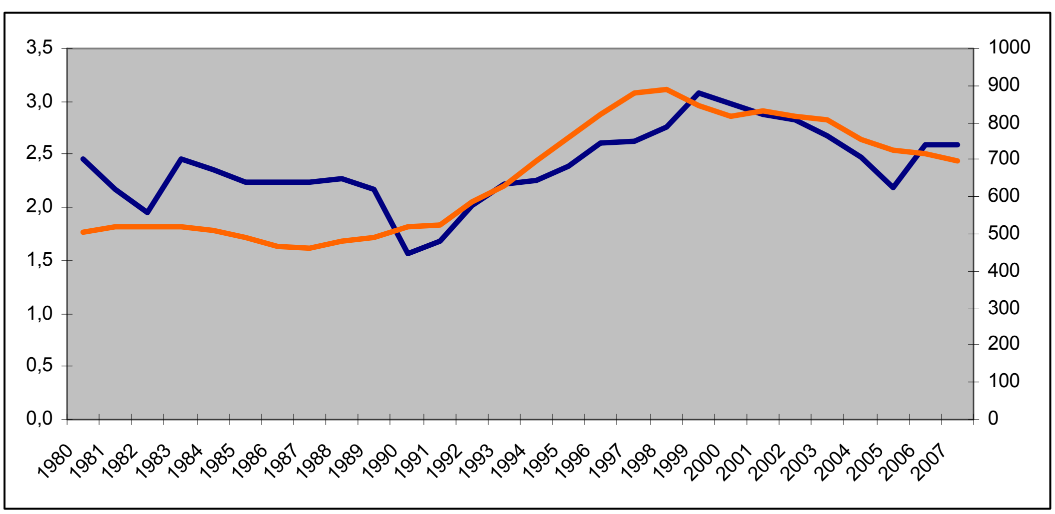
O início da indústria petrolífera argentina teve como objetivo a redução gradual da dependência externa por importações, e teve como marco relevante a fundação da YPF (Yacimientos Petrolíferos Fiscales) em 1922 empresa estatal do petróleo argentino.

Desde 1922 até 1993, quando a YPF foi efetivamente privatizada, a história do petróleo argentino e da YPF estiveram intimamente relacionados aos acontecimentos políticos e à política econômica de cada época. Foi uma trajetória de constantes reviravoltas quanto ao papel a ser exercido pela estatal e pelas condições de concorrência que deveriam vigir em cada período do tempo. Nos momentos em que a orientação política argentina era nacionalista, a YPF gozou de maior proteção mercadológica, o que de certa forma representa uma *proxy* de proteção ao comércio. Pelo outro lado, na época do governo militar dos anos 70 e início dos 80, a YPF era sujeita à concorrência externa em maior grau, pois o governo estimulava a entrada de agentes externos, o que representaria menor proteção ao comércio.

Após 1993, a estrutura industrial passou a ser bastante aberta, com a possibilidade de entrada de diferentes agentes externos na indústria. Com a entrada desses agentes e a privatização da YPF, pode-se dizer que a proteção ao comércio na indústria argentina do petróleo deixou de existir.

A proteção ao comércio na indústria petrolífera argentina teve como papel fundamental, grosso modo, a fundação e estabelecimento da mesma indústria. Por outro lado, nas épocas em que se estimulou o desmantelamento da indústria e da YPF, bem como a entrada de agentes externos, os resultados foram menos animadores, já que as reservas e a produção petrolífera daquele país diminuíram, como é possível ver no gráfico abaixo. Evidentemente que reformas mais bem conduzidas poderiam ter alcançado resultados mais expressivos nesses critérios.

Figura 1



Fonte: Elaboração própria a partir de dados do BP Statistical Review 2008

As instituições democráticas

As instituições democráticas na Argentina têm uma tradição de altos e baixos. Desde a etapa populista de Perón até o atual governo Kirchner aconteceram muitas reviravoltas políticas, com a ocorrência de golpes de estado, pressões populares e rígidas ditaduras militares. Estas tiveram severos impactos sobre os rumos da indústria do petróleo no país, pois suas condições de base eram freqüentemente alteradas com as freqüentes reviravoltas e suas respectivas políticas energéticas. O ambiente político incerto gerou, de certa maneira, também incertezas no campo energético. Nesse contexto, tanto governos democráticos como governos pouco democráticos exerceram influências negativas e positivas. Uma conclusão que se pode tomar desse complexo processo é que no atual momento de democracia aparentemente mais sólida, com a fundação em 2004 de uma nova estatal, a ENARSA, possivelmente os caminhos do petróleo na argentina de alguma maneira passem a ser menos tortuosos.

Os direitos de propriedade

A forma de outorga de áreas de exploração e produção de petróleo na Argentina sofreu do mesmo mal que os cambiantes rumos políticos do país. É consenso que regras claras e bem definidas de direitos de propriedade nessa indústria têm efeito benéfico. Para aplacar os resultados pouco favoráveis da mal conduzida reforma e também com o objetivo de aumentar o esforço exploratório no país, é necessário que o ambiente democrático relativamente sólido que hoje em dia se observa na Argentina garanta a continuidade dos contratos que se firmam.

4.2- Brasil

A proteção ao comércio

A indústria brasileira do petróleo foi fundada com foco na iniciativa privada. No entanto, com a fundação da Petrobras em 1953, a mesma foi nacionalizada. De 1953 até a abertura em 1997 a Petrobras obteve resultados muito positivos por ter proteção ao seu mercado. Isso por que, na mesma época, logrou acumular tanto muito amplos conhecimentos geológicos das bacias brasileiras bem como tecnologia muito avançada em águas profundas.

Aqui argumenta-se que, com a introdução do sistema de leilões em 1997, a Petrobras foi incentivada a tornar seus processos mais eficientes para ofertar da melhor forma possível nas rodadas. Tendo também esse *know-how* apriorístico adquirido na época de proteção à indústria nascente, a empresa foi capaz de arrematar e efetivamente prospectar naquelas áreas que ficariam conhecidas como o pré-sal. Por essas razões, a indústria brasileira petrolífera tem perspectivas boas de futuro.

As instituições democráticas

É notável que, tanto em épocas de democracia como de ditadura a indústria petroleira no Brasil foi incentivada e fortalecida pelos governos. A Petrobras nasceu naquilo que pode ser chamado de resquício do estado novo de Vargas, onde a política praticada no seu segundo governo ainda tinha um cunho nacionalista pouco democrático. Com a ditadura militar, a Petrobras foi claramente priorizada enquanto projeto nacional de independência energética. Por fim, a reforma que foi conduzida no período democrático claramente alcançou seu objetivo de perpetuar o projeto dessa independência petrolífera forânea.

Os direitos de propriedade

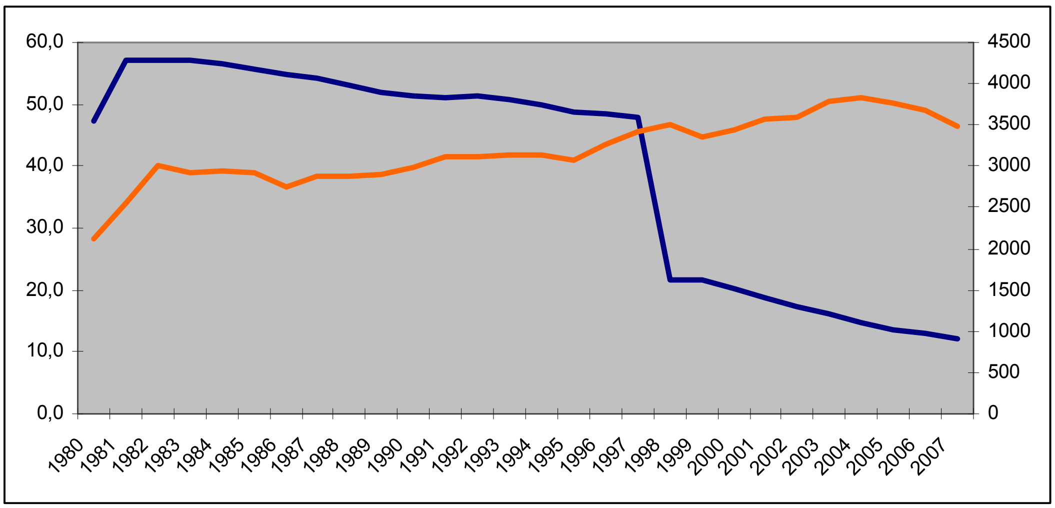
Como foi mencionado anteriormente, a forma como os direitos de propriedade foram tratados na IBP teve influência direta positiva sobre as boas perspectivas que essa indústria tem no atual momento. O sistema de leilões logrou combinar atração de bons investimentos estrangeiros em petróleo com o efetivo fortalecimento da Petrobras sem que houvesse uma desnacionalização pouco justificável na indústria.

4.3- México

A proteção ao comércio, as instituições democráticas e os direitos de propriedade

No México, a indústria petrolífera é verticalmente integrada e totalmente nacionalizada desde a criação da PEMEX nos anos 30. Essa tendência seguiu o projeto nacionalista praticado nos 70 anos do governo do PRI. Ademais, a empresa é diretamente subordinada ao congresso mexicano e seus excedentes petrolíferos financiam o tesouro mexicano. Num primeiro momento, este modelo revelou-se um sucesso, à medida que as reservas petrolíferas brutais do campo de Cantarell, encontradas nos anos 70, posicionaram o México de forma bastante favorável no cenário energético mundial. Além disso, as rendas petrolíferas que a PEMEX obteve foram uma providencial fonte de financiamento para o estado mexicano. À medida que o México atravessava crises econômicas severas nos anos 80 e 90 e em que as reservas petrolíferas não eram repostas no mesmo ritmo da produção, o modelo praticado na indústria petrolífera mexicana pareceu perder fôlego. O gráfico a seguir relaciona a variável produção, que é crescente, com a variável reservas, que caiu dramaticamente nos últimos anos. Ilustra-se, dessa forma, o quão delicada é a situação petroleira mexicana.

Gráfico 2




Fonte: Elaboração própria a partir de dados do BP Statistical Review 2008

Por esses motivos, no atual momento em que as instituições democráticas se renovam, parecer voltar à tona um debate que precisa rediscutir a forma como a PEMEX é protegida com relação às concorrentes externas e como são balanceados os direitos de propriedade na indústria. Esse debate poderia auxiliar no fortalecimento dessa indústria no país e melhorar as suas perspectivas de reservas e produção. Mais além, ajudaria na readaptação da política econômica daquele país, erroneamente dependente em excesso da produção nas *maquiladoras* e do setor petróleo. Os efeitos adversos da “doença holandesa” seriam mitigados e os indicadores sociais do México melhorados.

4.4- Venezuela

A proteção ao comércio

Nos seus primórdios, a estrutura da indústria petrolífera venezuelana beneficiou a atuação de empresas estrangeiras no país. Devido à abundância de reservas petrolíferas existentes naquele país e à proximidade em relação ao principal centro consumidor, as companhias estrangeiras se assentaram com facilidade no país.

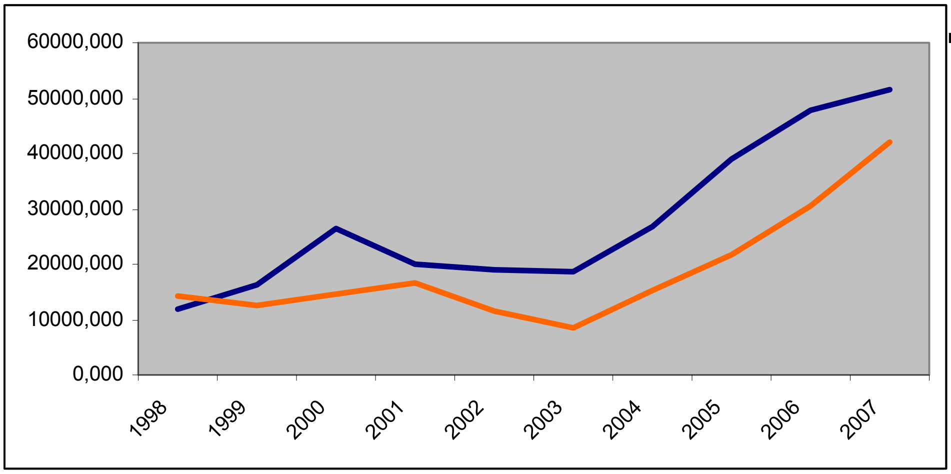
O movimento nacionalista dos anos 70 estabeleceu, na contramão desse processo, a nacionalização petrolífera do petróleo no país e a criação da PDVSA em 1975. No entanto, a atuação de empresas estrangeiras no país não foi impedida, visto que contratos especiais de atuação foram mantidos até os atuais dias. No entanto, a política chavista de gradativa nacionalização da economia tem aumentado a concentração industrial da atividade petrolífera venezuelana, como mostra a tabela abaixo.

Tabela 7

| Concentração industrial da indústria de petróleo da Venezuela | | | |
|---|---|---|---|
| Ano | Índice CR1 | Produção PDVSA em barris/dia | Produção total em barris/dia |
| 2007 | 73% | 2,321 milhões | 3,15 milhões |
| 2006 | 68% | 2,33 milhões | 3,427 milhões |
| 2005 | 64% | 2,109 milhões | 3,274 milhões |
| 2004 | 65% | 2,066 milhões | 3,148 milhões |
| Fonte: Elaboração própria a partir de dados da PDVSA | | | |

A clave explicativa de como a proteção à indústria petrolífera impacta na economia venezuelana é extremamente biunívoca. Existe, neste contexto, um grande abismo entre as boas intenções e o que é realmente feito. A Venezuela tradicionalmente padeceu do mal da “doença holandesa”, um fenômeno que, segundo o que se argumentou anteriormente, pode ser atenuado. Entretanto, requer que a vontade política se alie a bons instrumentos econômicos. A crescente nacionalização da indústria, que teria como faceta boa o influxo de aportes de rendas petrolíferas para as contas estatais e a possibilidade de criar mecanismos que estimulem a economia não-petrolífera, tem como contrapartida ruim a criação de mecanismos de gestão estatal inflados e pouco eficientes. Observa-se, segundo o gráfico abaixo, que as exportações petrolíferas em alta tem financiado as importações não-petrolíferas. Para que esse modelo tenha sucesso, é necessário que o preço do petróleo seja alto e que as importações se direcionem para bens de capital (corresponderam em 2007 a aproximadamente um quarto do total, segundo dados da IFS/FMI), de forma que os demais setores econômicos possam se desenvolver.

Gráfico 3




Fonte: Elaboração própria a partir de dados do IFS/IMF

As instituições democráticas

As instituições democráticas venezuelanas sempre foram extremamente frágeis. Existe um grande debate atualmente em curso se o atual modelo pode ser considerado democraticamente frágil ou não. O atual governo, embora democraticamente eleito, de certa forma arrasta o seu país para algumas posições, sobretudo em termos de política internacional, que não correspondem necessariamente à vontade da maioria, embora fortaleça os termos de troca políticos do país, tradicionalmente regidos por interesses das elites rentistas corruptas. Por outro lado, o acesso a bens públicos como educação ou saúde aumentou nos últimos anos, principalmente para as camadas mais pobres.

Pelas razões acima, se acredita que o projeto político atualmente em curso, democrático à sua maneira, é favorável em termos da redistribuição de renda petrolífera e da reversão das mesmas em bens públicos.

Os direitos de propriedade

Como os níveis de reservas petrolíferas do país são muito elevados, não há atualmente a necessidade de descobrir novas áreas petrolíferas. Por essa razão, não parece fazer sentido no momento instituir modelos de outurga de direitos de propriedades a agentes externos à PDVSA. Ao contrário, a centralização dos direitos atualmente vigentes em torno do projeto de nacionalização ajudou a canalizar as rendas para os cofres estatais. O foco, nesse ponto, está na adequada gestão dos recursos, e não na estrutura patrimonial da indústria petrolífera venezuelana.

## 4.5- Interpretações

A conclusão final dessa etapa do artigo é que existe um grande número de arranjos institucionais que podem levar ao sucesso de uma indústria petrolífera, que é caracterizado como a habilidade de reverter os benefícios dessa indústria ao todo da economia e da sociedade de um determinado país. Segundo a matriz de resultados abaixo, que tipifica como os três critérios aqui usados impactaram historicamente, é praticamente inviável determinar uma melhor prática. Muitos caminhos podem levar ao sucesso ou ao fracasso.

O caminho brasileiro, nesse contexto, parece ser aquele com maiores perspectivas de sucesso. Sustentam essa tese, além da organização industrial e das instituições em volta dessa indústria, também o estado de relativa solidez da economia brasileira no atual momento e a sorte geológica.

O caminho venezuelano, por uma só razão, pode ser considerado o segundo mais apto. Essa afirmação sustenta-se, grosso modo, pelo fato do país possuir gigantescas reservas de petróleo. A governança do petróleo e da economia no país atuam fortemente na direção contrária.

Embora as instituições políticas e econômicas da indústria de petróleo do México estejam em desalinho com o restante da economia e política do país, o México é um caso no qual as perspectivas ainda são boas. A razão disso é que não foram feitas reformas ainda, sugerindo a possibilidade de pensar e desenvolver melhores soluções originais. O México, nesse contexto, representa uma *tabula rasa*.

Por fim, o caso argentino parece o mais desolador. É bastante temerário supor, diante dos atuais desenvolvimentos, que o petróleo poderia estimular desenvolvimento econômico naquela nação.

Sem dúvida bons projetos institucionais para a indústria petrolífera têm impacto sobre caminhos bem trilhados. Mas é necessário ressaltar que não existe um caminho dominante que funcione como *benchmark*. Logo se rejeita a idéia de que exista uma "receita de bolo" para o sucesso, que funcione da mesma forma em todos os países. Essa conclusão está em alinhamento com a análise de Chang (2002).

Tabela 7

| Matriz de resultados | | | | | |
|---|---|---|---|---|---|
| | | Argentina | Brasil | México | Venezuela |
| Proteção ao comércio | Livre | - | + | - | +/- |
| | Fechado | + | + | +/- | +/- |
| Instituições democráticas | Sólidas | - | + | +/- | + |
| | Frágeis | + | + | + | - |
| Direitos de propriedade | Multiplicidade | - | + | +/- | - |
| | Unicidade | + | + | +/- | + |
| Fonte: Elaboração própria | | | | | |

5.- Conclusões

O objetivo central desse artigo foi analisar em que medida a demanda por petróleo mundial pode ser um fator a ajudar a que um país se desenvolva economicamente. Para alcançar esse objetivo, foi estimada uma função de demanda por petróleo de quatro países latino americanos: Argentina, Brasil, México e Venezuela. Como os coeficientes elasticidade-renda do mundo desses países são significativos, a demanda por petróleo do mundo, se aquecida, representar a possibilidade de arrecadar grandes rendas petrolíferas.

Nesse sentido, as rendas petrolíferas poderiam, em tese, financiar, se bem administradas, algum processo de desenvolvimento econômico de maior ou menor intensidade, de acordo com o tamanho da respectiva indústria petrolífera.

Para analisar em que medida esse processo poderia ocorrer, optou-se pela utilização do instrumental teórico de Chang (2002), que fez uma análise histórica e heterodoxa sobre como os países do mundo se desenvolveram economicamente. O autor considerou que os países desenvolvidos têm a tendência a vender “receitas de bolo” do desenvolvimento econômico que na verdade não se verificaram em sua integridade na prática. Chang (2002) analisou algumas práticas institucionais incluídas na chamada “receita de bolo”, das quais três foram escolhidas e adaptadas à realidade da indústria petrolífera. Em exercício de abstração, essas três – proteção à indústria nascente, instituições democráticas e direitos de propriedade – serviram como *proxies* da adequação das instituições políticas e econômicas que foram criadas para organizar os setores petrolíferos dos países analisados aqui.

Concluiu-se que, na ordem, as indústrias petrolíferas mais bem moldadas para lidar com os problemas e possibilidades que o petróleo impõe ou oferece são: Brasil, Venezuela, México e Argentina. No entanto, descartou-se a existência de um modelo único que funcione como uma receita de sucesso garantido.

Deveria nortear a escolha de modelos institucionais para a indústria petrolífera de cada país o reconhecimento e adequado tratamento das especificidades locais e regionais; e a combinação, com bom senso, das possibilidades boas que tanto a via capitalista, como a via de planejamento com base no estado podem proporcionar. Essa discussão encaixa-se bem no programa de pesquisa do novo desenvolvimentismo. São apresentados, a seguir, alguns aspectos que poderiam ser futuramente incluídos ou alterados na análise.

Do ponto de vista econométrico, poderia-se pensar na inclusão de *dummies* que refletissem sazonalidades ou participação na OPEP. Ademais, a busca por dados com menor periodicidade ou por uma série mais longa poderia tornar as estimações mais robustas.

Do ponto de vista analítico, seria bastante interessante comparar os resultados dos quatro países aqui analisados com outros países. Os EUA, por terem uma indústria bastante sólida e com instituições bem definidas, poderia servir como *bench mark* teórico. O caso da Colômbia teria bastante representatividade também, principalmente em virtude da precariedade de suas instituições, o que permitiria traçar paralelos com a Argentina. O Equador, por sua vez, permitiria traçar paralelos com a Venezuela, uma vez que o país pertence igualmente à OPEP, e também por que seu modelo político assemelha-se ao venezuelano. Por fim, o caso cubano representaria uma fronteira bastante instigante. Sua produção petrolífera encontra-se em seus primórdios. Contudo, suas boas perspectivas geológicas e geográficas permitem que o país torne-se exportador líquido de petróleo.

Outro ponto que merece ser destacado para futura análise é a questão da integração energética regional. O caso cubano ilustra bem essa possibilidade. A Petrobrás atua na prospecção de petróleo em águas cubanas, o que representa, de certa maneira, uma tentativa de cooperação energética entre um país pouco favorecido economicamente e um que desponta como principal candidato à liderança regional. Essa cooperação energética poderia, se extrapolada a nível continental, trazer ganhos de sinergia muito amplos para todos, com a transferência de tecnologia e rendas petrolíferas possivelmente acontecendo entre países que de certa forma se complementam, e, ao mesmo tempo, respeitam-se em termos de soberania econômica.

Por fim, o uso do DEA (Data Envelopment Analysis) poderia fornecer importante aporte teórico para analisar em que grau existe a possibilidade de traçar uma fronteira ótima para medir a eficiência relativa das indústrias petrolíferas desses países. Entretanto, é necessário destacar que o uso do DEA requer atenção para a escolha de quais medidas seriam usadas como insumos e produtos, o que sugere a busca de outros indicadores industriais que talvez se situem fora da análise de Chang.

6.- Referências bibliográficas


Adams, F.G., Miovic, P. (1968). “On relative fuel efficiency and the output elasticity of energy consumption in western Europe” *Journal of Industrial Economics*.

Amico, F. (2005). “Argentina: modelos macroeconomicos e integración regional” Buenos Aires: *Universidad Nacional de Lujan*.

Balestra, P., Nerlove, M. (1966). “Pooling Cross Section and Time Series Data in the Estimation of a Dynamic Model” *Econometrica*.

Barros, F.E. (2008). “O Modelo de Cointegração Aplicado à Estimação da Função de Demanda por Petróleo na América Latina” *Boletim Infopetro*, ano 9, no. 5.

Bernal, F. (2005). Petróleo, Estado y Soberania: Hacia la Empresa Multiestatal latinoamericana de Hidrocarburos. Buenos Aires: Editorial Biblos, 1. ed.

Bresser-Pereira, L.C. (2007). Doença holandesa e sua neutralização: uma abordagem ricardiana

Cano, W. (2000). *Soberania e Política Econômica na América Latina*. São Paulo: Editora Unesp, 1. ed.

Chang, H-J. (2003). Chutando a Escada: A Estratégia do Desenvolvimento em Perspectiva Histórica. São Paulo: Editora UNESP, 1. ed.

Darmstadter, J. et al. (1971). Energy in the world economy: a statistical review of trends in output, trade, and consumption since 1925. Baltimore: The Johns Hopkins Press, 1. ed.

Diniz, E. (org.) (2007). Globalização, Estado e Desenvolvimento: Dilemas do Brasil no novo Milênio. Rio de Janeiro: Editora FGV, 1. ed.

Fiorotti, A. (2005). “A Reestruturação da Indústria de Petróleo Sul Americana nos Anos 90” *COPPE/UFRJ, Rio de Janeiro*, XIX, 348, D.Sc. Planejamento Energético.

Furtado, C. (2008). *Ensaios* ***sobre a Venezuela: subdesenvolvimento com abundância de divisas*****. Rio de Janeiro: Contraponto, 1. ed.**

Galeano, E. (2006). *Las Venas Abiertas de América Latina*. Buenos Aires: Catálogos S.R.L., 23. ed.

Gately, D., Huntington, H.G. (2002) “The asymmetric effects of changes in price and income on energy and oil demand” *Energy Journal*, vol. 23, n. 1, p. 19-55.

Gujarati, D.N. (2006). *Econometria Básica*. São Paulo: Makron Books do Brasil Editora Ltda, 4. ed.

Johansen, S. (1992). “A representation of vector autoregressive processes integrated of order 2” *Econometric Theory*, n. 8, p. 188-202.

Johansen, S. (1995). Likelihood-based Inference in Cointegrated Vector Autoregressive Models. Oxford: Oxford University Press, 1. ed.

Johansen, S., Juselius, K. (1990) “Maximum likelihood estimation and inference on cointegration with application to the demand for money” *Oxford Bulletin of Economics and Statistics*, n. 52, p. 169-209.

Johansen, S. (1988). “Statistical analysis of cointegration vectors” *Journal of Economic Dynamics and Control*, n. 12, p. 231–254.

Kmenta, J. (1994). *Elementos de econometria: teoria estatística básica*. São Paulo: Editora Atlas, 1. ed.

Kozulj, R. (2002). “Balance de la privatización de la industria petrolera en Argentina y su impacto sobre las inversiones y la competencia en los mercados minoristas de combustibles” *Serie Recursos Naturales e Infraestructura*, n. 46, Santiago de Chile: CEPAL.

Krichene, N. (2007). “An Oil and Gas Model” Washington D.C.: *International Monetary Fund*.

Leite, A.D. (2004). *A Economia Brasileira: de onde viemos e onde estamos*.. Rio de Janeiro: Campus, 1. ed.

Leite, A.D. *A Energia do Brasil*. Rio de Janeiro: Elsevier, 2. ed.

Pesaran, M.H., Shin, Y. (1998). “Generalized Impulse Response Analysis in Linear Multivariate Models” *Economics Letters*, vol. 58, p. 17-29.

Pindyck, R.S. (1979). *The structure of the world energy demand*. Cambridge: MIT Press.

Pinto Jr., H. Q., Bregman, D. (2008). “Notas sobre a experiência internacional de aplicação de royalties” *Rio Além do Petróleo*, Rio de Janeiro: IETS.

Pinto Jr., H. Q. (org.) (2007). Economia da Energia: Fundamentos Econômicos, Evolução Histórica e Organização Industrial. Rio de Janeiro: Campus, 1. ed.

Piquet, R. (org.) (2007). *Petróleo e Região no Brasil*. Rio de Janeiro, Garamond, 1. ed.

Prebisch, R. (1962). “El desarollo economico de la America Latina y algunos de sus principales problemas” *Boletin Economico de America Latina*, vol. VII, no. 1.

Ruiz-Caro, A. (2006). “Cooperación e Integración Energética en América Latina y el Caribe” *Serie Recursos Naturales e Infraestructura*, n. 106, Santiago de Chile: CEPAL.

Tavares, M. C. (1982). Da Substituição de Importações ao Capitalismo Financeiro: Ensaios sobre Economia Brasileira. Rio de Janeiro: Zahar Editores, 1. ed.

Working, E.J. (1927). “What Do Statistical Demand Curves Show?” *Quarterly Journal of Economics*.

## 5. Technical and Economical Evaluation of Alternatives for Natural Gas Transportation

**Mr. Marko Antonio López Bendezú, Ph.D. Eloi Fernández y Fernández, Ph.D. Pedro Carajilescov**

Author & Coauthors:

Rua Humaita 104 - Apto. 304. Barrio Humaita
CEP 22261-001, Rio de Janeiro - Brasil
+55-21-96036362
markomarkini@aluno.puc-rio.br

Keywords: Transport cost, virtual pipeline, CNG, LNG, gas pipeline.

Abstract: Considering countries with a large territorial area, an obstacle for the expansion of the natural gas market consists in the lack of infrastructure for its transportation. Several alternatives have been considered in order to create local demand for gas, such as transportation in trucks as compressed (CNG) or liquefied (LNG) natural gas or even the traditional pipelines. An adequate selection of the modal will tend to reduce the transportation costs involved. So, the present study presents a technical discussion of the implications of each one of the alternatives and the transportation logistics. Finally, it is presented an economical comparison among the different modals as function of the amount of gas to be transported and as function of the distance.

## Introduction

A expansão do mercado do gás natural, em países de grande área territorial, é afetada pela falta da infra-estrutura para o seu transporte. A necessidade de se incentivar o uso massificado de gás natural, fora dos grandes centros de consumo, procura disponibilizar ao mercado um combustível limpo, eficiente, barato, abundante e que atende aos parâmetros de emissões fixados pelos órgãos de meio-ambiente, além de estimular o uso do gás natural como fonte de energia para uso industrial, doméstico e automotriz. O uso do gás natural tem forte impacto sobre os custos industriais, logísticos e ambientais em decorrência da substituição do óleo diesel, gasolina e GLP e produz menores níveis de emissões.

Tecnologias de transporte, conhecidas como gasodutos virtuais para GNC (Gás Natural Comprimido) e GNL (Gás Natural Liquefeito), podem levar o gás natural em regiões periféricas mesmo sem a existência de uma malha de gasoduto, estimulando e desenvolvendo novos mercados em cidades pequenas ou médias.

A análise técnico-econômica destes meios de transporte de gás natural é importante, não apenas como apoio à decisão sobre novos investimentos, mas para embasar a criação das condições necessárias para a prospecção de novos mercados, tornando-se elementos indutores de consumo, até que o mercado se torne suficientemente maduro para ser atendido por um gasoduto. Posteriormente, o gasoduto virtual pode ser desviado para novas regiões, com aproveitamento total dos equipamentos.

No presente trabalho, através de uma análise de fluxo de caixa, os modais de transporte são analisados, para cada combinação binária de vazão a ser transportada e distancia a ser percorrida, finalizando com o cálculo do custo de transporte do gás natural. São levadas em consideração as variáveis: consumo, distâncias entre os locais de abastecimento e entrega, tempo de viagem, tipo de rota, estrutura de estradas, atendimento às normas de transporte, ao meio-ambiente e à segurança das condições climáticas. Do ponto de vista técnico, são considerados: tipo de cilindro, capacidade de armazenamento e transporte, forma de compressão, tipo de liquefação, forma de carregamento, descarregamento e abastecimento.

## Estudo das Tecnologias de Transporte de Gás Natural

Atualmente, existem quatro alternativas tecnológicas para o transporte de gás natural desde a fonte (do campo de produção, gasoduto ou rede de distribuição) ate o mercado (os consumidores dos setores residencial, comercial, industrial, elétrico e transporte), tal como se mostra na Figura 1: (a) gasodutos, (b) transporte com redução de volume como GNC, GNL e HGN, (c) conversão em outros produtos (GTL), (d) conversão para outra forma de energia, como energia elétrica e transmissão por cabo submarino para a costa terrestre (GTW), e e) transporte do gás como commodity (GTC). [1] Para nosso estudo serão avaliadas formas de transporte terrestre de gás natural, que basicamente podem ser transportados por gasodutos e caminhões.

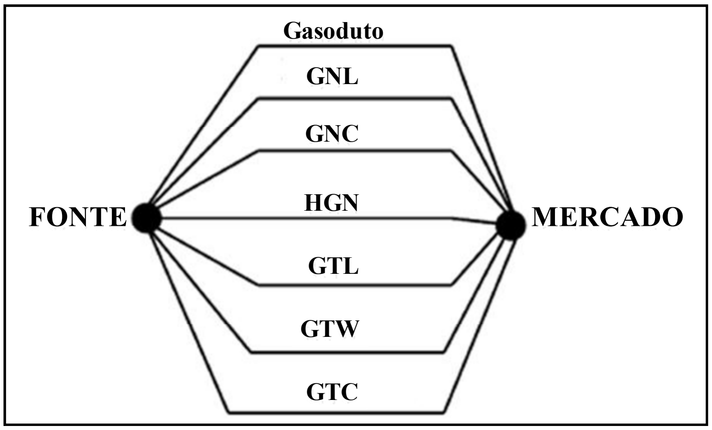



Figura 1: Tecnologias de transporte de gás natural

Justifica do Gasoduto Virtual

As vantagens do uso do gasoduto são as seguintes:

Criação do mercado de gás em lugares sem infra-estrutura e/ou distribuição. Permitem fornecer gás natural as populações sem encena aos gasodutos.

Antecipação das receitas com a venda do gás natural. Consolidando o consumo e preparando a região para o futuro recebimento do gasoduto convencional, depois de comprovada a sua viabilidade.

Redução do risco do mercado na expansão do transporte e/ou distribuição. A expansão é proporcional ao crescimento do mercado.

Antecipação do retorno do investimento na infra-estrutura.

O equipamento pode ser re-utilizado em outras regiões. Pode ser deslocado para uma nova região à ser desenvolvida.

Diversificação da matriz energética. Sua flexibilidade para aproveitar o gás natural em sua totalidade, na indústria, no comércio e no setor domiciliar.

Deslocamento de outros combustíveis líquidos. O uso do gás teria um forte impacto sobre os custos industriais, logísticos e ambientais em decorrência da substituição do óleo diesel, gasolina e GLP por uma fonte primaria de mais baixo custo e menores níveis de emissões.

Gás Natural Comprimido (GNC)

O gás natural é processado e acondicionado em cilindros, à temperatura ambiente e pressão próxima à condição de mínimo fator de compressibilidade, aproximadamente à 220 bar normalmente, segundo ANP 2]. O Gás Natural Comprimido ocupa um volume aproximadamente 268 vezes menor que o volume ocupado nas condições normais. Este processo, que é apresentado, esquematicamente na Figura 2, requer três etapas: compressão, transporte e descompressão.

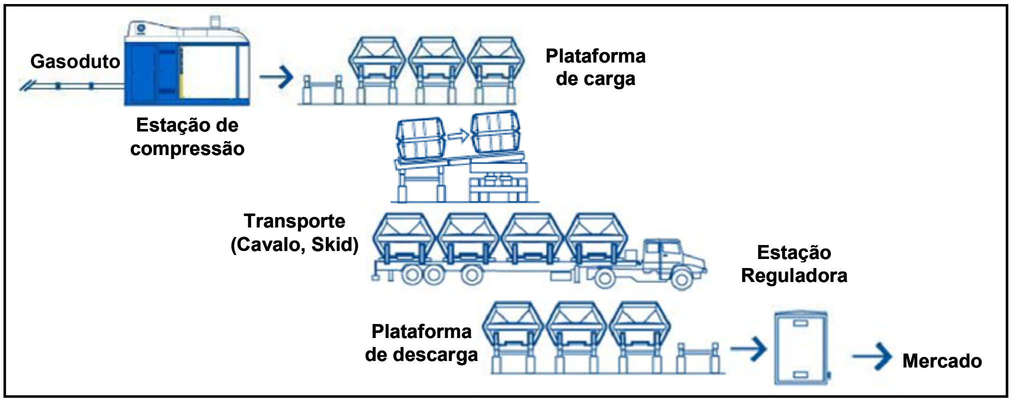



Figura 2: Esquema de gasoduto virtual do GNC.

O compressor, conectado a um gasoduto, comprime o gás até 250 bar dentro dos módulos de transporte. Tais módulos se encontram sobre plataformas, permitindo o abastecimento e intercâmbio de módulos com o transporte de forma segura e eficiente.

Operacionalmente, os módulos vazios, transportados por caminhões, são substituídos por módulos cheios. Essa troca é realizada por máquinas, minimizando o tempo de carga e descarga dos módulos. O veículo realiza o transporte rodoviário dos módulos a velocidades normais para o transporte de cargas.

Finalmente, ao chegar ao ponto de consumo, os módulos são descarregados sobre plataformas, as quais são projetadas para tempos mínimos de carga e descarga. Após passar por uma estação redutora, os módulos finalmente se conectam à rede de abastecimento doméstico ou industrial.

Gás Natural Liquefeito (GNL)

Fluido no estado líquido em condições criogênicas, composto predominantemente de metano e que pode conter quantidades mínimas de etano, propano, nitrogênio ou outros componentes normalmente encontrados no gás natural, ANP 1]; em outras palavras é o gás natural liquefeito, resfriado a temperaturas inferiores a -160°C. Este processo permite a redução do volume do fluido em cerca de 600 vezes.

O processo de transporte com GNL compreende três etapas desde a toma de gás natural até o mercado consumidor, tal como se mostra na Figura 3: Planta de Liquefação, onde se contempla filtrado, secado e resfriamento; Sistema de Transporte, que é feito por meio de tanques criogênicos; Planta de Re-gaseificação, onde se volta a converter o liquido em gás.

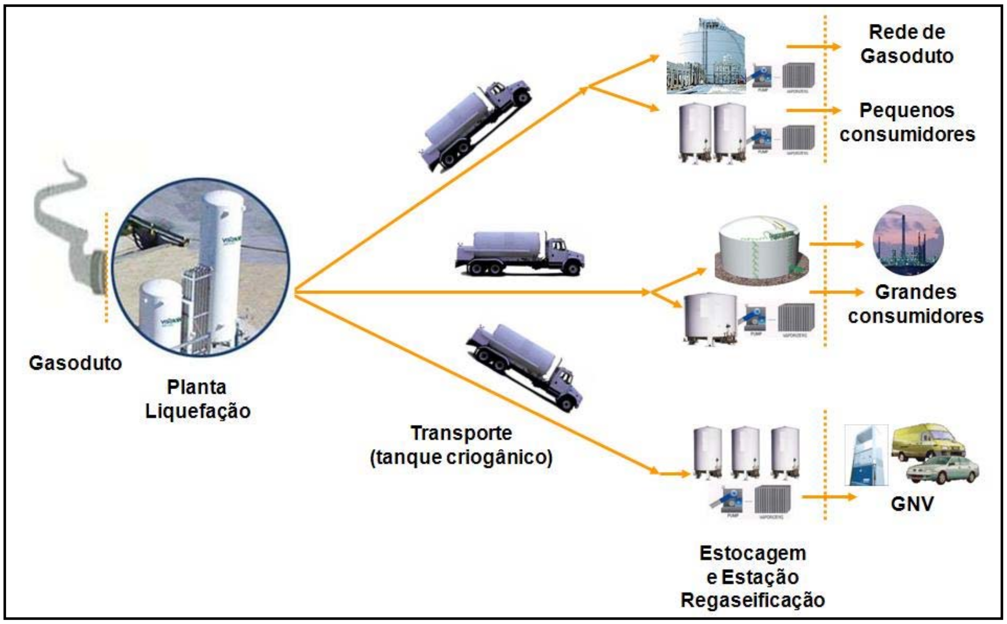



Figura 3: Esquema de gasoduto virtual do GNL.

As tecnologias para produzir GNL se dividem em dois grupos: de grande escala e de pequena escala. As de grande escala produzem acima de meio milhão de toneladas por ano do GNL. Uma das tecnologias existente consiste na tecnologia de cascata de resfriamento pela ação de solventes (propano, etileno e metano) para níveis cada vez mais frios, Begazo et al. 3] & Barreiro 4].

Nas plantas de pequena escala, existem diversas alternativas, entre elas a Tecnologia de Cryofuel, que se baseia no resfriamento produzido por um único solvente em lugar de ser uma cascata de solventes como nas plantas grandes. Alem desta, duas linhas tecnológicas novas vem surgindo: resfriamento por efeito Joule-Thomson e a tecnologia Tasher (*Thermo Acoustic Stirling Heat Engine and Refrigeration*). O principio Joule-Thomson consiste, fundamentalmente, em sistemas de troca de calor, expansão e separação líquido-gás. A tecnologia Tasher se encontra em desenvolvimento nos EUA, consistindo na compressão/expansão através de ondas sonoras de alta freqüência aplicadas ao gás. 3, 4]

No mercado já tem companhias, como a Hamworthy 5], que desenvolvem plantas de liquidificação de gás natural de pequena escala com capacidade de produção a partir de 5 ton de GNL por dia (6,9 mil·$m^3$/dia) e segundo Barreiro

4], até existem protótipos de capacidade de 1,5 mil·m3/dia de gás natura desenvolvidos pela Universidade de Curtin em Perth, Austrália.

Alguns provedores de pequenas plantas de GNL no mercado são: Air Products and Chemicals Inc. (EUA), Black & Veatch Pritchard (EUA), Chart Industries Inc. (EUA), CH-IV Cryogenics (EUA), Chicago Bridge & Iron Company (EUA), Chart (EUA), Cryogenics (EUA), Hamworthy KSE (Noruega), KryoPak Inc. (EUA) and Linde (Alemanha). 6]

Embora, uma das desvantagens da tecnologia do GNL consiste no alto investimento, a maior parte do capital total é direcionada para a construção da planta de liquefação, mas os avanços tecnológicos, dos últimos anos, têm levado à uma diminuição dos investimentos e do custo de operação das plantas de liquefação. 7]

A logística de abastecimento é similar àquele do diesel ou da gasolina, consistindo no recebimento do combustível por caminhões-tanque providos de sistema de refrigeração. Os componentes são mais complexos, pois o GNL deve ser mantido a baixas temperaturas. A transferência de GNL entre containeres é realizada por uma bomba centrífuga, podendo ser submersa ou separada entre os terminais. O processo de re-gasificação consiste em levar o gás natural novamente a seu estado gasoso e se efetua nos vaporizadores. Alem disso, se da ao gás a pressão com a que ingressará para a rede de transporte pelos gasodutos. 8]

Gasodutos

Os gasodutos transportam gás natural na forma gasosa, sendo do tipo “ponto a ponto”. A operação é simples e segura, envolvendo um pequeno número de conexões.

O esquema de um gasoduto é apresentado na Figura 4, sendo composto por tubulações, estações de compressão, regulador de pressão com medidor de vazão, válvula de bloqueio, estação de supervisão e controle, proteção catódica e revestimento interno e externo, Burman 9].

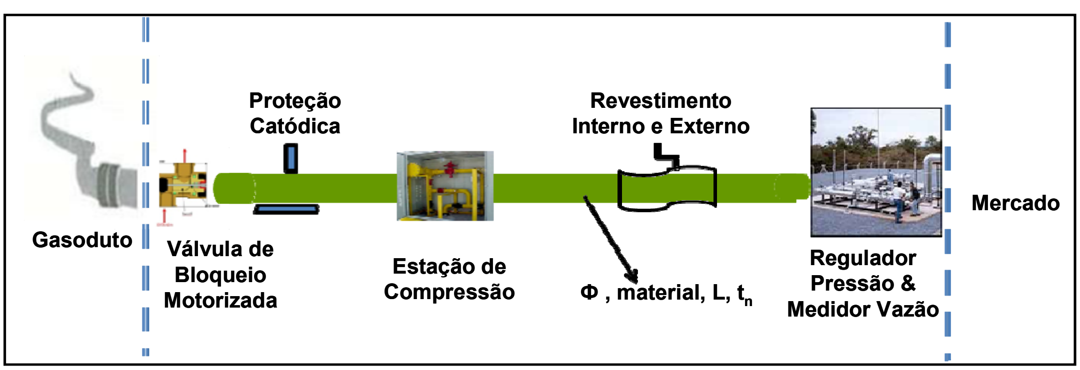



Figura 4: Vista esquemática de um gasoduto.

As principais características físicas dos gasodutos são: diâmetro interno, espessura da parede do duto, comprimento ou extensão. Ao longo da extensão, são instaladas válvulas de bloqueio automáticas, com espaçamento determinado pelas normas (por exemplo: uma válvula de bloqueio a cada 15 km, aproximadamente), com a finalidade de bloquear o gasoduto em caso de rompimentos e manutenção. Nas travessias de rios, lagos e pântanos, também, são instaladas válvulas de bloqueio, Burman 9] & Axpe [10].

Segundo Axpe [10] normalmente, o custo de investimento nas tubulações representa 90% do total. As principais variáveis dos gasodutos são: diâmetro, pressão de operação, distancia e terreno. Outros fatores tais como o clima, os custos de mão de obra, a densidade populacional e os direitos de passagem, podem afetar os custos de construção significativamente.

No entanto, o custo definitivo fica afetado por numerosos fatores, isso não significa que seja impossível fazer uma estimativa geral do que pode custar um gasoduto. O Banco Mundial publica uma regra à que chama Rule-of-Thumb na que oferece uma estimativa inicial que associa só duas variáveis, o diâmetro e o comprimento. Segundo esta regra o custo se situa entre 15 e 30 dólares por cada polegada de diâmetro e por cada metro de comprimento, recomendando inclusive usar 20 dólares para um primeiro cálculo, também se pode usar como referencia o custo de gasodutos que se construíram recentemente. [10]

Análise do Custo de Transporte de Gás Natural

O custo é calculado de modo que o valor presente desse fluxo de caixa, descontado pela taxa de retorno definida, seja nulo (a taxa de retorno definida é a taxa interna de retorno do fluxo de caixa). Ou seja, o valor presente da receita total a ser gerada pela venda do serviço de transporte (entradas de caixa), deve ser igual ao valor presente das saídas de caixa.

A equação para o cálculo do custo de transporte pode ser escrita a partir da fórmula de cálculo do valor presente:

$$\sum_{i=1}^{n} \frac{V_i \cdot Custo}{\left(1+r\right)^i} = \sum_{i=1}^{n} \frac{Inv_i + C_i - VR_n}{\left(1+r\right)^i} \quad (3.1)$$

Onde:

$V_i$ = Demanda no ano i, em mil•$m^3$.

$Inv_i$ = Investimento realizado no ano i, em US$.

$C_i$ = Custos de operação e manutenção referentes ao ano i, em US$.

$VR_n$ = Valor residual ao final do ano n, em US$.

r = Taxa de retorno, em %.

n = Prazo de avaliação, em anos.

Todas as variáveis na equação acima devem ser conhecidas, menos o Custo, que é a variável procurada.

Com base principalmente na informação conseguida de representante de GALILEO (Argentina), NEOgás (Brasil) e FIBA (USA) que possuem o sistema de GNC; a informação de GásLocal (Brasil, consórcio formado pela White Martins, Petrobras a própria GásLocal) que possuem o sistema de GNL e os custos unitários por quilometro-polegada para a construção de um gasoduto se procedeu a realizar as cotizações dos equipamentos, incluído investimento, instalações e custos de operação & manutenção.

Estimativa do Número de Caminhões para modal GNC e GNL

O custo da logística de transporte começa com a estimativa do levantamento do número de caminhões (i.e. carretas e cavalo) para o modal GNC e GNL necessários para atender a cada combinação de volume e distância. Desta forma, foi desenvolvido um modelo capaz de abarcar as considerações logísticas relacionadas a estes custos.

A estimativa do número de caminhões foi feita a partir da demanda (V) em mil•m$^3$/dia e distância percorrida (L) em km. Logo é possível calcular os itens cujas fórmulas podem ser vistas na Tabela 1.

Tabela 1: Formulário para calcular o número de caminhões

| Item | Fórmula |
|---|---|
| Tempo de estrada da carreta (horas) | $T_{car}^{e} = \frac{2 \cdot L}{V_m}$ |
| Tempo de consumo por carreta (horas) | $T_{car}^{cons} = \frac{24 \cdot Vol_{car}^{ef}}{1000 \cdot V}$ |
| Tempo total gasto por carreta (horas) | $T_{car}^{Tot} = T_{car}^{a} + T_{car}^{tb} + T_{car}^{e} + T_{car}^{cons}$ , para GNC<br>$T_{car}^{Tot} = T_{car}^{a} + T_{car}^{d} + T_{car}^{e}$ , para GNL |
| Número de carretas/dia descarregando | $N_v = \frac{1000 \cdot V}{Vol_{car}^{Tot}}$ |

| | |
|---|---|
| Número de carretas | $N_{car} = (1 - P_{cb}) \frac{24 \cdot T_{car}^{Tot}}{T_{car}^{o} \cdot T_{car}^{cons}}$ , ($N_{car} \geq 2$) |
| Número de cavalos | $N_{cav} = N_{car} - 2$ , para GNC<br>$N_{cav} = N_{car}$ , para GNL |

Na Tabela 2, se mostra um resumo dos dados de entrada adotados, vale lembrar que os dados são estimados para uma operação normal e qualquer sensibilidade pode variar nos resultados.

Tabela 1: Dados de entrada para o cálculo do número de caminhões

| Dados Input | | | GNC | GNL |
|---|---|---|---|---|
| Velocidade média do caminhão | $V_m$ | [km/h] | 40, 60, 80 | |
| Volume efetivo por carreta | $Vol_{car}^{ef}$ | [m$^3$] | 5.700 | 24.400 |
| Tempo de abastecimento por carreta | $T_{car}^{a}$ | [h] | 1 | 2 |
| Tempo de transbordo por carreta | $T_{car}^{tb}$ | [h] | 1 | - |
| Tempo descarregamento por carreta | $T_{car}^{d}$ | [h] | - | 1 |
| Tempo de operação diária por carreta | $T_{car}^{o}$ | [h] | 20 | |
| Percentual de carreta de back-up | $P_{cb}$ | [%] | 20% | |

A partir desses componentes é possível calcular os integrantes do custo de investimento e operacionais do sistema de transporte.

Custos do Sistema de Transporte

O custo de investimento é a soma da quantidade de caminhões (isto o número de carretas e cavalo, para o caso de GNC também o número de módulos) que se precisa para atender a demanda de gás natural, o resumo das formulas se mostra na Tabela 3.

Tabela 3: Custo de investimento do sistema de transporte

| Dados Input e Output [US$] | GNC | GNL |
|---|---|---|
| Custo do Investimento em módulos | $CI_{\text{mod}} = N_{\text{mod}} \cdot N_{car} \cdot P_{\text{mod}}$ | |
| Custo do Investimento em carreta | $CI_{car} = N_{car} \cdot P_{car}$ | |
| Custo do Investimento em cavalos | $CI_{cav} = N_{cav} \cdot P_{cav}$ | |
| Custo do Investimento Total | $CI_{trans}^{Tot} = CI_{mod} + CI_{cav} + C_{car}$ , para GNC<br>$CI_{trans}^{Tot} = CI_{cav} + C_{car}$ , para GNL | |

A estimativa do custo operacional do sistema de transporte é baseada nos dois principais dados de entrada, quais sejam: custo fixo e custo variável. Na Tabela 4, se mostra um exemplo dos custos envolvidos.

Tabela 4: Exemplo de uma planilha de custos

| **Input de dados** | | | **Output** | | |
|---|---|---|---|---|---|
| **Custos da empressa** | | | **Itens de custo fixo** | | |
| Salário do motorista | [R$/mês] | 1.300 | Depreciação | [R$/mês] | |
| Horas de trabalho/mês | [h.h./mês] | 176 | Remuneração de capital | [R$/mês] | |
| Encargos e benefícios do motorista | [R$/mês] | 562.5 | Mão de obra | [R$/mês] | 1.862,50 |
| Taxa de oportunidade | [% a.a.] | 12% | IPVA/Seguro Obrigatório | [R$/mês] | 100,00 |
| Custo administrativo | [R$/mês] | 500 | CF | [R$/mês] | **1.962,5** |
| **Dados do veículo** | | | Custo administrativo | [R$/mês] | 500,00 |
| Consumo de combustível | [km/litro] | 2.53 | CF c/ custos administrativos | [R$/mês] | **2462,5** |
| Intervalo entre troca de óleo | [km] | 10.000 | **Itens de custo variável** | | |
| Litros de óleo por troca | [litro] | 30 | Combustível | [R$/km] | 0,26 |
| Número de pneus | [-] | 18 | Óleo | [R$/km] | 0,01 |
| Intervalo entre troca de pneu/recapagem | [-] | 2 | Pneu | [R$/km] | 0,07 |
| Número de manutenção | [R$/km] | 0.13 | Manutenção | [R$/km] | 0,13 |
| Intervalo entre lubrificações | [km] | 2.000 | Custo variável | [R$/km] | **0,47** |
| **Dados de mercado** | | | | | |
| Valor de aquisição do veículo | [R$] | 165.000 | | | |
| Vida útil do veículo | [mês] | 120 | | | |
| Valor residual do veículo | [R$] | 65.000 | | | |
| Preço do óleo | [R$/litro] | 2.7 | | | |
| Preço do combustível | [R$/litro] | 0.65 | | | |
| Preço do pneu | [R$] | 620 | Tipo de cambio | [US$/R$] | 1,80 |
| Preço da recapagem | | 180 | Custos fixos | [US$/mês] | **4.433** |
| IPVA/Seguro Obrigatorio | [R$/ano] | 1.200 | Custo variáveis | [US$/km] | **0,843** |

Um resumo dos dados de entrada e as formulas e mostrado na Tabela 5, os valores dos custos totais de fixos e variáveis vale para qualquer valor de demanda e distancia.

Tabela 5: Custo operacional do sistema de transporte

| Custo Operacional | | | GNC - GNL |
|---|---|---|---|
| Custo fixo mensal | Cf | [US$] | 4,433 |
| Custo variável por km rodado | Cv | [US$/km] | 0,843 |
| Distância percorrida por ano | $L_a$ | [km] | $L_a = 2 \cdot L \cdot d \cdot N_v$ |
| Custos operacionais total | $CO_{trans}$ | [US$/ano] | $CO_{trans}^{Tot} = 12 \cdot N_{cav} \cdot Cf + Cv \cdot L_a$ |

Custos da Unidade de Compressão de GNC

A unidade de compressão e só uma variável da demanda (V, em mil·m$^3$/dia) do projeto, uma forma de dimensionar quanto e a potencia total do sistema de compressor. O custo de combustível depende do tipo de compressor utilizado. Como visto anteriormente, são admitidos dois tipos de acionamento de compressor: à gás e elétrica. Como forma de exemplo na Tabela 6 a seguir exemplifica a forma de cálculo descrita para uma demanda de 100 mil·m$^3$/dia e uma distancia de 100 km.

Tabela 6: Exemplo de Cálculo do Custo da Unidade de Compressão

| **Cálculo do Custo da Unidade de Compressão** | | | |
|---|---|---|---|
| Demanda | $V$ | [mil·m$^3$/dia] | 100 |
| Distância percorrida | $L$ | [km] | 100 |
| Potencia total dos compressões | $Pot_{tot}$ | [kW] | 440 |
| Consummo anual de energia | $Con_{energ}$ | [MWh/ano] | 4.225 |
| Custo de Investimento | $CI_{comp}$ | [MMUS$] | 0,85 |
| Custo de O&M | $CO_{comp}$ | [MMUS$] | 0,29 |
| VPL das Saídas de Caixa | | [MMUS$] | 2,8 |
| Demanda de Capacidade | $V$ | [mil·m$^3$/ano] | 36.000 |
| VPL Demanda de Capacidade | | [mil·m$^3$/ano] | 238.433 |
| Vida útil da estação compressora | $n$ | [anos] | 20 |
| Taxa de desconto | $r$ | [%] | 14% |
| Custo do Sistema do Compressor | $Custo$ | [US$/mil·m$^3$] | 11,6 |
| | | [US$/MMBTU] | 0,314 |

Custos na Planta de Liquefação e no Sistema de Estocagem

Para estimar o custo de investimento da planta de liquefação, é necessário determinar, previamente, a capacidade desejada da referida planta, sendo que tal capacidade é função do volume de gás natural a ser transportado. A metodologia aqui considerada assume que o projeto arca com os custos de investimento nos sistemas de armazenamento de GNL no mercado final. O custo de operação destes tanques ficará, todavia, a cargo dos compradores do GNL. Na Tabela 7 é feito um exemplo deste cálculo para demandas de 100, 400 e 1000 mil·m$^3$/dia, vale lembrar que a não é função da distancia.

Tabela 7: Exemplo de Cálculo do Custo da Planta de Liquefação e Estocagem

| **Cálculo do Custo da Planta de Liquefação e Estocagem** | | | | | |
|---|---|---|---|---|---|
| Demanda | $V$ | [mil·m$^3$/dia] | 100 | 400 | 1.000 |
| Quantidade a ser estocada | $Es$ | [m$^3$GNL] | 492 | 1.967 | 4.918 |
| Capacidade da planta de liquefação | $Cap_{PL.proj}$ | [ton$_{GNL}$/ano] | 26.946 | 107.784 | 269.461 |
| Consumo de energia da planta | $Con_{energ.PL}$ | [mil·m$^3$/ano] | 6.353 | 25.412 | 63.529 |
| Custo de Investimento da planta | $CI_{PL.proj}$ | [MMUS$] | 10,8 | 24,8 | 43,0 |
| Custo de Investimento da estocagem | $CI_{tan.proj}$ | [MMUS$] | 0,3 | 0,7 | 1,2 |
| Custo de O&M da planta de liquefação | $CO_{PL}$ | [MMUS$] | 2,9 | 10,9 | 26,7 |
| VPL das Saídas de Caixa | | [MMUS$] | 30,1 | 97,7 | 221,0 |
| Demanda de Capacidade | $V$ | [mil·m$^3$/ano] | 36.000 | 144.000 | 360.000 |
| VPL Demanda de Capacidade | | [mil·m$^3$/ano] | 238.433 | 953.731 | 2.384.327 |
| Vida útil da Planta Liquefação | $n$ | [anos] | 20 | | |
| Taxa de desconto | $r$ | [%] | 14% | | |
| Custo Unitario da Liquefação | *Custo* | [US$/mil·m$^3$] | 126,1 | 102,5 | 92,7 |
| | | [US$/MMBTU] | 3,42 | 2,78 | 2,51 |

Custos do Gasoduto

Para calcular o investimento e os custos de operação & manutenção de um gasoduto em função do comprimento e a vazão, primeiro se requer conhecer as características (dimensionamento) do gasoduto. Para cada projeto abarca muitas variáveis, como já tínhamos mencionado, uma estimativa do custo de investimento de gasoduto pode ser feita pela Rule-of-Thumb que associa as variáveis a vazão e o comprimento do gasoduto. A Tabela exemplifica a forma de cálculo descrita para diferentes valores de distância e demanda.

Tabela 8: Exemplo de Cálculo do Custo de Transporte do Gasoduto

| Cálculo do Custo do Transporte do Gasoduto | | | | | | | |
|---|---|---|---|---|---|---|---|
| Demanda | *V* | [mil $m^3$/dia] | 100 | | | 400 | 1.000 |
| Comprimento do gasoduto | *L* | [km] | 100 | 400 | 1.000 | 100 | |
| Diâmetro do gasoduto | *D* | [in] | **6,0** | **14,0** | **22,0** | **10,0** | **16,0** |
| Custo unitário de construção | *Cu* | [US$/m in] | **22,8** | **20,0** | **18,5** | **21,5** | **19,6** |
| Custo de Investimento | *CI* | [MMUS$] | 13,7 | 112,3 | **406,6** | 21,5 | 31,3 |
| Custo de O&M | *CO* | [MMUS$] | 0,7 | 5,6 | 20,3 | 1,1 | 1,6 |
| VPL das Saídas de Caixa | | [MMUS$] | 18,2 | **149,5** | **541,3** | 28,6 | **41,7** |
| Demanda de Capacidade | *V* | [mil $m^3$/ano] | **36.000** | | | **144.000** | **360.000** |
| VPL Demanda de Capacidade | | [mil $m^3$/ano] | **238.433** | | | **953.731** | **2.384.327** |
| Vida útil | *n* | [anos] | 20 | | | | |
| Taxa de desconto | *r* | [%] | 14% | | | | |
| Custo de transporte | *Custo* | [US$/mil $m^3$] | **76,3** | **626,8** | 2.270,1 | 120,0 | 174,8 |
| | | [US$/MMBTU] | 2,07 | 16,96 | 61,51 | 3,25 | **4,74** |

Resultados: Comparação entre modais

A determinação do custo de transporte de gás natural se baseou na estimativa dos custos de investimento e operacionais para diferentes combinações de duas variáveis chaves: volume a ser entregue (de 0-1.000 mil·$m^3$/dia), e distância a ser percorrida (de 0-1.000 km).

Foram analisados os efeitos da quantidade de gás natural, a ser transportada diariamente, o efeito da distância, as velocidades dos veículos, assim como a taxa de retorno do investimento, comparando-se os resultados para os diversos modais considerados.

Demanda de caminhões por distância percorrida

Como pode ser observado na Figura 5, supondo uma demanda de 100.000 $m^3$/dia, o número de caminhões de GNC aumenta rapidamente com a distância a ser percorrida, enquanto que o crescimento das carretas de GNL se dá de forma mais lenta. Isto se deve à densidade energética do GNL em comparação com o GNC.

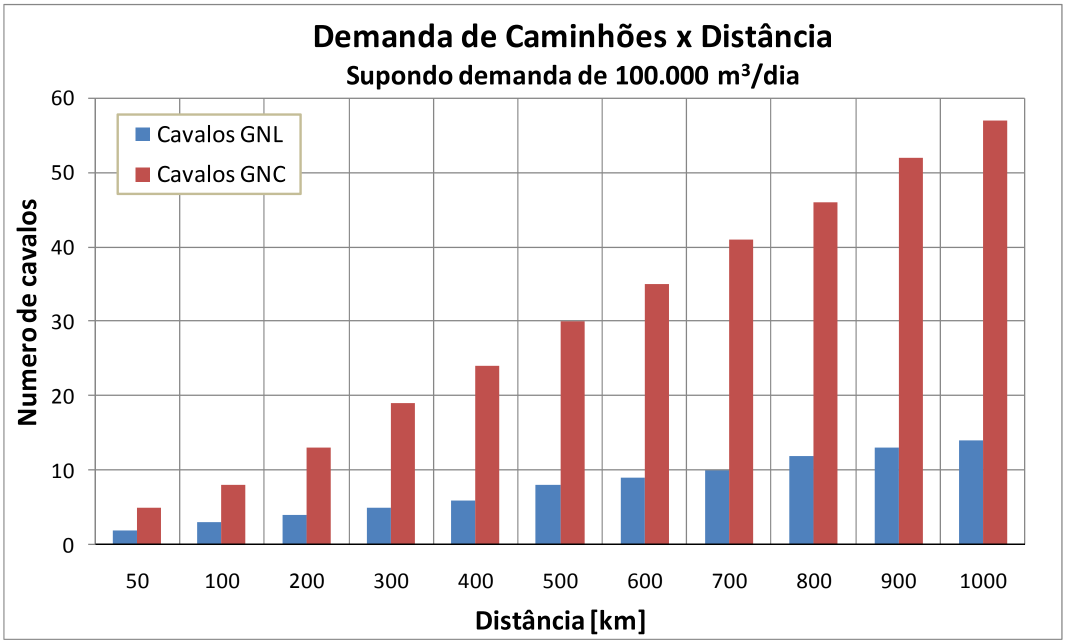



Figura 5: Variação dos números de carretas em função da distância.

Como as carretas de GNC não possuem a capacidade de transportar um grande volume de GN, comparadas as GNL, estas são obrigadas a fazer maior número de viagens, em comparação às carretas de gás liquefeito, para atender o mesmo cliente. Com a tecnologia disponível atualmente, um caminhão de 40 toneladas de GNC pode transportar cerca de 5.700 $m^3$, em quanto que um caminhão similar de GNL pode transportar em torno de 24.400 $m^3$.

Escolha do Modal de Transporte do GN

A construção de um gráfico onde se possa escolher o melhor modal de transporte dada uma demanda de GN e uma distância percorrida e o objetivo de nosso estúdio, no entanto existem sensibilidades entre as mais importantes a velocidade media do caminhão no trecho percorrido e taxa de retorno que foram analisadas. Vale lembrar que tudo isto para as premissas técnicas e econômicas estabelecida neste trabalho para fazer a comparação.

A Figura 6, para uma taxa de retorno de 14% e caminhões viajando à velocidade média de 40km/h, apresenta as situações onde um dado modal resulta em menor custo de transporte do GN, em função da distância e demanda. Observou-se que a utilização de gasodutos se justifica em casos de altas demandas. Para distâncias acima de 250 km, o GNL se mostra altamente competitivo. O GNC é atraente apenas para baixas demandas e pequenas distâncias embora este modal exija menor custo de investimento e operacional para distâncias curtas.

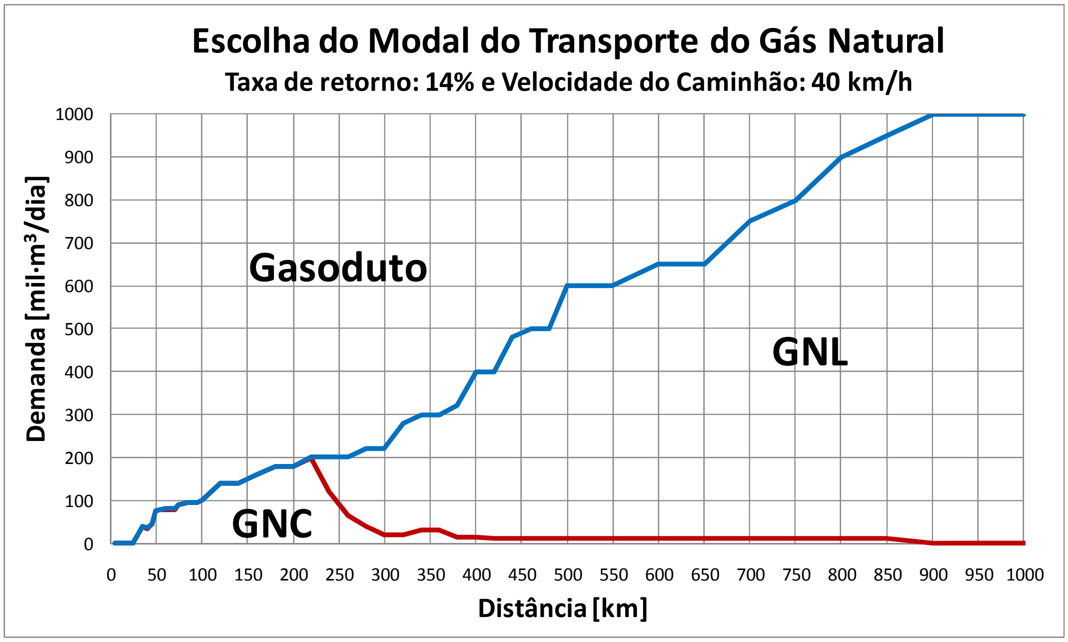



Figura 6: Efeito da distância na escolha do modal para uma dada demanda de GN.

O efeito da velocidade média dos veículos é apresentado na Figura 7, para uma taxa de retorno de 14%. Observa-se que a possibilidade dos veículos poderem viajar a maiores velocidades tende a favorecer o uso do GNC, cuja área de utilização tende a se ampliar sobre os demais modais, assim como favorece o GNL sobre o uso de gasodutos. Já que os investimentos em carretas assim como seus custos operacionais sofrem uma queda do número de caminhões e pelo aumento de viagens ao dia.

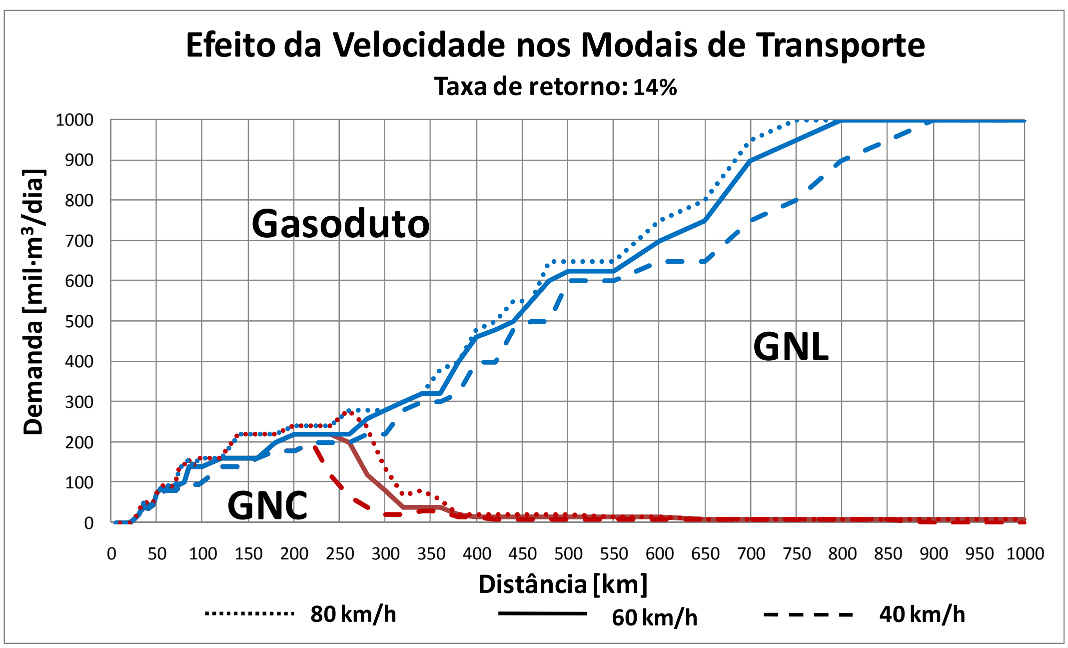



Figura 7: Efeito da velocidade dos modais de transporte.

Ao comparar os valores presentes descontados ao: 12%, 14% e 16%, se vê na Figura 8 que o custo de do GNC tem pequeno efeito, só na região limite entre o GNL e gasoduto para distâncias e demandas altas percebe-se o efeito da taxa de retorno.

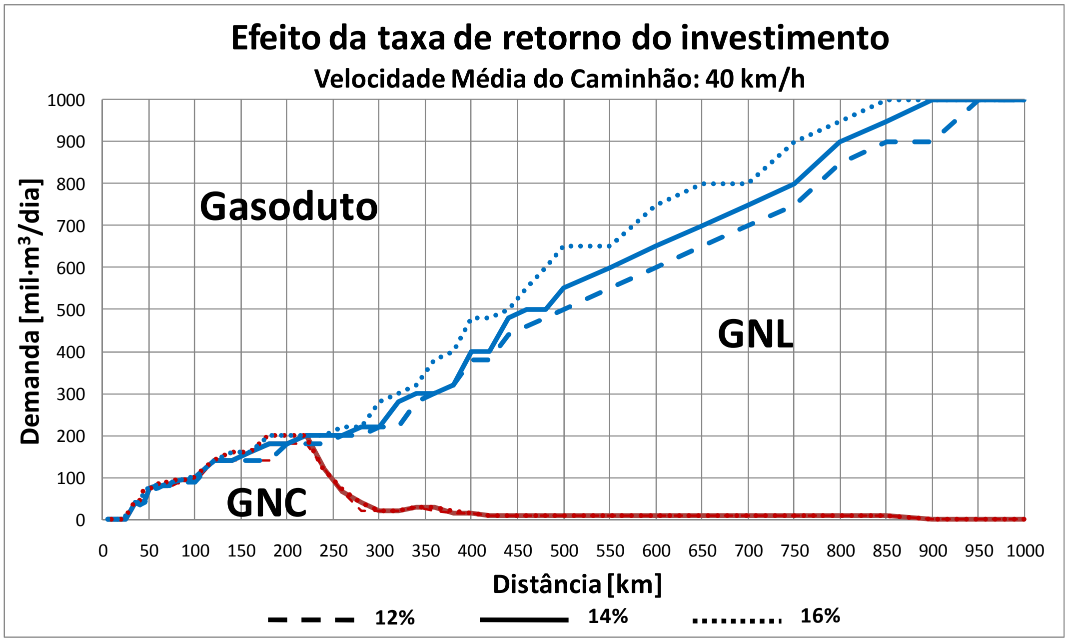



Figura 8: Efeito da taxa de retorno do investimento.

Custo do transporte

As figuras anteriores mostram a competitividade do modal para o menor custo de transporte de GN, mas não se pode obter o valor do custo de transporte. Para isto devem-se construir outros dois gráficos: custo de transporte versus a distância percorrida dada uma demanda e custo de transporte versus a demanda dada uma distancia. Vale lembrar que isto para uma sensibilidade dada.

Para quantidades pré-definidas diárias de gás a Figura 9 apresenta o custo de transporte do GN, em US$/MMBTU, em função das distâncias a serem transportadas, alem disso mostra-se para cada demanda diária o modal mais atraente. Por exemplo, para uma demanda de 100 mil·m$^3$/dia até uma distância de aproximadamente 120 km é mais competitivo utilizar gasoduto, para distancias até 250 km é melhor GNC e para distâncias superiores o GNL; quando a demanda é de 400 mil·m$^3$/dia a melhor escolha do modal até 440 km é o gasoduto e para distancias superiores é GNL; e assim para cada demanda pode-se fazer um analise. Observe-se também que o custo de transporte é diretamente proporcional à distância transportada.

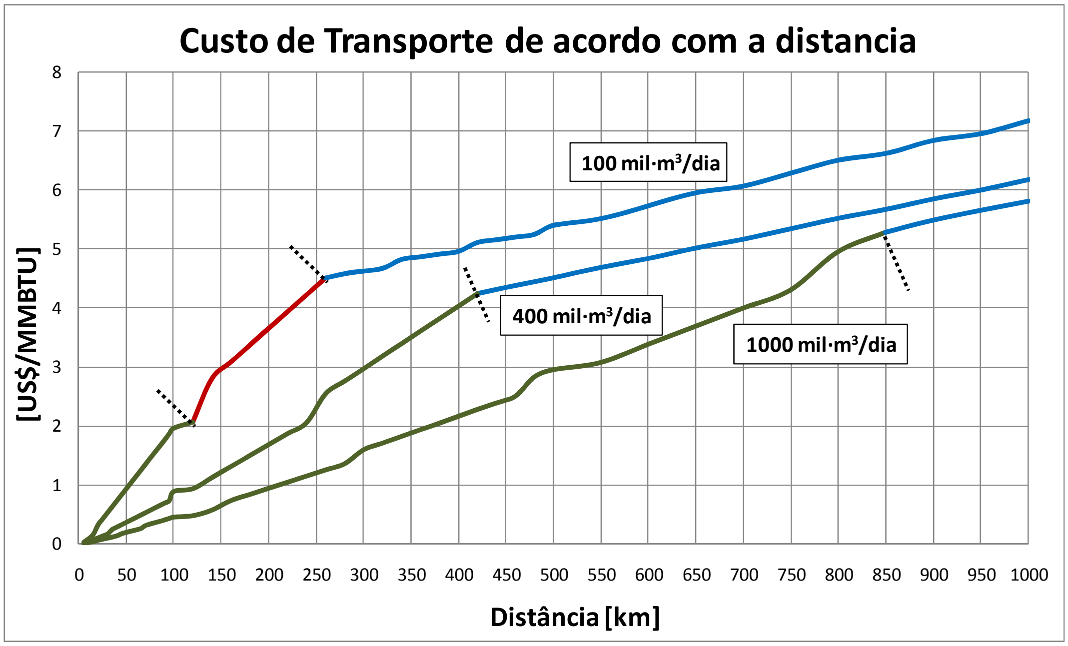



Figura 9: Custo do transporte em função da distância.

Para distâncias pré-definidas a Figura 10 apresenta o custo de transporte do GN, em função das demandas diárias, analogamente que a figura anterior para cada distância pode-se observar o modal mais competitivo. Por exemplo, para uma distância de 1000 km o modal mais competitivo é GNL; quando a distancia é 400 km com uma demanda de ate 15 mil·m$^3$/dia a melhor escolha é o GNC, para 15 a 400 mil·m$^3$/dia é o GNL e para demandas superiores a 400 mil·m$^3$/dia é o gasoduto. Mostra-se que o custo de transporte é indiretamente proporcional à demanda diária.

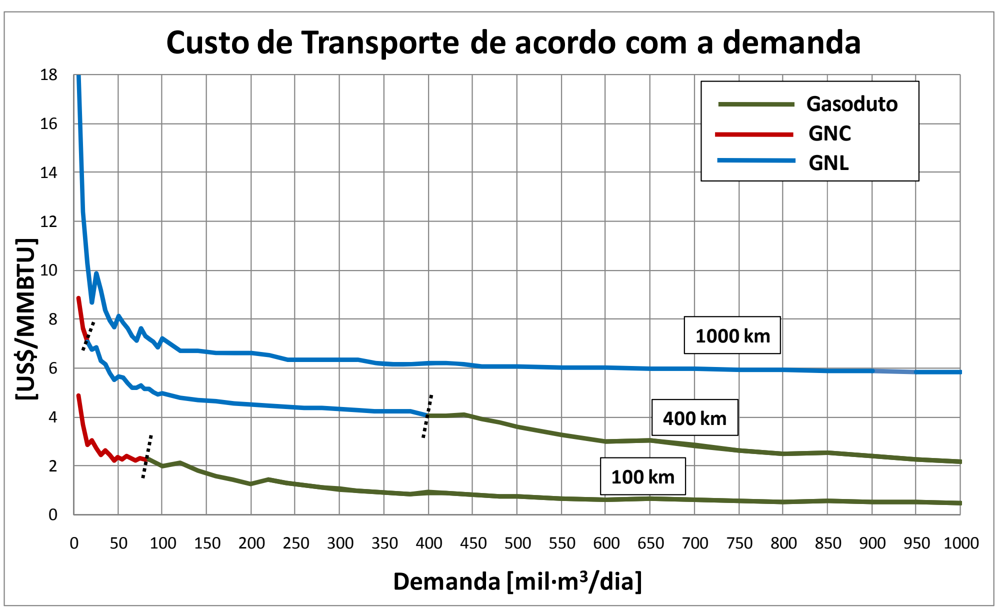



Figura 10: Custo do transporte em função da demanda.

## Conclusões

Foi realizada uma discussão das alternativas tecnológicas de transporte e logística do gás natural com a qual se armou uma metodologia para o cálculo do custo de transporte. As principais conclusões derivadas da analise são listadas a seguir:

Devido à densidade energética do GNL em comparação com o GNC o número de carretas de GNC aumenta rapidamente com a distância a ser percorrida e por isso apresentou grande impacto nos custos de investimento e de operação.

Para avaliar o emprego das alternativas tecnologias de transporte de gás natural se desenhou uma gráfica onde dada uma combinação do volume a ser transportada e distancia pode-se obter o modal mais competitivo.

Observou-se que a utilização de gasodutos se justifica em casos de altas demandas e distâncias abaixo de 500 km, para distâncias acima deste valor, o GNL se mostra altamente competitivo e o GNC é atraente apenas para baixas demandas e pequenas distâncias.

O efeito da velocidade aumenta a competitividade do GNC e GNL contra o gasoduto, por isto é necessário definir qual será a rota ótima para cada projeto em questão.

À taxa de retorno tem pequeno efeito no custo de transporte, é quase imperceptível para demandas e distancias baixas.

Para obter o valor do custo de transporte construíram-se dois gráficos um em função da distância e outra em função da demanda, onde se observou que o custo de transporte é diretamente proporcional à distância e indiretamente proporcional com a demanda diária.

Finalmente temos que mencionar que a introdução do gás natural fica assegurada quando o preço do gás, incluindo preço na entrada (fonte), mais o transporte, mais o custo de transporte do modal, mais a tarifa de distribuição é menor do que o preço do energético substituível. Ou seja, é necessário avaliar em cada caso, em particular o mercado à ser abastecido para saber se tem viabilidade econômica para desenvolver o projeto do modal escolhido.

## References

1 DAVE, R. H.; THOMAS, S. Review of ways to transport natural gas energy from countries which do not need the gas for domestic use. Trinidad and Tobago: Elsevier Ltd., 2002.

2 AGÊNCIA NACIONAL DO PETRÓLEO, GÁS NATURAL E BIOCOMBUSTÍVEIS (ANP). Glossário ANP. Disponível em: <http://www.anp.gov.br/glossario>. Acesso em: 20 mai. 2008.

3 BEGAZO, C. D. T.; CARVALHO, E. C.; SIMÕES-MOREIRA, J. R. Small-scale LNG Plant Technologies. Hydrocarbon World 2007, v. 1, p. 28-33, 2007.

4 BARREIRO, E. El GNL y sus tecnologías. Petrotecnia, p. 66-70, 2003.

5 HAMWORTHY. Disponível em: <http://www.hamworthy.com>. Acesso em: 10 jul. 2008.

6 PERRUT, F. M. Potencial para Difusão das Tecnologias Alternativas ao Transporte do Gás Natural no Brasil: O Caso Gás Natural Comprimido e Gás Natural Liquefeito. 2005. 72 f. Monografia (Bacharelado) – Instituto de Economia, Universidade Federal de Rio de Janeiro (UFRJ). Rio de Janeiro, 2005.

7 CORNOT-GANDOLPHE, S. et al. The challenges of further cost reductions for new supply options (pipeline, LNG and GTL). Tokyo, Japan: 22nd World Gas Conference, 2003.

8 PITA, G. Introducción al GNL. [S.I.:s.n.], 2006.

9 BURMAN, V. Transporte Dutoviário de Gás Natural. 2004. 58 f. Monografia (Especialização) - Engenharia de Gás Natural, Departamento de Engenharia Química, Universidade Federal da Bahia. Bahia, 2004.

10 AXPE, A. M. ¿Cuánto cuesta un gasoducto? Caracas, Venezuela: Soberania, 2006.

# 6. How Long will Central and South American Petroleum Last?

**Roberto F. Aguilera**

International Institute for Applied Systems Analysis (IIASA)

Schlossplatz 1, A-2361, Laxenburg, Austria

Tel: 43 2236 807 262

Email: aguilera@iiasa.ac.at

Abstract: This paper evaluates the threat that depletion creates for conventional oil in the Central and South American region. It does so by estimating the endowment volumes of oil in the region, including volumes from provinces not previously assessed by other organizations. The volumes for the previously unassessed provinces are estimated using a Variable Shape Distribution (VSD) model.

The results indicate that Central and South American conventional oil is more abundant than usually assumed, and can be produced at costs below current market oil prices, and substantially below mid-2008 prices. From an availability perspective, the implication is that the region's dependence on conventional oil need not come to an end over the next few decades.

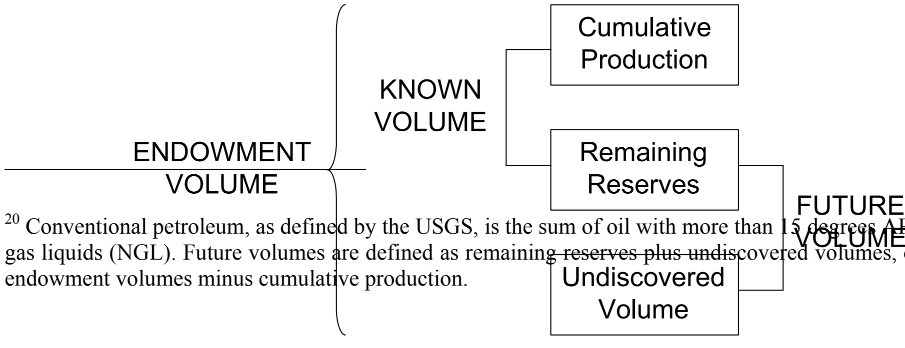
1. Introduction

Due to the concern of some experts about an approaching energy crisis, Aguilera (2006) and Aguilera et al. (2009) construct global cumulative long run supply curves for conventional petroleum, and unconventional sources of liquids including heavy oil, oil sands and oil shale. The conventional petroleum portion of the supply curves include future volumes that the USGS (2000) has estimated using a time horizon of 30 years.[20] For our purposes, the USGS figures suffer from the shortcoming that they do not take into account volumes from those provinces that were not expected to be exploited within the adopted 30-year time horizon. As indicated in USGS (2000), the world can be divided into 937 provinces, of which 409 had been evaluated in the study (i.e. 528 provinces had not been assessed).

In Central and South America (CSA), endowment volumes (which are equal to known plus undiscovered volumes; see Figure 1) are given for 22 provinces. In total, the USGS states that there are 122 CSA provinces. Thus, the volumes in 100 of those provinces are not presented in USGS (2000). This paper estimates endowment volumes for the unassessed provinces using a new size distribution model, originally developed in Aguilera (2006), called the Variable Shape Distribution (VSD) model (also see Aguilera et al., 2007; Aguilera et al., 2008; Aguilera et al., 2009).

Figure 1

The relationship between cumulative production, remaining reserves and undiscovered volumes. Terminology from USGS (2000).




[20] Conventional petroleum, as defined by the USGS, is the sum of oil with more than 15 degrees API, gas, and natural gas liquids (NGL). Future volumes are defined as remaining reserves plus undiscovered volumes, or equivalently, as endowment volumes minus cumulative production.

## 2. Earlier Methods

Previous size distribution models used to estimate oil volumes of un-assessed areas include the log-normal and the Pareto distributions.[21,22] Initial efforts to characterize the distribution of nature's oil resources led researchers to conclude that lognormal distributions provided the best fit of data available at the time (Kaufman, 1962). Over the ensuing years, several researchers at the USGS discovered that the lognormal distribution provided overly pessimistic results (Drew, 1997). They observed that, with additional exploration, there was an on-going discovery process that could better be modeled with a Pareto distribution. The difference between the two distributions can be seen in Figure 2, where they are shown as density distributions.

It is generally acknowledged that the Pareto distribution tends to overestimate oil resources, while the lognormal distribution tends to underestimate them.

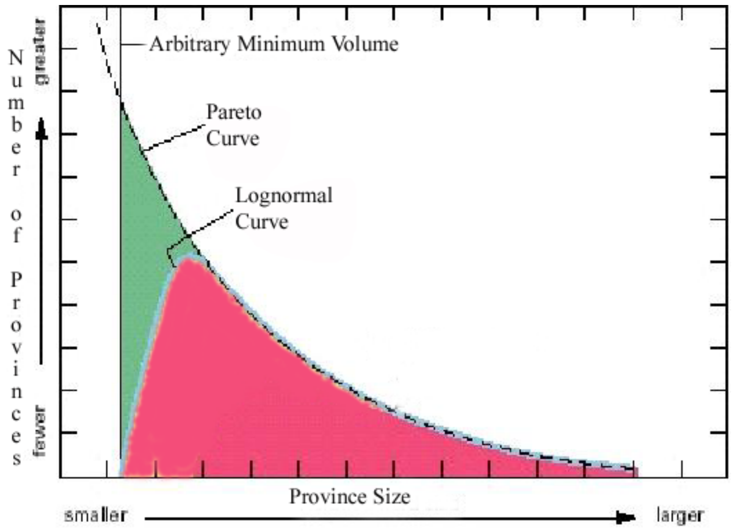
Figure 2

Density distributions of number of provinces versus province size (adapted from Barton, 1995).

---

[21] The log-normal distribution is a continuous distribution in which the logarithm of a random variable is normally distributed.

[22] The Pareto distribution is also known as the power law, Bradford, hyperbolic, fractal, scaling, Zipf (when the slope is 1.0), log-geometric, and J-shape distributions. The Pareto distribution, named after the Italian economist Vilfredo Pareto, is a power law distribution, where the exponent of the power law is constant.




2.1 The Pareto Distribution

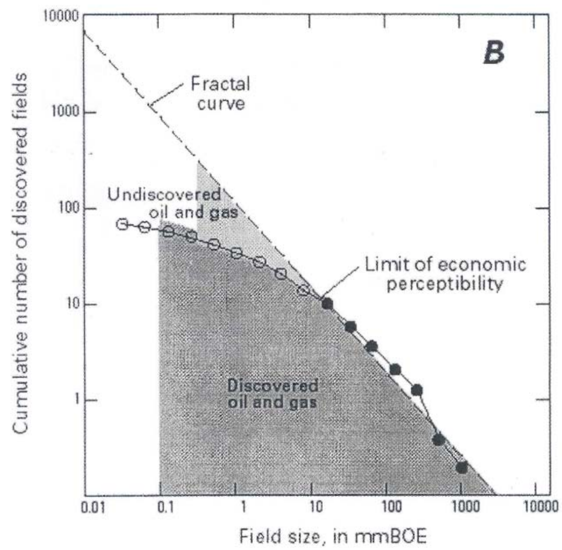
Mandelbrot (1982) also indicates that the size distribution of oil resources could be modeled with the Pareto (i.e. fractal) distribution.[23] The Pareto distribution specifies that a log-log plot of the cumulative number of discovered oil fields versus the size of the field could result in an approximate straight line with a constant negative slope. The straight line is generally observed for the larger fields, as shown by the solid circles in Figure 3 (Barton, 1995). The slope of the dashed straight line is known as the 'shape parameter' of the Pareto distribution. The open circles represent discovered (known) volumes of oil and gas below levels that are presently economically viable, or the limit of economic perceptibility. The area under the curve is the cumulative volume of discovered oil and gas. The straight line is extrapolated to an arbitrary minimum volume to calculate the undiscovered oil and gas, which is equal to the area between the straight line and the open circles. The method can be used for any selected population, from the most specifically-defined oil and gas play, to the world.

Figure 3

Cumulative number of discovered oil and gas fields versus size of the field (Barton, 1995).

---

[23] The Pareto distribution is the probability distribution characteristic of fractals. Mandelbrot (1982) defines a fractal as a structure that contains an organized arrangement of repeating patterns over many ranges of scale. In fractals, the part is reminiscent of the whole. Some fundamental properties of fractals are self-similarity, self-affinity and scale invariance.




A Pareto distribution is provided by a power law of the form (Barton and Scholz, 1995):

$$N(V) = CV^{-a_p}$$

(1)

where:

*C* - constant of proportionality.

*V* - specified oil volume.

*N(V)* - number of provinces with a volume greater than or equal to V.

$a_p$ - constant (scale invariable) shape parameter, which is also known as Pareto exponent, Pareto constant, or fractal dimension.

Taking logarithms of both sides of Equation 1 leads to:

$$\log N(V) = \log(C) - a_p \log V$$

(2)

Equation 2 indicates that a plot of *N(V)* versus *V*, on log-log coordinates, should result in a straight line with a slope equal to $-a_p$ and an intercept, at *V* = 1, equal to *C*.

Historically, all the methods used to forecast oil volumes have been "based on an assumed form of the size-frequency distribution of the natural population of oil and gas accumulations" (Barton, 1995). The Variable Shape Distribution (VSD) is different in that we start by observing the curvature (on a log-log plot) given by the size and number of a sample of provinces from USGS (2000), including the largest provinces. We then develop the VSD model which allows the data to determine the specified relationship between the size and number of provinces.

## 3. The Variable Shape Distribution (VSD) Model

This section begins by describing the VSD model, and then estimates and validates its parameters.[24] Finally, the model is used to estimate endowment volumes of conventional oil for those provinces that the USGS has not assessed. Other models commonly used to forecast oil supply are life cycle models (e.g. Hubbert's logistic curves), rate of effort models, geologic-volumetric models, subjective probability models, discovery process models and econometric models. As stated in Adelman et al. (1983, p. 90), "the concept of deposit size distribution is an essential component of models of petroleum supply designed to reflect industry behavior in a logical way."

### 3.1 Description of the Variable Shape Distribution (VSD) Model

The VSD methodology starts by ranking the CSA provinces assessed by USGS (2000), in decreasing order by volume. When the data is plotted on log-log coordinates, the vertical axis shows the rank of a province according to its volume, while the horizontal axis shows the volume of the province. The VSD calculates volumes for unassessed provinces, assuming most of the larger provinces have already been assessed. That is, the slope of the approximate straight line given by the assessed, larger provinces remains constant as we include unassessed provinces in the ranking.

As mentioned earlier, all the earlier methods used to forecast oil volumes have been based on an assumed form of the size-frequency distribution of the natural population of oil accumulations. In this paper, we start by observing the curvature given by the USGS (2000) data points on a log-log plot. We then develop the VSD model (see Equations 3-4) which allows the data to determine the specified relationship between the size and number of provinces.

---

[24] Aguilera et al. (2007) provides the mathematical development of the VSD model.

As with all size distribution models, the original sample used to estimate the parameters contains most of the largest and promising data. This allows one to estimate the slope and intercepts, on log-log coordinates, of the straight line given by the largest data (these parameters remain constant during the forecasting stage). The previously unassessed data will then generally contain smaller volumes than the assessed. Furthermore, many of the unassessed provinces are in areas where oil may exist but due to location and other factors are likely to be higher cost resources.

### 3.2 An Example of the VSD Using World Data (from Aguilera et al., 2009)

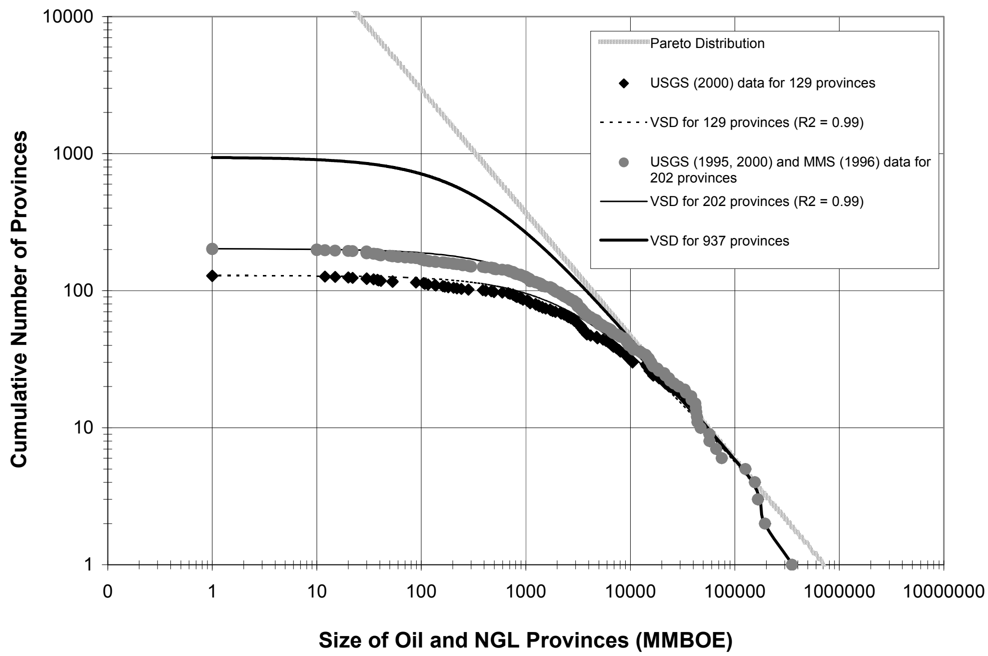
As an illustration, USGS (2000) provides estimates of the world oil and NGL endowment for 129 provinces, excluding the provinces of the United States. We then use non-linear regression to estimate the parameters of the VSD model that provides the best fit of the USGS (2000) data. As Figure 4 shows, the dotted curve generated by the estimated VSD model provides a very good fit of the actual data.

The estimated VSD model is next employed to assess the size distribution relationship among all assessed provinces, those in the United States as well as those elsewhere. The parameter values estimated with the previous sample are used. Volumes of the oil and NGL endowment for provinces in the United States are available from the USGS National Oil and Gas assessment (1995) and Minerals Management Service Outer Continental Shelf assessment (1996). When combined with the provinces of the rest of the world, a total of 202 assessed provinces are available. Figure 4 shows that the estimated VSD curve again provides a very good fit of the actual data. In addition, the volumes for individual provinces generated by the estimated VSD model compare very well with the values estimated by geological methods (see Aguilera, 2006; Aguilera et al., 2007).

According to the USGS, the world can be divided into 937 provinces, of which they have provided endowment volume for 202 provinces. Thus, the VSD model is then used to estimate the size distribution relationship for all of the 937 provinces of the world, including those not previously assessed. Again, the model is run using the estimated parameter values from the first sample. The size distribution relationship is shown in Figure 4 and allows us to estimate the endowment volumes of oil and NGL in the previously unassessed provinces, assuming most of the larger provinces have already been assessed. The good fit for the previous two samples (including a high $R^2$ and comparable volumes) provides some confidence that the estimated volumes for 937 provinces are reasonable.

Figure 4

Endowment of Oil and NGL – Number of Provinces versus Province Size




3.3 Parameter Estimation and Validation for CSA

Using CSA data from the USGS (2000) study, this section estimates and validates the VSD model for the region. A sample of 22 CSA oil endowment volumes (shown in the second column of Table 1), assessed by USGS (2000), have been used to estimate the parameters of the VSD model using non-linear regression.

Table 1

Oil Endowment Volumes, 22 CSA Provinces assessed by USGS (2000)

| | |
|---|---|
| $R^2$ coefficient of determination = | **0.9924868** |

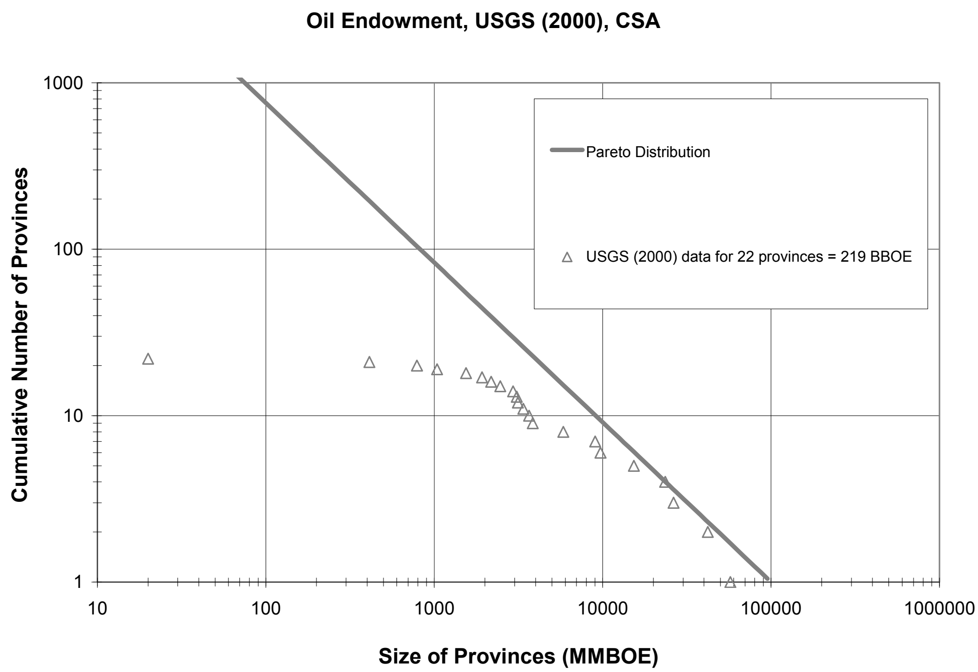
| | | | |
|---|---|---|---|
| $a_p$ = | 0.96 | $N_x$ = | 22 |
| $r_m$ = | 0.000215 | $N_m$ = | 1 |
| | | $V_x$ = | 100,000 |
| $V_s$ = | 50000 | $V_m$ = | 22 |
| Ψ = | 0.28 | $a_m$ = | 0.36603 |
| severity = | 9 | $(r_m)^{am}$ = | 0.04545 |

| Province Code | Province Name | Cumulative # of World Provinces $N_t$ | Oil Endowment (MMBOE) | $r_v$ | $r_t$ | $a_t$ | function | $\hat{V}_i$ (MMBOE) |
|---|---|---|---|---|---|---|---|---|
| | **TOTAL** | | **219,474** | | | | | **219,480** |
| 6099 | Maracaibo Basin | 1 | 57,256 | 0.95270 | 0.95291 | 0.00000 | 2.34825E-01 | 58855.051 |
| 6098 | East Venezuela Basin | 2 | 42,078 | 0.43986 | 0.44007 | 0.84446 | 8.05827E-03 | 43091.558 |
| 6035 | Campos Basin | 3 | 26,349 | 0.27332 | 0.27354 | 0.84749 | 4.18688E-04 | 27323.675 |
| 6036 | Santos Basin | 4 | 23,494 | 0.19146 | 0.19167 | 0.83918 | 3.36538E-05 | 19165.565 |
| 6021 | Guyana-Suriname Basin | 5 | 15,310 | 0.14298 | 0.14319 | 0.82808 | 3.68303E-06 | 14319.085 |
| 6041 | Putumayo-Oriente-Maranon Basin | 6 | 9,699 | 0.11101 | 0.11122 | 0.81584 | 4.99338E-07 | 11122.444 |
| 6096 | Llanos Basin | 7 | 9,033 | 0.08839 | 0.08861 | 0.80293 | 7.85927E-08 | 8860.997 |
| 6060 | Falklands Plateau | 8 | 5,833 | 0.07158 | 0.07180 | 0.78949 | 1.37084E-08 | 7179.763 |
| 6058 | San Jorge Basin | 9 | 3,844 | 0.05861 | 0.05883 | 0.77555 | 2.55787E-09 | 5882.856 |
| 6055 | Neuquen Basin | 10 | 3,659 | 0.04832 | 0.04853 | 0.76106 | 4.96094E-10 | 4853.462 |
| 6081 | Talara Basin | 11 | 3,383 | 0.03996 | 0.04018 | 0.74597 | 9.75091E-11 | 4017.662 |
| 6090 | Middle Magdalena | 12 | 3,135 | 0.03305 | 0.03326 | 0.73015 | 1.89575E-11 | 3326.432 |
| 6034 | Espirito Santo Basin | 13 | 3,089 | 0.02725 | 0.02746 | 0.71347 | 3.55422E-12 | 2746.007 |
| 6037 | Pelotas Basin | 14 | 2,938 | 0.02231 | 0.02252 | 0.69574 | 6.24248E-13 | 2252.391 |
| 6045 | Santa Cruz-Tarija Basin | 15 | 2,466 | 0.01807 | 0.01828 | 0.67669 | 9.90837E-14 | 1828.085 |
| 6029 | Sergipe-Alagoas Basin | 16 | 2,179 | 0.01439 | 0.01460 | 0.65597 | 1.35412E-14 | 1460.052 |
| 6059 | Magallanes Basin | 17 | 1,920 | 0.01117 | 0.01138 | 0.63304 | 1.48441E-15 | 1138.413 |
| 6107 | Lesser Antilles Deformed Belt | 18 | 1,546 | 0.00834 | 0.00856 | 0.60708 | 1.16485E-16 | 855.591 |
| 6063 | Malvinas Basin | 19 | 1,041 | 0.00584 | 0.00606 | 0.57661 | 5.32537E-18 | 605.764 |
| 6117 | Greater Antilles Deformed Belt | 20 | 790 | 0.00363 | 0.00385 | 0.53872 | 9.09721E-20 | 384.558 |
| 6083 | Progreso Basin | 21 | 412 | 0.00168 | 0.00189 | 0.48553 | 1.55798E-22 | 189.122 |
| 6103 | Tobago Trough | 22 | 20 | 0.00000 | 0.00022 | 0.36603 | 5.01621E-31 | 21.500 |
| 6022 | Foz do Amazonas Basin | 23 | NA | | | | | |

Figure 5 shows this data on a log-log plot of the cumulative number (rank) of provinces versus the size of the provinces. These data points are represented by clear triangles. Note that the data shows leftward curvature as the volumes become smaller.

Figure 5

USGS (2000) data shows endowment volumes for sample of 22 CSA provinces.




The next step is to use the VSD model to provide the best possible fit of the USGS (2000) data in Figure 5. In Equation 3, we present the VSD model as a non-linear least squares (NLS) model. In particular, the problem is:

$$\min_{\{V_x, a_p, V_S, \psi, S\}} \sum_{i=1}^{n} (V_i - \hat{V}_i)^2$$

(3)

Subject to:

$$\hat{V}_i = \frac{\left\{\left[\left(\frac{1}{N_t} - \left(\frac{V_m}{V_x}\right)^{\left(\frac{\log N_x - \log N_m}{\log V_x - \log V_m}\right)}\right)^{\frac{1}{a_p}} + \frac{V_m}{V_x}\right] \cdot V_x\right\} \times (\psi)}{(\psi) + [1-(\psi)] \cdot \left[1 - \exp\left(-\left\{\left[\left(\frac{1}{N_t} - \left(\frac{V_m}{V_x}\right)^{\left(\frac{\log N_x - \log N_m}{\log V_x - \log V_m}\right)}\right)^{\frac{1}{a_p}} + \frac{V_m}{V_x}\right] \cdot V_x\right\} \div V_s\right)\right]^S} \tag{4}$$

where:

$a_p$ - slope of straight line approximated from USGS sample points with larger province volumes (same as slope of Pareto distribution).

$N_m$ - minimum number of USGS provinces (= 1).

$N_t$ - cumulative number of provinces.

$N_x$ - maximum number of provinces.

$S$ - severity exponent that controls the steepness of the slope of the estimated VSD curve where it separates from the Pareto straight line (on the right tail of the distribution, near the largest volumes).

$V_m$ - minimum USGS province volume (BOE).

$V_s$ - approximate volume (BOE) at which the USGS data begins to deviate from the Pareto straight line (on the right tail of the distribution, near the largest volumes).

$\hat{V}_i$ - estimated volume of a province (BOE).

$V_x$ - maximum volume (BOE) given by the Pareto straight line (at $N_m$ = 1).

$\psi$ - separation ratio that controls the amount of separation between the Pareto straight line and the estimated VSD curve (on the right tail of the distribution, near the largest volumes).

As seen in Equation 3, there are five parameters being estimated in the VSD equation - $V_x$, $a_p$, $V_s$, $\psi$, and S – that cause the equation to best fit the volumes from USGS (2000). The parameters are estimated based on visual inspection of the curves, comparison of volumes, and inspection of the coefficient of determination ($R^2$). The VSD model is run on the sample of 22 provinces for which oil endowment data from USGS (2000) exists. The following estimates of the five parameters give the best fit:

Maximum volume given by Pareto straight line ($V_x$) at $N_m$ equal to 1 = 100,000 MMBOE

Pareto shape exponent ($a_p$) = 0.96

Volume of separation ($V_s$) = 50,000 MMBOE

Separation ratio ($\psi$) = 0.28

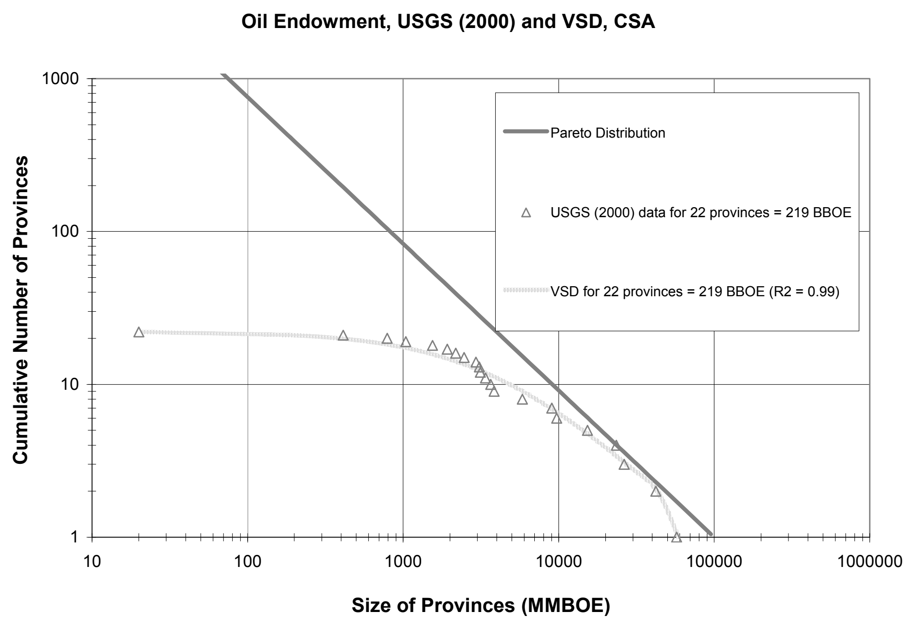
Severity exponent ($S$) = 9

### 3.4 VSD Validation

Figure 6 is the same as Figure 5, but now shows a continuous curve, which is the estimated curve generated by the VSD model, using the above parameters.

Figure 6

VSD estimate for 22 CSA provinces. USGS (2000) data shows endowment volumes for 22 CSA provinces.




Visual inspection of the USGS (2000) data points and the estimated VSD curve shows a good fit, even for the largest provinces that do not lie on the Pareto straight line. In addition, the VSD calculated oil endowment volume of 219 billion BOE, shown at the top of the ninth column ($\hat{V}_i$) in Table 1 compares well with the 219 billion BOE published in USGS (2000). This is supported mathematically by an $R^2$ coefficient of determination equal to 0.99. The good fit provides an initial validation of the VSD model. Estimated volumes ($\hat{V}_i$) generated by the VSD model for each province (presented in the ninth column of Table 1) compare favorably with the actual USGS (2000) estimates (shown in the fourth column of Table 1).

In addition, the VSD model has been further validated using the cases of (1) known oil, gas, and NGL, (2) future oil, gas, and NGL, and (3) gas and NGL endowment. In all cases, the estimated volumes are very close to the actual USGS volumes. Also, the coefficients of determination ($R^2$) are always either 0.98 or 0.99 (results other than oil endowment are not shown in this paper; for more information about these cases, see Aguilera, 2006; Aguilera et al., 2007; Aguilera et al., 2008; Aguilera et al., 2009).

### 3.5 Application of VSD to Un-assessed Provinces

Given the validations in the previous sections, the VSD model can now be used to forecast oil endowment volumes in previously unassessed CSA provinces.

The USGS has indicated that the region can be divided into 122 provinces, of which they have presented volumes for 22. Table 2 provides a list of the previously assessed and unassessed provinces in the CSA region.

Table 2

Assessed and Previously Unassessed Provinces in the CSA region

| | Region | Assessed Provinces |
|---|---|---|
| 1 | Central and South America | Maracaibo Basin |
| 2 | Central and South America | East Venezuela Basin |
| 3 | Central and South America | Campos Basin |
| 4 | Central and South America | Santos Basin |
| 5 | Central and South America | Guyana-Suriname Basin |
| 6 | Central and South America | Putumayo-Oriente-Maranon Basin |
| 7 | Central and South America | Llanos Basin |
| 8 | Central and South America | Falklands Plateau |
| 9 | Central and South America | San Jorge Basin |
| 10 | Central and South America | Neuquen Basin |
| 11 | Central and South America | Talara Basin |
| 12 | Central and South America | Middle Magdalena |
| 13 | Central and South America | Espirito Santo Basin |
| 14 | Central and South America | Pelotas Basin |
| 15 | Central and South America | Santa Cruz-Tarija Basin |
| 16 | Central and South America | Sergipe-Alagoas Basin |
| 17 | Central and South America | Magallanes Basin |
| 18 | Central and South America | Lesser Antilles Deformed Belt |
| 19 | Central and South America | Malvinas Basin |
| 20 | Central and South America | Greater Antilles Deformed Belt |
| 21 | Central and South America | Progreso Basin |
| 22 | Central and South America | Tobago Trough |

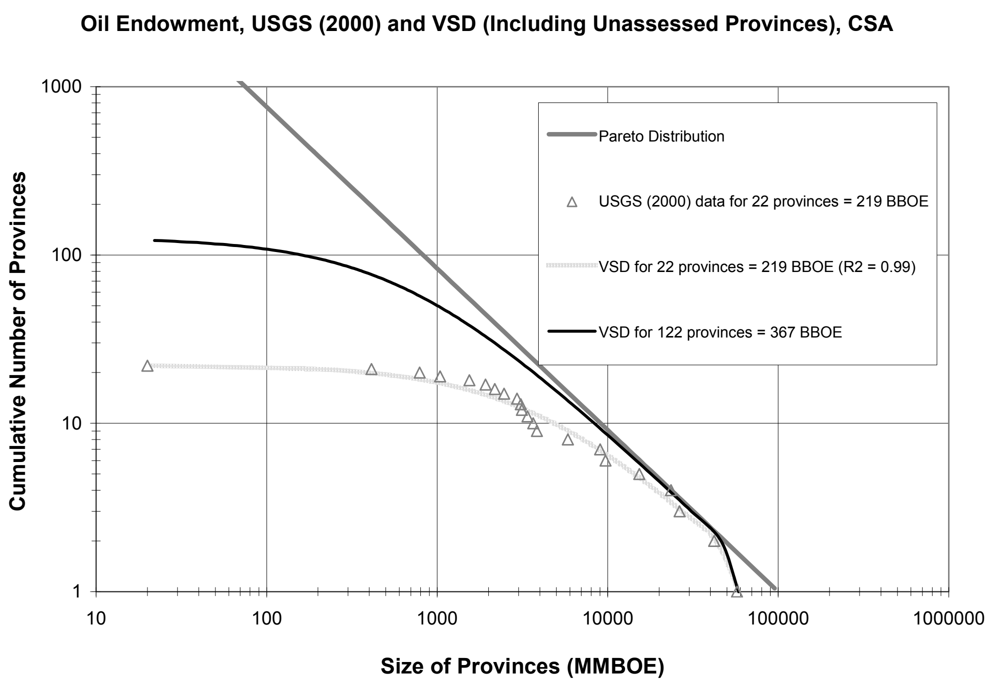
| | Region | Unassessed Provinces |
|---|---|---|
| 23 | Central and South America | Foz do Amazonas Basin |
| 24 | Central and South America | Reconcavo Basin |
| 25 | Central and South America | Cuyo Basin |
| 26 | Central and South America | Barinas-Apure Basin |
| 27 | Central and South America | Upper Magdelena |
| 28 | Central and South America | Potigar Basin |
| 29 | Central and South America | Falcon Basin |
| 30 | Central and South America | Solimoes Basin |
| 31 | Central and South America | Lower Magdelena |
| 32 | Central and South America | Oran-Olmedo Basin |
| 33 | Central and South America | Caera Basin |
| 34 | Central and South America | Guajira Basin |
| 35 | Central and South America | Central Chile Forearc Basin |
| 36 | Central and South America | Cesar Basin |
| 37 | Central and South America | Temuco Basin |
| 38 | Central and South America | Madre dos Dios Basin |
| 39 | Central and South America | Eastern Cordillera Basin |
| 40 | Central and South America | Ucayali Basin |
| 41 | Central and South America | Cariaco Basin |
| 42 | Central and South America | Bahia Sul Basin |
| 43 | Central and South America | Santana Platform |
| 44 | Central and South America | Tucano Basin |
| 45 | Central and South America | Amazonas Basin |
| 46 | Central and South America | Parana Basin |
| 47 | Central and South America | Barreieinas Basin |
| 48 | Central and South America | Altiplano Basin |
| 49 | Central and South America | Perija-Venezuela-Coastal Ranges |
| 50 | Central and South America | Tacutu Basin |
| 51 | Central and South America | Guyana Shield |
| 52 | Central and South America | Brazilian Shield |
| 53 | Central and South America | Brazilian Shield |
| 54 | Central and South America | Brazilian Shield |
| 55 | Central and South America | Andean Province |
| 56 | Central and South America | Familina Province |
| 57 | Central and South America | North Patagonia Province |
| 58 | Central and South America | Deseado Province |

| | Region | Unassessed Provinces |
|---|---|---|
| 59 | Central and South America | Sucunduri Province |
| 60 | Central and South America | Parecis Province |
| 61 | Central and South America | Xingu Province |
| 62 | Central and South America | Parnaiba Basin |
| 63 | Central and South America | Sao Francisco Basin |
| 64 | Central and South America | Diamantina Province |
| 65 | Central and South America | Araripe Province |
| 66 | Central and South America | San Luis Basin |
| 67 | Central and South America | Pernambuco Basin |
| 68 | Central and South America | Jatoba Basin |
| 69 | Central and South America | Santiago Basin |
| 70 | Central and South America | Huallaga Basin |
| 71 | Central and South America | Acre Basin |
| 72 | Central and South America | Beni Basin |
| 73 | Central and South America | Chaco Basin |
| 74 | Central and South America | Bolsones Basin |
| 75 | Central and South America | Bermejo Basin |
| 76 | Central and South America | Mascasin Basin |
| 77 | Central and South America | Mercedes Basin |
| 78 | Central and South America | Laboulaye-Macachin Basin |
| 79 | Central and South America | Salado Basin |
| 80 | Central and South America | Nirihuau Basin |
| 81 | Central and South America | Colorado Basin |
| 82 | Central and South America | East Patagonia Basin |
| 83 | Central and South America | Malvinas Plateau |
| 84 | Central and South America | Malvinas Trough |
| 85 | Central and South America | Moquegua-Tamaruga Basin |
| 86 | Central and South America | Salar de Atacama Basin |
| 87 | Central and South America | Curico Basin |
| 88 | Central and South America | Osorno-Llanquihue Basin |
| 89 | Central and South America | Diego Ramirez Basin |
| 90 | Central and South America | Madre de Dios Basin |
| 91 | Central and South America | Penas Basin |
| 92 | Central and South America | Mollendo-Tarapaca Basin |
| 93 | Central and South America | Pisco Basin |
| 94 | Central and South America | Lima Basin |
| 95 | Central and South America | Salaverry Basin |
| 96 | Central and South America | Trujillo Basin |
| 97 | Central and South America | Sechura Basin |
| 98 | Central and South America | Lancones Basin |
| 99 | Central and South America | Manabi Basin |
| 100 | Central and South America | Borbon Basin |
| 101 | Central and South America | Cauca Basin |
| 102 | Central and South America | Choco Pacific Basin |
| 103 | Central and South America | Pacific Offshore Basin |
| 104 | Central and South America | Bonaire Basin |
| 105 | Central and South America | South Caribbean Deformed Belt |
| 106 | Central and South America | Sierra Nevada de Santa Marta |
| 107 | Central and South America | West-Central Cordillera |
| 108 | Central and South America | Neogene Volcanic Belt |
| 109 | Central and South America | Aves Ridge |
| 110 | Central and South America | Venezuela Basin |
| 111 | Central and South America | Beata Ridge |
| 112 | Central and South America | Columbian Basin |
| 113 | Central and South America | Middle America Province |
| 114 | Central and South America | North Nicaraguan Rise |
| 115 | Central and South America | South Nicaraguan Rise |
| 116 | Central and South America | Puerto Rico Trench |
| 117 | Central and South America | Bahama Platform |
| 118 | Central and South America | Cayman Trough |
| 119 | Central and South America | Cayman Ridge |
| 120 | Central and South America | Chiapas Massif-Nuclear Central America |
| 121 | Central and South America | Yucatan Basin |
| 122 | Central and South America | Maya Mountains |

The estimated VSD curve for all 122 provinces is shown in Figure 7. The total oil endowment volume is calculated to be 367 billion BOE. Again, the same control parameters as before have been used to generate the curve and volumetric estimates. The only change is the number of provinces being evaluated, equal to 122. The estimate of 367 billion BOE cannot be compared with any volumes estimated by the USGS or other organizations, since all 122 provinces have not been previously assessed. However, given the validations discussed earlier (and the validations in Aguilera, 2006; Aguilera et al., 2007; Aguilera et al., 2008; Aguilera et al. 2009), one can have confidence that the estimate is reasonable.

Figure 7

VSD estimate for 122 CSA provinces (including unassessed provinces).




While the VSD model provides volumes for all 122 provinces, it does not indicate which volumes correspond to which provinces. As Table 3 shows, we have allocated the volumes from assessed and unassessed provinces among CSA countries on the basis of each country's share of proved reserves (BP, 2008).

The largest volumes are allocated to Venezuela, which accounts for about three quarters of the oil endowment volumes.

Table 3

Allocation by Country of CSA Oil Endowment Volumes

Oil Endowment from VSD model for 122 Provinces (BBOE) = **367**

| Region | Oil Proved Reserves (BBOE) *(Source: BP 2008)* | % of Total | Oil Endmt from VSD Model (BBOE) | Oil Endmt plus Reserve Growth (BBOE) |
|---|---|---|---|---|
| Argentina | 2.6 | 2.3 | 8.5 | 12.2 |
| Brazil | 12.6 | 11.4 | 41.7 | 59.6 |
| Colombia | 1.5 | 1.4 | 5.0 | 7.1 |
| Ecuador | 4.3 | 3.8 | 14.1 | 20.1 |
| Peru | 1.1 | 1.0 | 3.6 | 5.2 |
| Trinidad & Tobago | 0.8 | 0.7 | 2.6 | 3.7 |
| Venezuela | 87.0 | 78.3 | 287.2 | 410.6 |
| Other Cent. & S. America | 1.3 | 1.2 | 4.3 | 6.1 |
| **TOTAL** | **111.2** | **100.0** | **367.0** | **524.7** |

## 4. Reserve Growth

Reserve growth is a factor defined by the USGS as the increase in reserves of a previously discovered field through time.

Reserve growth provides a very significant increase to oil, gas and NGL volumes. The ‘pessimists’, for various reasons, do not generally give consideration to reserve growth. However, in spite of the complexity of estimating reserve growth, it is essential to account for this factor when assessing the availability of oil volumes.

Reserve growth, as classified by the USGS, applies to ‘known’ volumes (cumulative production plus remaining reserves). In this study, reserve growth also applies to endowment volumes. It is estimated by calculating a percentage for reserve growth, based on ‘known’ volumes from USGS (2000), and applying it to estimated oil endowment volumes of both assessed and unassessed provinces.

We have calculated reserve growth percentages using values from Table 4. In the ‘world total’ section, for instance, we calculate the reserve growth percentage of known oil, which amounts to 42.97%. This comes from dividing reserve growth (688 BBOE) by the summation of cumulative production plus remaining reserves (710 BBOE + 891 BBOE).

Table 4

Calculation of Reserve Growth Percentages - based on data from USGS (2000)

| | Mean Oil (Billion barrels) | Mean Gas (BBOE) | Mean NGL (Billion barrels) | Total Mean Petroleum (Billion barrels) |
|---|---|---|---|---|
| **World (excluding USA)** | | | | |
| Undiscovered conventional | 649 | 778 | 207 | 1634 |
| Reserve growth (conventional) | 612 | 551 | 42 | 1205 |
| Remaining reserves | 859 | 770 | 68 | 1697 |
| Cumulative production | 539 | 150 | 7 | 696 |
| **Total** | **2659** | **2249** | **324** | **5232** |
| Known volumes | 1398 | 920 | 75 | 2393 |
| **Reserve growth based on known volumes (%)** | **43.78** | **59.89** | **56.00** | **50.36** |

| | Mean Oil (Billion barrels) | Mean Gas (BBOE) | Mean NGL (Billion barrels) | Total Mean Petroleum (Billion barrels) |
|---|---|---|---|---|
| **USA** | | | | |
| Undiscovered conventional | 83 | 88 | combined with oil | 171 |
| Reserve growth (conventional) | 76 | 59 | combined with oil | 135 |
| Remaining reserves | 32 | 29 | combined with oil | 61 |
| Cumulative production | 171 | 142 | combined with oil | 313 |
| **Total** | **362** | **318** | combined with oil | **680** |
| Known volumes | 203 | 171 | combined with oil | 374 |
| **Reserve growth based on known volumes (%)** | **37.44** | **34.50** | **combined with oil** | **36.10** |

| | Mean Oil (Billion barrels) | Mean Gas (BBOE) | Mean NGL (Billion barrels) | Total Mean Petroleum (Billion barrels) |
|---|---|---|---|---|
| **World Total** | | | | |
| Undiscovered conventional | 732 | 866 | 207 | 1805 |
| Reserve growth (conventional) | 688 | 610 | 42 | 1340 |
| Remaining reserves | 891 | 799 | 68 | 1758 |
| Cumulative production | 710 | 292 | 7 | 1009 |
| **Total** | **3021** | **2567** | **324** | **5912** |
| Known volumes | 1601 | 1091 | 75 | 2767 |
| **Reserve growth based on known volumes (%)** | **42.97** | **55.91** | **56.00** | **48.43** |

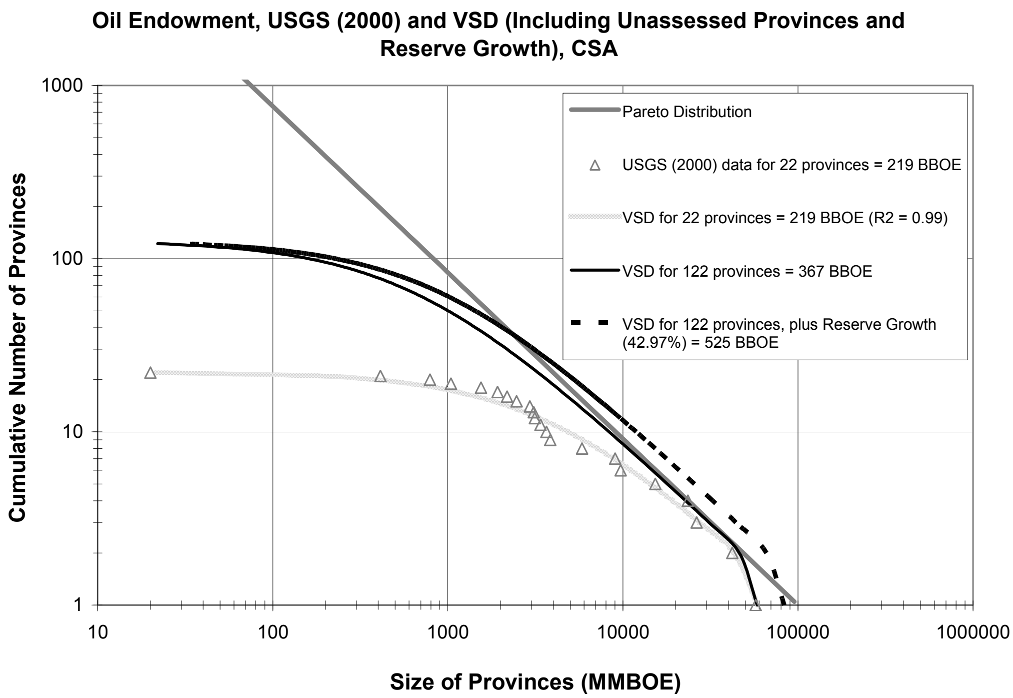
## 4.1 Discussion of Application

The calculated percentages of reserve growth are used in the estimation of endowment volumes plus reserve growth of both the previously assessed and unassessed provinces. The basic assumption in the application of reserve growth is that the reserve growth percentages based on known volumes will be the same for endowment volumes. The ranking of endowment volumes plus reserve growth, by size, will be the same as the ranking of the endowment volumes without reserve growth.

The estimated VSD curve for oil endowment plus reserve growth (42.97%), for 122 provinces, is presented in Figure 8. This figure is same as Figure 7, with the only difference being the addition of the ‘oil endowment plus reserve growth’ curve. It lies to the right of the original curve showing the VSD estimate of 122 provinces without reserve growth. It shows that at each province, each volume is now 42.97% greater than the original estimate. In other words, the original curve has been shifted to the right by 42.97%. The estimated oil endowment volume plus reserve growth, for 122 provinces, is 525 billion BOE.

Figure 8

VSD estimate for 122 CSA provinces (including unassessed provinces and reserve growth).




5. Cumulative Supply Curves

Figure 9 shows cumulative supply curves for conventional oil in the CSA region that are constructed using the data presented in Table 5. They are constructed by graphing the volumes, by country, that can be produced economically at various average costs of production. The grey curve represents oil volumes without reserve growth and shows a volume of 367 BBOE. The data for the production costs come from various sources (see Table 5). For some countries, various production costs are given. External costs, it is important to note, are not considered, largely because there is no consensus on what these costs are.

Figure 9

Cumulative Long-Run Supply Curves for CSA Conventional Oil

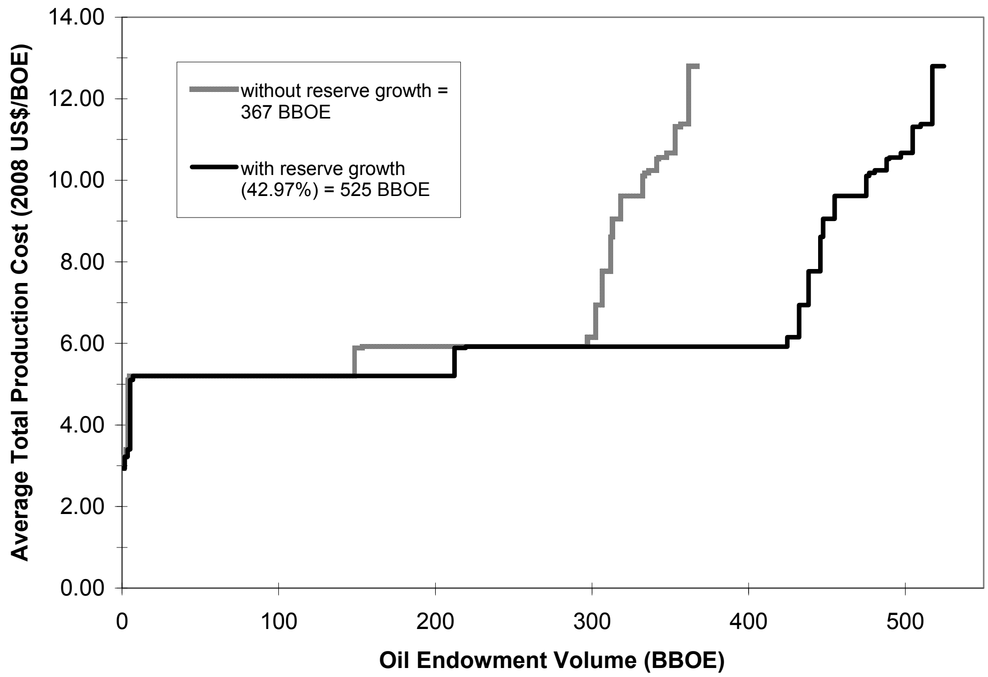



Figure 9 also shows a supply curve that takes into account estimated reserve growth. As can be seen, this curve reflects the same costs as in the grey curve (which does not consider reserve growth), but each block or step now represents a larger volume, due to the expected reserve growth. Incorporating reserve growth increases volumes for oil to 525 BBOE.

Table 5

Oil Endowment Volumes and Average Production Costs by Country

| 1 | 2 | 3 | 4 | 5 | 6 |
|---|---|---|---|---|---|
| **Location** | **Oil Endowment (BBOE)** | **Oil Endmt plus Future Reserve Growth (BBOE)**<br><br>**Oil Growth = 42.97%** | **Average Capital Cost (2008US$/BOE)** | **Average Operating Cost (2008US$/BOE)** | **Average Total Production Cost (2008US$/BOE)** |
| Argentina | **8.5** | **12.2** | 0.27 | 2.67 | **2.93** |
| | | | 1.12 | 2.10 | **3.22** |
| | | | 0.92 | 2.48 | **3.40** |
| | | | 2.48 | 2.63 | **5.11** |
| | | | 3.74 | 4.86 | **8.61** |
| | | | - | - | **10.11** |
| | | | 3.96 | 6.56 | **10.52** |
| Brazil | **41.7** | **59.6** | 2.55 | 3.60 | **6.15** |
| | | | - | - | **7.77** |
| | | | 4.53 | 4.53 | **9.05** |
| | | | - | - | **10.24** |
| | | | 6.64 | 3.92 | **10.55** |
| | | | 6.08 | 4.59 | **10.67** |
| | | | 7.41 | 3.97 | **11.38** |
| | | | 7.04 | 5.76 | **12.80** |
| Colombia | **5.0** | **7.1** | 2.77 | 3.12 | **5.89** |
| Ecuador | **14.1** | **20.2** | 4.53 | 5.09 | **9.62** |
| Peru | **3.6** | **5.1** | 4.53 | 6.79 | **11.31** |
| Trinidad & Tobago | **2.6** | **3.7** | 3.39 | 6.79 | **10.18** |
| Venezuela | **287.2** | **410.6** | 1.36 | 3.85 | **5.20** |
| | | | 2.96 | 2.96 | **5.92** |
| Other CSA | **4.3** | **6.1** | - | - | **6.94** |
| | | | | | |
| **TOTAL OIL ENDOWMENT VOLUME (BBOE):** | **367** | **525** | | | |

**Sources**
Compania Espanola de Petroleos Sociedad Anonima, CEPSA (2005)
United States Geological Survey (2000)
Variable Shape Distribution (VSD) model
Wood Mackenzie (2004-2006)

## 6. Life Expectancies

The life expectancies for any particular energy resource depends on three factors—its future volumes, its current production, and the growth over time of its production.[25] Table 6 reports life expectancies for CSA conventional oil. The rows indicate how many years the future volumes for these resources would last assuming production grows in the future at 0%, 2% or 4% a year. The table

[25] Future volumes are equal to endowment volumes minus cumulative production. Thus, CSA cumulative production of 64 BBOE (presented in USGS, 2000) is subtracted from the CSA endowment volumes presented earlier, resulting in the following future volumes:

From USGS (2000): 219 BBOE – 64 BBOE = 155 BBOE
Including Unasessed Provinces: 367 BBOE – 64 BBOE = 303 BBOE
Including Unassessed Provinces and Future Reserve Growth: 525BBOE – 64 BBOE = 461 BBOE

indicates that with production growth of 2% a year (which has been the CSA average annual growth in production over the past several decades) future volumes from previously assessed provinces assuming no reserve growth would last for 41 years. Adding in future volumes from unassessed provinces increases this figure to 62 years and considering reserve growth pushes it to 78 years.

Table 6

Life Expectancies

| 1 | 2 | 3 | | | | 5 |
|---|---|---|---|---|---|---|
| **CSA Conventional Oil** | **CSA Future Volumes (BOE)** | **2005-2007 CSA [a] Average Annual Production (BOE)** | **Life Expectancy in Years, at Various [b] Growth Rates in Production** | | | **CSA Average Annual [c] Growth in Production, 1977-2007 (%)** |
| | | | **0%** | **2%** | **4%** | |
| From USGS (2000) | 1.55E+11 | | **63** | **41** | **31** | |
| Including Unassessed Provinces | 3.03E+11 | 2.48E+09 | **122** | **62** | **44** | 2.01 |
| Including Unassessed Provinces and Reserve Growth | 4.61E+11 | | **186** | **78** | **53** | |

Notes:
a. Average annual production comes from British Petroleum (2008)
b. Life expectancies estimated by this study
c. Average annual growth in production calculated from British Petroleum (2008)

## 7. Conclusion

The Variable Shape Distribution (VSD), a size distribution model, is unique in that it allows actual oil resource data to determine the relation between the size and number of provinces. In the past, all methods were based on an assumed form of the size distribution of resources.

The VSD model is estimated and validated using data from USGS (2000). The study presents CSA volumes for 22 provinces out of a total of 122, so there are 100 provinces left unassessed. Given the validations of the VSD demonstrated in this paper (and in Aguilera, 2006; Aguilera et al., 2007; Aguilera et al., 2008; Aguilera et al., 2009), the model can be used to evaluate reasonable endowment volumes of all 122 provinces of the CSA region.

For the case of oil endowment – which is used as an illustrative example in this analysis – the VSD estimates a total of 367 billion BOE in 122 provinces. If reserve growth is accounted for, the oil endowment volume increases to 525 billion BOE.

Thus, the quantity of available conventional oil in CSA is greater than commonly assumed, since there is a tendency to overlook unassessed provinces and reserve growth. An important implication is that CSA conventional oil is likely to last far longer than some concerned experts claim. In addition, the costs of production are lower than current oil prices, and substantially lower than mid-2008 prices.

## 8. References

Adelman, M.A., J.C. Houghton, G.M. Kaufman and M.B. Zimmerman (1983), *Energy Resources in an Uncertain Future: Coal, Gas, Oil, and Uranium Supply Forecasting*, Cambridge, MA: Ballinger Publishing Company.

Aguilera, R.F. (2006), "Assessing the Long Run Availability of Global Fossil Energy Resources", PhD Dissertation, Colorado School of Mines, Golden, CO.

Aguilera, R.F., E.B. Balistreri and J.C. Cuddington (2007), "Assessing Previously

Unassessed Petroleum Provinces using the Variable Shape Distribution (VSD) Model." Working Paper, Colorado School of Mines and Pontificia Universidad Catolica de Chile. Also, submitted for possible presentation to the American Association of Petroleum Geologists (AAPG) Annual Convention and Exhibition in Denver, Colorado, USA, June 7-10, 2009.

Aguilera, R. F., T. Harding, F.Krause and R. Aguilera (2008), "Natural Gas Production from Tight Formations: A Global Perspective." Presented at the *19th World Petroleum Congress* in Madrid, Spain, June 29-July 3.

Aguilera, R.F., Eggert, R.G., Lagos, G., and Tilton, J.E. (2009), "Depletion and the Future Availability of Petroleum Resources", Energy Journal 30 (1): 161-194.

Barton, C.C. (1995), "A New Approach to Estimating Hydrocarbon Resources",

United States Geological Survey Fact Sheet,

http://energy.usgs.gov/factsheets/HydroRes/estimat.html

Barton, C.C. and Scholz, C.H. (1995), "The Fractal Size and Spatial Distribution of Hydrocarbon Accumulations", *Fractals in Petroleum Geology and Earth Processes*. Edited by Barton, C.C. and LaPointe, P.R. New York: Plenum Press.

British Petroleum (2008), *Statistical Review of World Energy 2008*, London: British Petroleum.

Compañía Española de Petróleo Sociedad Anónima – CEPSA (2005). Personal

Communication with H. Quiroga.

Drew, L. J. (1997), Undiscovered Petroleum and Mineral Resources, Assessment and Controversy, New York and London: Plenum Press.

Kaufman, G. M. (1962), Statistical Decision and Related Techniques in Oil and

*Gas Exploration*, Englewood Cliffs, NJ: Prentice-Hall.

Mandelbrot, B. B. (1982), *The Fractal Geometry of Nature*, San Francisco, CA: Freeman.

Minerals Management Service (1996), An Assessment of the Undiscovered Hydrocarbon Potential of the Nation´s Outer Continental Shelf, Report MMS 96-0034.

United States Geological Survey (1995), *National Oil and Gas Assessment*, CD-ROM.

United States Geological Survey (2000), *World Petroleum Assessment*, CD-ROM.

Wood Mackenzie (2004-2006), Upstream Asset Analysis Reports.

# 7. The Impact of Biofuels on Western Hemisphere Energy security

**Amy Myers Jaffe And Ronald Soligo**[26]

In the search for energy security and a sustainable, environmentally friendly fuel, biofuels are considered the low hanging fruit of alternative energy. Brazil has pioneered the use of sugarcane-based ethanol as a transportation fuel producing 16.3 billion liters (4.3 billion US gallons) in 2006. The Brazilian automobile industry has adapted with 72% of automobiles manufactured (including exports) in 2007 being flexfuel vehicles. Petrobras forecasts output for 2020 to rise to 46 billion liters (12 billion gallons), of which 16.5 million liters (4.3 billion gallons) will be exported.

The United States has an increasing need for ethanol as a gasoline additive and supplemental fuel. The U.S. Energy Bill of 2005 required 7.5 billion gallons of renewable fuel to be produced annually in the United States by 2012. The *Energy Independence and Security Act of 2007* increased the Renewable Fuels Standard (RFS) to require nine billion gallons of renewable fuels to be consumed annually by 2008 and progressively increase to a 36-billion gallon renewable fuels annual target by 2022. But questions remain whether the US can meet these ambitious targets and whether continued growth in US corn-based ethanol will have deleterious impacts on global food markets and local environmental protection in the Mississippi basin.

This paper will investigate whether the US would be better advised to meet its growing ethanol needs with imported ethanol from Latin America. Imported ethanol, which totaled only 450 million gallons in 2007, could play an important role in meeting US consumption targets but is currently blocked by complicated US tariff and quota rules as well as economic sanctions against Cuba.

[26] Wallace S. Wilson Fellow for Energy Studies, James A Baker III Institute for Public Policy, and Department of Economics, Rice University, 6100 Main Street, Houston, TX 77005, USA.

This paper investigates the long-term potential for the development of ethanol supplies in the Western hemisphere and discusses the impact of current US trade policies in the Western Hemisphere on the emergence of these supplies. Countries in the Caribbean, Central America and the Andean region of South America all have potential to develop a vibrant ethanol industry based on sugarcane. Preliminary work suggests that Cuba alone could produce up to 2 billion gallons per year if its sugar industry could be restored. This paper will look at the possibility for the lifting of US trade sanctions and the impact it could have on the development of Cuba's ethanol industry. This paper will also attempt some estimates of the potential ethanol sugarcane-based production in the Western Hemisphere and the relative economics of US domestic ethanol versus imported suppliers. The authors will also look at how ethanol markets are likely to develop and discuss the contribution that ethanol can make to energy supply diversity and security in the Hemisphere. Latin America also has the potential to produce other biofuels – especially biodiesel. This potential will also be discussed.

Flexibility as a source of value in the production of alternative fuels: The ethanol case

Carlos Bastian-Pinto[a], Luiz Brandão [a], Warren J. Hahn[b],

[a] Pontifícia Universidade Católica, Rua Marques de São Vicente, 225 – Gávea, Rio de Janeiro, Brazil, tel +55 21 21389304, carlos@bastian.com .

[b] Pepperdine University, 24217 Baxter Drive, Malibu, California 90265, USA

Keywords: Commodity price models, Option valuation, Renewable fuels

Abstract: There is typically a high degree of flexibility associated with the production of alternative fuels due to the ability to source from different input raw materials or to produce different output products based on market conditions. In this paper, we consider the particular example of ethanol and seek to quantify the incremental value from flexibility in its production from sugarcane in Brazil. We accomplish this by first jointly modeling the stochastic processes for the prices of the two relevant commodities, sugar (a food commodity) and ethanol (an energy commodity) in discrete time as a bivariate lattice. This framework allows us to value the option to switch output products based on the respective price signals of the two commodities. However, unlike the usual assumption of geometric Brownian motion stochastic processes, we use the more realistic case of mean reverting commodity price processes. We estimate the parameters for these processes by applying a regression-based procedure to empirical sugar and ethanol data collected during a period from 1998 through 2007. Our modeling results show that the option to switch outputs has significant value, even under the assumption of mean reverting prices, which has implications for both producers and policy-makers alike.

## Introduction

With the recent rise in oil prices, eventual long term exhaustion of world oil reserves and projected growth in demand for energy in the coming years, alternative sources of renewable energy have become increasingly sought after. One alternative which has gained widespread acceptance in Brazil is sugar cane based ethanol automotive fuel. Development of this market began in the early 1980's, driven by the government's "pro-álcool" program which included production subsidies and a mandatory mix of 20% ethanol to all fuel. After two decades and several initial setbacks, the state subsidies have now been removed and productive capacity has increased dramatically. On the consumption side, the majority of all new auto sales are now flex fuel cars, which can run on any mix of gas and ethanol. As a result, Brazil presently ranks second in the world in terms of total use of bio-fuels, with ethanol currently accounting for 45% of total small vehicle fuel consumption (UNCTAD, 2007; UNICA, 2007).

The main source of ethanol in Brazil is sugar cane, which previously was almost entirely grown to produce sugar, another commodity in which Brazil is a leading world player. Currently, ethanol is also rapidly gaining commodity status in the larger world market. According to the Renewable Fuels Association (RFA, 2007), the largest ethanol producers in 2005 were the United States with 4,265 million gallons, Brazil with 4,227 million gallons, China with 1,004 million gallons, and India with 449 million gallons.

Brazil's ethanol production industry is supported by sugar cane based ethanol's cost advantage relative to corn based ethanol, which is the main source of US production and which is heavily dependent on government subsidies. Many Brazilian sugar cane processors have invested in flexible plants that can produce either sugar or ethanol, since sugar cane can be transformed into sugar in a process that produces a small quantity of ethanol as a byproduct, or processed in an ethanol distillation process to produce ethanol exclusively. Although such plants require a larger up front investment, it appears that the potential for option value is intuitively considered by processors, as most plants currently under construction in Brazil are flexible (sugar/ethanol) facilities.

To value the switching option that is available to the processors, prices of both commodities must be modeled using a joint method that can capture the correlation between the price movements of each commodity. Approaches based on the bivariate lattice introduced by Boyle (1988) for modeling dual geometric Brownian motion (GBM) price processes have been used to value these types of options, however, as noted by Schwartz (1997) and others, prices of most commodities are best modeled by mean reverting processes, and this applies in the case of sugar and ethanol as well.

This paper's main objective is to apply a discrete time lattice based methodology for modeling mean reverting stochastic processes in order to quantify the incremental value due to a flexible production process. We begin the paper with a description of the sugar-ethanol production setting in Brazil in Section 2. Section 3 outlines a bivariate lattice approach to modeling mean reverting stochastic commodity price processes, and Section 4 follows with the empirical data analysis and stochastic process parameter specification, as well as the option value modeling assumptions and methodology utilized. In Section 5 we present our modeling results and compare them to both the results from a simulation model and the results when GBM stochastic processes are used to model the commodity prices. We conclude in Section 6 with a summary of findings and implications.

The Brazilian sugar/ethanol industry

The ethanol production industry in Brazil today runs without the benefit of government subsidy, and Brazilian sugar cane based ethanol has become by far the world's most competitive bio-fuel (Goldemberg, 2007). Approximately 5.8 million hectares (ha) are currently being used to grow sugar cane in Brazil, of which about 2.9 million hectares are directed for ethanol production (Szwarc, 2006). This number is somewhat variable, due to switching between ethanol and sugar production. Each ha planted with sugar cane can produce approximately 6,800 liters[27] of ethanol.

Sugar-Ethanol producing companies in Brazil are responsible for the processing of sugar cane into the two products. It is both an agricultural and industrial endeavor that includes choosing sugar cane varieties, planting and harvesting at the appropriate time, processing and storage. Industrial investments can either be done directly in a flexible plant (capable of producing sugar, ethanol or both) or in a single product facility (sugar or ethanol), which can later be retrofitted to produce the complementary product.

Sugar cane processing plants are highly energy efficient, since the massive bagasse and straw volumes generated by cane processing are used as fuel for the furnaces that generate the steam necessary for the process. These furnaces typically also generate surplus electrical power which is sold to local power companies. As a result, the energy efficiency ratio (energy output divided by energy input) for sugarcane ethanol production is 8.3, which compares favorably to the ratios for the other major ethanol feedstock (Szwarc, 2006).

A relatively efficient sugar plant can currently produce 107 kg (235 lb)[28] out of every metric ton of sugar cane processed, along with some syrup byproduct

---

[27] 1 gallon = 3.79 liters
[28] 1 kg = 2.2 lb

which can be converted to 12 liters of ethanol (3.17 gal). The same ton of sugar cane, if processed in an ethanol plant, will produce 80 liters of ethanol (21.14 gal), which is an increase of approximately 14% from 1980s levels, due to productivity gains. Thus, the mass balance for processing one ton of sugar cane is:

1 ton sugar cane = 107 kg sugar + 12 liters ethanol = 80 liters ethanol (1)

With this parity defined, and given the price signals for the two output commodities, processors can decide which mix of products they will output for every crop without switching cost once the industrial investment on a flexible plant has been made.

Stochastic modeling of ethanol and sugar prices

The discrete binomial lattice approach developed by Cox et al. (1979) for modeling the stochastic process of an underlying asset and valuing contingent options has found widespread application, since it generalizes the Black-Sholes-Merton model (1973) and addresses some of that model's restrictions. It is simple to implement, flexible to use, depends on a limited number of parameters, and converges weakly to a GBM as the time interval diminishes. However, there are instances when the underlying prices modeled do not follow a stochastic process similar to a GBM. A common example is the market price of many types of commodities, which may instead follow a mean reverting stochastic process.

Mean reverting processes are a type of Markov process where the sign and degree of the drift are dependent on the current level of a variable, which reverts to a long-term equilibrium level that we typically assume is the long-term mean. Unfortunately, relative to a GBM, a mean reverting process is more complicated to approximate with a probability lattice with binomial chance nodes. As a result, methods employing Monte Carlo simulation and discrete trinomial trees (Hull, 1999) have been developed for modeling mean reverting processes. Unfortunately both methods have drawbacks when used for valuation; simulation-based approaches are computationally intensive, especially for problems with multiple concurrent options, and trinomial trees are more difficult to implement because they require involved methodologies for specifying valid branching probabilities and lattice cell sizes to ensure convergence to the stochastic process.

The simplest form of mean reverting process is the one factor Ornstein-Uhlenbeck process, also called an Arithmetic mean reverting process, which has the form shown in Eq. (2):

$$dY_t = \eta\left(\bar{Y} - Y_t\right)dt + \sigma dz_t \tag{2}$$

For commodity price modeling, in Eq. (2) $Y_t$ is the log of price, η is the mean reversion coefficient, $\overline{Y}$ is the log of the long term mean price, *σ* is the process volatility and *dz* is a Weiner process. The log of price is commonly used since it is generally assumed that commodity prices are lognormally distributed[29]. This is convenient, because if *Y = log(y)*, then *y* cannot be negative. The expected value and variance of the Ornstein-Uhlenbeck process are given by Eq. (3) and (4):

$$E[Y_t] = \overline{Y} + \left(Y_0 - \overline{Y}\right)e^{-\eta T} \tag{3}$$

$$Var[Y_t] = \frac{\sigma^2}{2\eta}\left(1 - e^{-2\eta T}\right) \tag{4}$$

These expressions show that when $T \to \infty$, then $VAR[Y_t] \to \frac{\sigma^2}{2\eta}$, as opposed to $\infty$, as is the case with a GBM. Other variations of mean reverting processes include the Geometric Mean Reverting model (Dixit and Pindick, 1994), given by $dY_t / Y_t = \eta\left(\overline{Y} - Y_t\right)dt + \sigma dz_t$, and a similar model proposed by Battacharya (1978), which is given by $dY_t = \eta\left(\overline{Y} - Y_t\right)dt + \sigma Y_t dz_t$. The logic of a mean reverting process comes from micro-economics; when prices are low (or below their long-term mean), demand for the product tends to rise while its production tends to diminish. This is because the consumption of a commodity with low prices will typically increase, while the lower revenues for the producing firms will lead them to postpone investments and cease production, reducing the availability of the commodity. The opposite will happen if prices are high (or above their long term-mean). Empirical studies such as Pindyck and Rubinfeld (1991) have confirmed that prices of many commodities follow mean reverting stochastic processes. In the case of oil price modeling, Dias (2005) provides a survey of the different stochastic processes that have been used, most of which have a mean reverting component (Table 1).

Table 1 Classes of models used for oil price

| Type of Stochastic Model | Name of Model | Main References |
|---|---|---|
| Unpredictable Model | Geometric Brownian Motion (GBM) | Paddock, Siegel & Smith (1988) |

---

[29] See Appendix 1 for the relationship between the processes for Price and Log(Price)

| | | |
|---|---|---|
| Predictable Model | Pure Mean Reverting Model (Mean reverting process) | Schwartz (1997, model 1) |
| More Robust Models | Two and Three Factor Model | Gibson & Schwartz (1990), and Schwartz (1997, models 2 & 3) |
| | Reversion to Uncertain Long-Run Level | Pindick (1999) and Baker, Mayfield & Parsons (1998) |
| | Mean Reversion with Jumps | Dias & Rocha (1999) |

The applicability of these processes to different types of problems is a complicated issue. Although the GBM is extensively used to model a wide range of uncertain variables and offers great ease of use, mean reverting processes are generally considered better-suited to model commodities prices and interest rates. On the other hand, we note that it may still be possible and appropriate to use GBM models in such cases as short duration price series. Another issue is that single factor pure mean reverting models (Ornstein-Uhlenbeck processes) with a fixed long-term equilibrium level can be too simplistic in some instances, and might not perform any better than a GBM model. In such cases, the best approach might be to combine a mean reverting model with a GBM for the equilibrium level, as proposed by Schwartz and Smith (2000), although such process are more difficult to implement for valuation purposes.

Binomial approximation to mean reverting processes

Nelson and Ramaswamy (1990) developed a general approach for discrete time approximations of stochastic processes which is applicable to mean reverting Ornstein-Uhlenbeck processes. Their approach is a simple binomial sequence of *n* periods of length $\Delta t$ with a time horizon $T = n\Delta t$ that models the general form stochastic differential equation $dY = \mu(Y,t)dt + \sigma(Y,t)dz$ as:

$Y_t^+ \equiv Y + \sqrt{\Delta t}\sigma(Y,t)$ (up move) (5a)

$Y_t^- \equiv Y - \sqrt{\Delta t}\sigma(Y,t)$ (down move) (5b)

$q_t \equiv 1/2 + 1/2\sqrt{\Delta t}\dfrac{\mu(Y,t)}{\sigma(Y,t)}$ (probability of up move) (5c)

$1-q_t$ (probability of down move) (5d)

Substituting in the Ornstein-Uhlenbeck parameters from Eq. (2) into Eq. (5a-d) yields:

$$Y_t^+ \equiv Y + \sqrt{\Delta t}\sigma \qquad \text{(up move)} \qquad (6a)$$

$$Y_t^- \equiv Y - \sqrt{\Delta t}\sigma \qquad \text{(down move)} \qquad (6b)$$

$$q_t \equiv 1/2 + 1/2\sqrt{\Delta t}\,\frac{\eta\left(\overline{Y} - Y_t\right)}{\sigma} \qquad \text{(probability of up move)} \qquad (6c)$$

$$1\text{-}q_t \qquad \text{(probability of down move)} \qquad (6d)$$

Since the calculated probabilities cannot be negative or greater than 1, it is necessary to censor the values of $q_t$ to the range between 0 and 1, as shown in Eq. (7):

$$q_t = \begin{cases} 1/2 + 1/2\eta\left(\overline{Y} - Y_t\right)\sqrt{\Delta t}/\sigma & 0 \le q_t \le 1 \\ 0 & q_t \le 0 \\ 1 & q_t \ge 1 \end{cases} \qquad (7)$$

This can be summarized in the following nested formula:

$$q_t = \max\left(0, \min\left(1, 1/2 + 1/2\sqrt{\Delta t}\,\frac{\eta\left(\overline{Y} - Y_t\right)}{\sigma}\right)\right). \qquad (8)$$

In the branching of the binomial lattice, the up and down state space increments are $\Delta Y^+ = \sigma\sqrt{\Delta t}$ and $\Delta Y^- = -\sigma\sqrt{\Delta t}$, respectively. If *Y* is the log of the price *y*, then the increments are $\Delta y^+ = e^{\sigma\sqrt{\Delta t}}$ and $\Delta y^- = e^{-\sigma\sqrt{\Delta t}}$. These are the familiar forms utilized in the GBM lattice modeling, and result in a binomial value lattice similar to the one obtained from a GBM (Cox et al., 1979). The calculated probabilities and censoring of these probabilities will yield a model that converges weakly to a mean reverting process, as was shown by Nelson and Ramaswamy (1990). It is important to note that at each node of the lattice, the probability of an up move ($q_t$) will change depending on $Y_t$ according to Eq. (8), which is what allows the mean reverting behavior to be modeled.

Converting to a risk neutral process

There are two ways of discounting cash flows for the purpose of valuation: 1) directly using the risk adjusted rate and 2) using a Martingale probability measure with the risk-free rate. The second approach is typically used in valuing options because it is difficult to determine the appropriate risk-adjusted rate when real options are present.

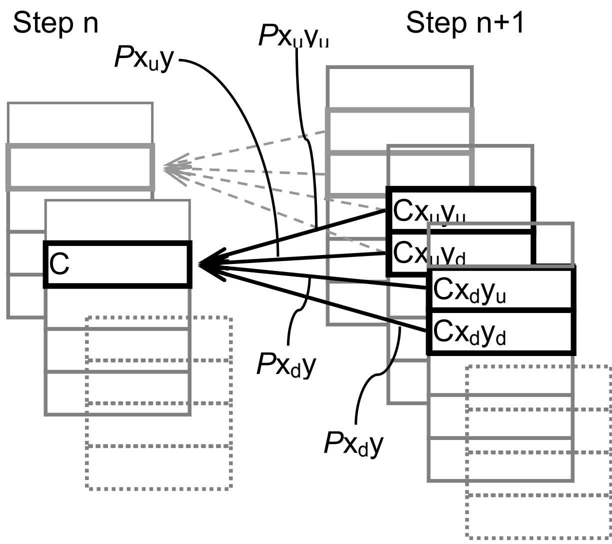
In the Martingale probability approach, the stochastic process used for the value of the underlying asset is adjusted according to the risk level so that future payoffs can be discounted at the risk free rate. As an example, when a discrete model of a GBM stochastic process is used, the probability of an up move in the lattice is set to $p = \frac{1+r-d}{u-d}$, where *r* is the risk-free discount rate, *u* is the factor for a upward movement in the lattice and $d = \frac{1}{u}$ is the corresponding factor for a downward move (Cox et al., 1979).

With a mean reverting process, a similar adjustment is made to the probability calculations. To do this, we substitute $\bar{Y}' = \bar{Y} - \frac{\pi}{\eta}$ for $\bar{Y}$ in Eq. (8), where $\bar{Y}'$ is the risk-adjusted long term mean, $\bar{Y}$ is the un-adjusted long term mean, $\pi$ is the project risk premium, and $\eta$ is the mean reversion speed coefficient (Dixit and Pindyck, 1994 and Schwartz, 1997). More detailed discussion of the basis for the risk adjustment can be found in Appendix 2.

Bivariate discrete modeling of mean reverting processes

The modeling approach used in this paper is based on a bivariate lattice combining two uncertain variables. The notion of a bivariate lattice was first introduced by Boyle (1988) and was also later discussed by Copeland and Antikarov (2003), who proposed a “quadranomial” lattice model with two correlated uncertainties, each following a GBM. In order to construct a bivariate lattice, the joint probabilities of each of the four outgoing branches at each node must be determined (Fig. 1). As shown in the figure, to value an option *C* at time step *n* in such a lattice, we sum of the values at the four subsequent nodes at time step *n+1* multiplied by their respective risk-neutral probabilities, discounted at the risk free rate *r*.

Fig.1. Option value in a bivariate lattice.




It follows that this dual variable approach is particularly useful for valuing real options to switch. Gonçalves et al. (2005) analyze a production switching option available to a Brazilian flexible sugar-ethanol plant, and model the underlying uncertainties using two distinct GBM diffusion processes. However, as noted by Schwartz (1998), Laughton and Jacoby (1993), and others, if commodity prices are indeed mean reverting, then a lognormal geometric Brownian diffusion model can significantly overestimate uncertainty in the resultant cash flows from a project, and result in overstated option values. Therefore, the Copeland and Antikarov quadranomial model cannot be directly used for modeling two one factor mean reverting processes, since the probabilities at each branch must change throughout the lattice. Kulatilaka (1993) provides an approach for valuing a switching option where the two input variables are modeled as a single mean reverting process for relative price; however, this approach is limited to cases with relatively simple value functions that can be written in terms of this type of variable.

To value switching options in more general cases we need to jointly model two variables, such the log of two commodity prices, $X = \ln(x)$ and $Y = \ln(y)$, each following a different mean reverting stochastic process:

$$dX = \eta_x \left(\overline{X} - X\right)dt + \sigma_x dz \qquad (9a)$$

$$dY = \eta_y \left(\overline{Y} - Y\right)dt + \sigma_y dz \qquad (9b)$$

with increments:

$$\Delta_X = \sigma_x \sqrt{\Delta t} \qquad (10a)$$

$$\Delta_Y = \sigma_y \sqrt{\Delta t} \quad (10b)$$

For these two processes, we can specify the joint probabilities for both *X* and *Y* moving up ($p_{uu}$), *X* moving up and *Y* moving down ($p_{ud}$), *X* moving down and *Y* moving up ($p_{du}$), and both *X* and *Y* moving down ($p_{dd}$), respectively as:

$$p_{uu} = \frac{\Delta_X \Delta_Y + \Delta_Y \nu_X \Delta t + \Delta_X \nu_Y \Delta t + \rho \sigma_X \sigma_Y \Delta t}{4 \Delta_X \Delta_Y} \quad (11a)$$

$$p_{ud} = \frac{\Delta_X \Delta_Y + \Delta_Y \nu_X \Delta t - \Delta_X \nu_Y \Delta t - \rho \sigma_X \sigma_Y \Delta t}{4 \Delta_X \Delta_Y} \quad (11b)$$

$$p_{du} = \frac{\Delta_X \Delta_Y - \Delta_Y \nu_X \Delta t + \Delta_X \nu_Y \Delta t - \rho \sigma_X \sigma_Y \Delta t}{4 \Delta_X \Delta_Y} \quad (11c)$$

$$p_{dd} = \frac{\Delta_X \Delta_Y - \Delta_Y \nu_X \Delta t - \Delta_X \nu_Y \Delta t + \rho \sigma_X \sigma_Y \Delta t}{4 \Delta_X \Delta_Y} \quad (11d)$$

where $p_{uu} + p_{ud} + p_{du} + p_{dd} = 1$.

These probabilities are dependent on the drift for each process as well as the correlation $\rho$ between the increments of the two processes. The drifts of the respective processes are given by: $\nu_X = \eta_x \left( \bar{X} - X_t \right) - 1/2 \sigma_x^2$ and $\nu_Y = \eta_y \left( \bar{Y} - Y_t \right) - 1/2 \sigma_y^2$.

Unfortunately, a four branch node of such a joint process cannot be directly censored when necessary, as the mean reverting model requires. Hahn and Dyer (2006) solve this issue by applying Baye's Rule to decompose the joint probabilities into the products of marginal and conditional probabilities. To obtain the conditional probabilities, the joint probabilities are divided by the marginal probabilities for $X$,

$$p_u = \frac{1}{2} + \frac{1}{2} \frac{\nu_X \Delta t}{\Delta_X} \quad (12a)$$

$$p_d = \frac{1}{2} - \frac{1}{2} \frac{\nu_X \Delta t}{\Delta_X}, \quad (12b)$$

which yields the following conditional probabilities for $Y$:

$$p_{u|u} = \frac{\Delta_X \left( \Delta_Y + \Delta t \nu_Y \right) + \Delta t \left( \Delta_Y \nu_X + \rho \sigma_X \sigma_Y \right)}{2 \Delta_Y \left( \Delta_X + \Delta t \nu_X \right)} \quad (13a)$$

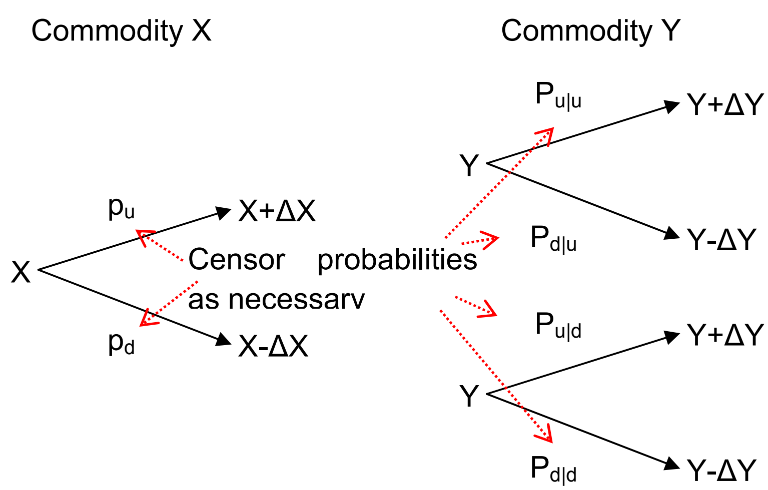
$$p_{d|u} = \frac{\Delta_X(\Delta_Y - \Delta t \nu_Y) + \Delta t(\Delta_Y \nu_X - \rho \sigma_X \sigma_Y)}{2\Delta_Y(\Delta_X + \Delta t \nu_X)} \quad (13b)$$

$$p_{u|d} = \frac{\Delta_X(\Delta_Y + \Delta t \nu_Y) - \Delta t(\rho \sigma_X \sigma_Y + \Delta_Y \nu_X)}{2\Delta_Y(\Delta_X + \Delta t \nu_X)} \quad (13c)$$

$$p_{d|d} = \frac{\Delta_X(\Delta_Y - \Delta t \nu_Y) - \Delta t(\Delta_Y \nu_X - \rho \sigma_X \sigma_Y)}{2\Delta_Y(\Delta_X + \Delta t \nu_X)}. \quad (13d)$$

Note that in this formulation, $p_{u|u} + p_{d|u} = 1$ and $p_{u|d} + p_{d|d} = 1$. These probabilities allow the four branch node with joint probabilities to be split into a marginal-conditional sequence (Fig. 2) where all probabilities can again be censored in the manner of Eq. (8).

Fig. 2. Marginal-conditional node sequence for two commodities.




Switching option valuation methodology

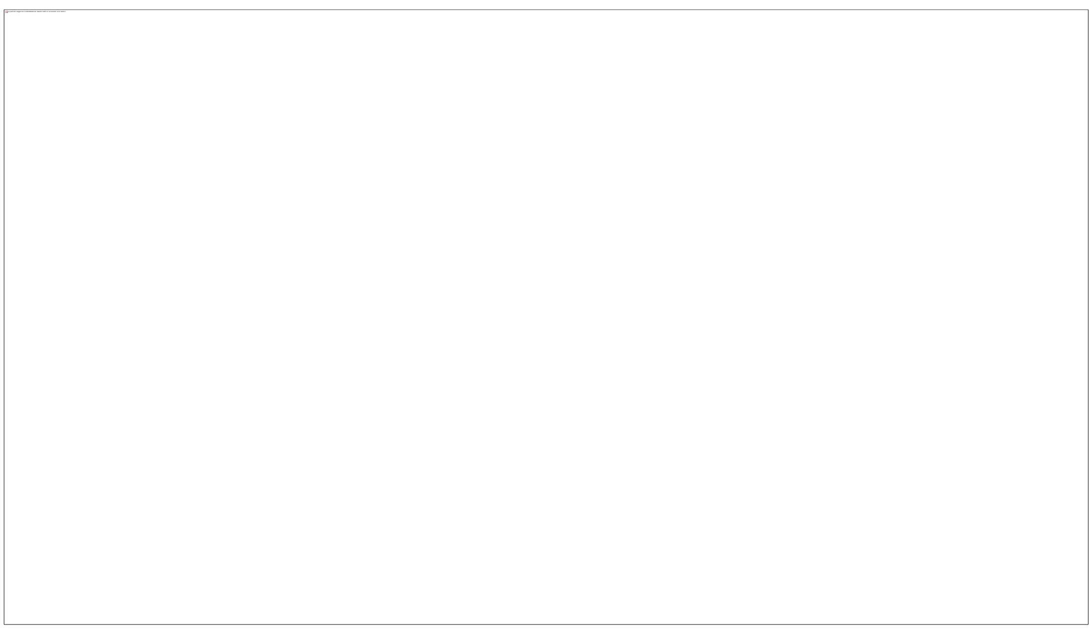
In this section, we analyze the incremental value due to the flexibility afforded sugar cane processors to switch production from ethanol to sugar/ethanol or vice-versa in any given time period.

Data collection

Data based on daily observations of sugar and ethanol prices directly paid to processors was obtained from CEPEA (2007) and are available online. For ethanol, prices are a mean between anhydrous and hydrated alcohol (70% of the former, and 30% of the latter, both produced in the facilities in these proportions). Although we only used prices paid in the state of São Paulo, they were assumed to be representative of the general case due to the fact that this state produces about 64% of these commodities in Brazil and they are a reference widely utilized in research on the ethanol-sugar sector (Pretyman, 2005). Prices are in local currency, R$ (Reais)[30], and for ethanol are given per liter (R$/l), whereas for sugar they are in 50 Kg bags (R$/50 kg), which is the standard unit in the sector.

Both series of prices were collected from May 1998 to July 2007 on a monthly average basis, resulting in 112 data periods (almost 10 years), and were deflated by the most widely used Brazilian inflation indicator, IGP-DI (FGV), also on a monthly basis. In Fig. 3 they are plotted together on different scales for visual comparison. All prices shown in the figure are in local currency, R$ (Real), which currently trades for about $R\$1.00 \cong US\$0.55$.

Fig. 3. Ethanol and sugar price data series.



Source: CEPEA (2007), UNICA (2007).

The model parameters were estimated using a procedure based on the methodology outlined by Dixit and Pindick (1994) which allows simultaneous estimation of all parameters from discrete time series.31 From these series we were able to calculate the parameters needed for the mean reverting processes

---

[30] As of November 2007, the going exchange rate was R$ 1.8 / USD.
[31] See Appendix 3 for details on the parameter estimation procedure

used in the model. For both series, a simple linear regression was run with $\log(P_t) - \log(P_{t-1})$ as the dependent variable and $\log(P_{t-1})$ as the independent variable. The resulting regression equation is therefore $\log\left(P/P_{t-1_t}\right) = \beta_0 + \beta_1 \log\left(P_{t-1}\right) + \varepsilon$.

The mean reversion coefficients $\eta$ can then be obtained from the regression output as $\eta = \frac{-\log(\beta_1 + 1)}{\Delta t}$ and the volatility of the series and long term mean are given by $\sigma = \sigma_\varepsilon \sqrt{\frac{2\log\left(\beta_1 + 1\right)}{\Delta t\left[\left(\beta_1 + 1\right)^2 - 1\right]}}$, where $\sigma_\varepsilon^2$ is the variance of the regression's errors, and $\bar{P} = \exp\left[-\frac{\beta_0}{\beta_1} + \frac{\sigma^2}{2\eta}\right]$, respectively. Plotted regression lines and their corresponding equations for our data can be seen in Fig. 4.

Fig. 4. Regression to determine stochastic process parameters.

The correlation calculated between the return of the two series (sugar and ethanol) was found to be ρ = 0.5786. All stochastic process parameters are summarized in Table 2. As can be observed, prices for both commodities are currently below their long-term means.

Table 2 Stochastic process parameters for ethanol and sugar

| | Sugar | Ethanol |
|---|---|---|
| Initial Price | 24.29 R$ / 50 kg bag | 0.643 R$ / liter |
| Long-term mean | 35.74 R$ / 50 kg bag | 0.8526 R$ / liter |

| | Month | Semester | Year | Month | Semester | Year |
|---|---|---|---|---|---|---|
| Volatility ($\sigma$) | 11.02% | 27.00% | 38.18% | 10.52% | 25.77% | 36.45% |
| Mean reversion coefficient ($\eta$) | 0.1109 | 0.6657 | 1.3314 | 0.0843 | 0.5060 | 1.0120 |

Option value model methodology

The model we use measures the present value of cash flows generated from processing 2,600,000 tons of sugar cane annually, either as ethanol or as sugar, with some ethanol as a by product (Gonçalves, 2006). This represents a relatively large processing plant, equivalent to 1% of the total Brazilian sugar cane processing capacity. The time horizon chosen is five years, in half year periods ($T$ = 5, $n$ = 10, $\Delta t$ = 0.5). The project risk premium ($\pi$) of 6% was estimated as the ethanol-sugar sector deflated risk premium, calculated from listed companies in the Sao Paulo stock exchange. It is coincidentally very close to the present deflated risk free rate ($r$) of 6% in Brazil, a figure which is based on the real interest rate of Brazilian government bonds, as well as the risk free rates used in similar works (Dias, 2005 and Gonçalves, 2005).

With these parameter values, the risk adjusted long term means are:

$$\overline{x}' = e^{\left(\bar{X}-\frac{\pi}{\eta}\right)} = e^{\left(\ln(0.8526)-\frac{6\%}{1.012}\right)} = 0.8150 \text{ R\$/liter for Ethanol} \quad (14a)$$

$$\overline{y}' = e^{\left(\bar{Y}-\frac{\pi}{\eta}\right)} = e^{\left(\ln(35.74)-\frac{6\%}{1.3314}\right)} = 33.687 \text{ R\$/50 kg for Sugar} \quad (14b)$$

Project cash flow values are calculated as follows:

For pure ethanol processing, the projected ethanol price (R$/liter) is multiplied by 80 (liters per ton of sugar cane) and then by 0.96% (4% discount due sales tax). This result, minus 29.67 R$/ton (variable cost), is then multiplied by 2,600 (yearly sugar cane tons processed/1,000). The final result is obtained by subtracting fixed costs of R$ (1,000) 28,726, and multiplying by 81% to reflect the income tax.

For sugar processing, sugar price (in R$/50 Kg bags) is multiplied by 2.14 (107 kg of sugar from one ton of sugar cane, in 50 Kg bags) and then by 0.84 (16% discount due sales tax), plus 12 (liters of by-product of ethanol per ton of sugar cane) multiplied by ethanol price (R$/liter), and then by 0.96 (4% discount due sales tax). This result, minus 31.94 R$/ton (variable cost), is then multiplied by 2,600 (yearly sugar cane tons processed/1,000). The final result is again obtained by subtracting fixed costs of R$ (1,000) 28,726, and multiplying by 81% to reflect the income tax.

For a flexible plant, the higher of these two values is chosen. This follows, because even with the flexibility of choosing any mix between the two outputs, a corner solution is always the optimal one due to the linear relationship between cash flow and product prices.

Fixed and variable costs account not only for industrial, but also for agricultural costs, and the latter is the same for both processes (Gonçalves et al., 2006). These algorithms are summarized in Eq. (15) and (16).

$$CF_{Eth} = \left(\left[\left(80P_{Eth}\left[1-4\%\right]\right)-29.67\right]2{,}600-28{,}726\right)\left(1-19\%\right) \quad (15)$$

$$CF_{Sug} = \left(\left[\left(2.14P_{Sug}\left[1-16\%\right]+12P_{Eth}\left[1-4\%\right]\right)2{,}600-31.94\right]-28{,}726\right)\left(1-19\%\right) \quad (16)$$

The deterministic cases using these equations and expected values for the two commodity prices are listed in Table 3.

Table 3 Deterministic base case economics

| | Process: | MRM (R$ 000) |
|---|---|---|
| Base cases: | Pure Ethanol | 176,584 |
| | Sugar (ethanol byproduct) | 209,716 |

To model the variability in project value, lattices for both commodities were constructed using the approach described in Section 3.1, with the results shown in Fig. 5 and Fig. 6. These two lattices were then jointly modeled according to their correlation using the approach described in Section 3.3. The marginal probabilities of an up move in the lattice are dependent on the log of the price value at each node, according to Eq. (8). Then, as we have split the price movement into marginal and conditional steps, as in Fig. 3, we generate the conditional probabilities using the expressions given in Eq. (13a-d). Although this approach is numerically intensive, it is relatively straightforward to implement in an Excel worksheet.

Fig. 5. Risk neutral process lattice for sugar.

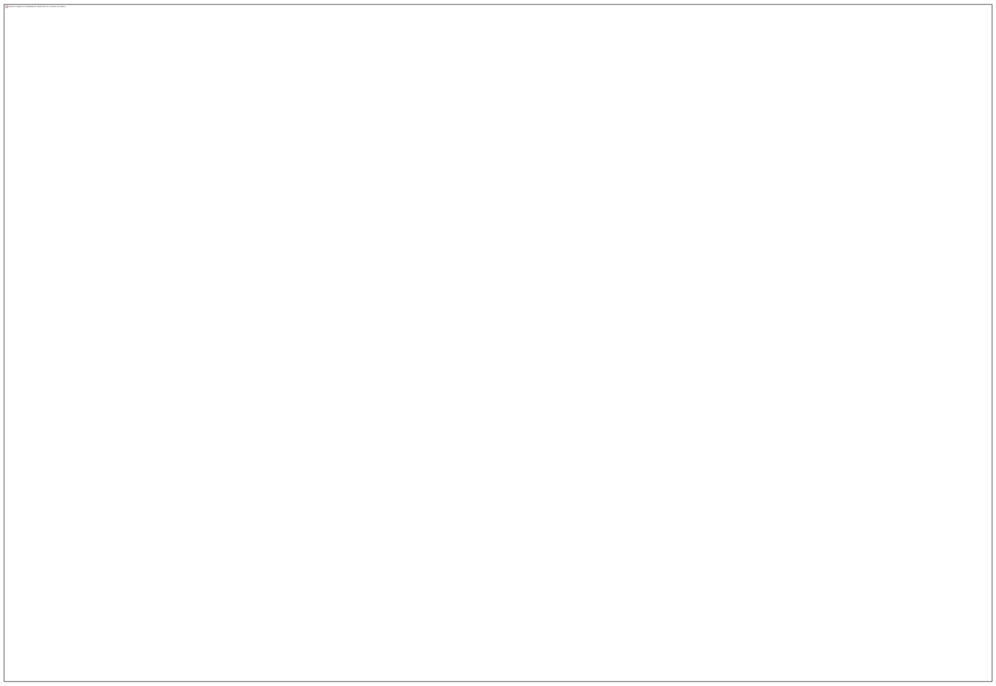
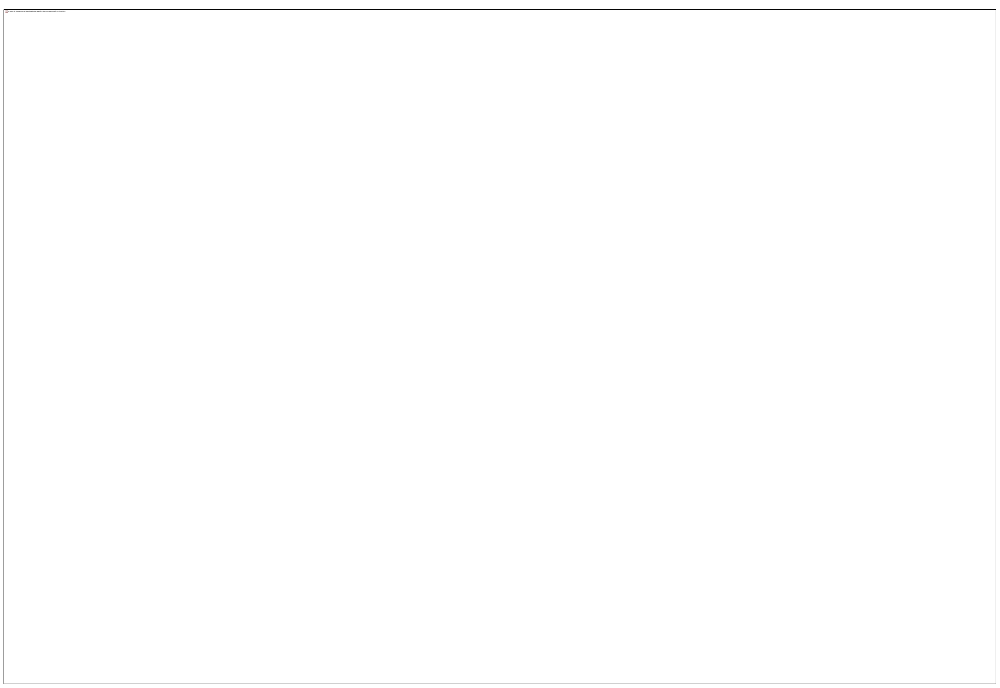


Fig. 6.  Risk neutral process lattice for ethanol.



With the resulting bivariate price lattice, an algorithm is applied to each node to produce an optimal decision regarding the option available to the producer; either to produce ethanol or to produce sugar and some ethanol as a by-product during the semester. The algorithm is outlined in the following equation:

$$Max\left[CF_{Ethanol}, CF_{Sugar}\right] \left(0.5\frac{semester}{year}\right) \quad (17)$$

Beginning one time period from the end of the bivariate lattice (in period 9 out of 10), we then apply Eq. (17) and work backwards recursively to period 0, calculating the value at each node as the discounted sum, at the risk free rate, of the four subsequent nodes in the lattice weighted by the joint probabilities, which are in turn the result of multiplying the marginal probabilities of ethanol (which was chosen to be the first variable) by the conditional probabilities for sugar at each node, and adding the value of the cash flow at the node considered. We end up at period 0 with the present value of 1 ton of processed sugar cane per month, during five years, with the semester option of choosing between to two possible outputs.

## Results

### Results from bivariate lattice model

Using the method described in the previous section, we obtained a result of R$ 240,009,000 for the present value of a flexible plant processing 2,600,000 tons of sugar cane every year during five years. This can then be compared to the values of R$ 176,584,000 for an ethanol only producing plant and R$ 209,716,000 for a sugar producing plant (which produces some ethanol as by product) that are shown in Table 3. These results represent increases of 35.9%and 14.4% in value, respectively, relative to the non-flexible plants. Thus, the percent value of the switching option is 14.4% (flexible production compared with the highest value base case) relative to the case with no flexibility, and the absolute incremental value of the switching option is R$ 30,293,000. It is interesting to note that even with the sugar producing plant having a higher present value than the ethanol plant, the average mix of the Brazilian industry was about 51% ethanol and 49% sugar in 2005, with the ethanol fraction increasing (Pretyman, 2005). We can conclude that even if it is only based on intuition, processors are well aware of the value of flexibility, and are therefore investing in flexible plants.

### Comparison with results from a simulation model

Simulation models can be difficult to implement for more complex options, particularly where early exercise is possible, however they can be used for relatively simple call, put, or switching options. Since the sugarcane processing switching option can be exercised in each period without costs (after the initial cost of investment in a flexible plant) and since the option is also independent of all decisions made before or after a particular point, we can reconstruct the valuation problem as a bundle of European options. Thus, we have an alternative means of obtaining the value of the switching option. Although the computational disadvantages of simulation based approaches for these types of problems are well-documented (Tseng and Lin, 2007), we can nonetheless obtain results via simulation with the same input data and then use those results to validate the results obtained with the bivariate mean reverting lattice approach.

GBM

The value obtained from a simulation with 100,000 iterations using @RISK® was R$ 235,109,000 for the flexible plant, which is -2.04% different from the result from the bivariate lattice method. This difference is due to the discrete increment in the bivariate lattice of $\Delta T$ = 0.5, which may still be considered relatively large; however, we could decrease the difference further by simply decreasing $\Delta T$.

Comparison with results when GBM price processes are assumed

As we mentioned previously, the GBM diffusion process is very simple and straightforward to model and implement, but its drawback is that it may not fit the empirical data. We have shown that for the two commodities analyzed in this paper, the mean reverting diffusion process provides a reasonable fit, whereas a GBM may not be as appropriate. To illustrate, in Fig. 7 and Fig. 8 we show the projections of ethanol and sugar mean prices, respectively, as well as the 90% confidence intervals derived from both the mean reverting process and GBM.

Fig. 7. Ethanol price projections (non-risk neutral).

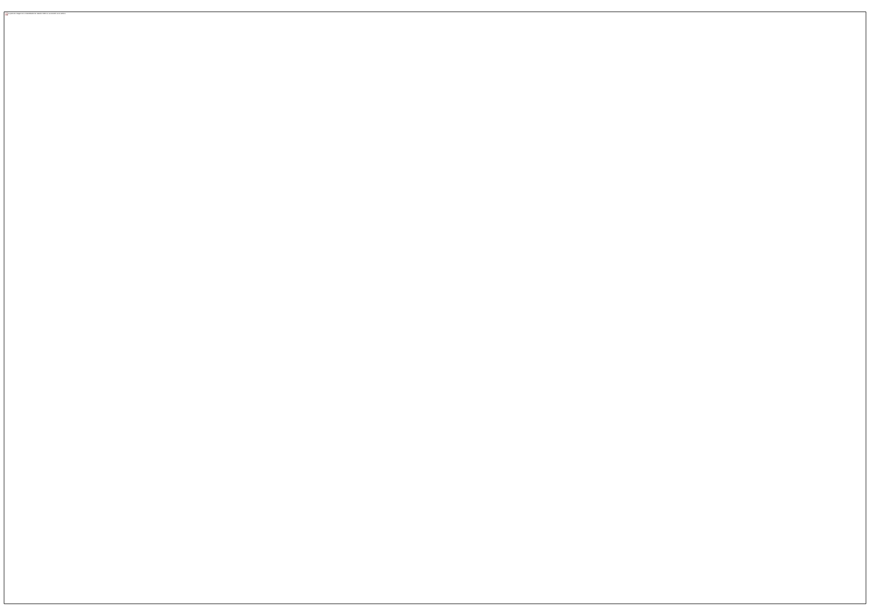
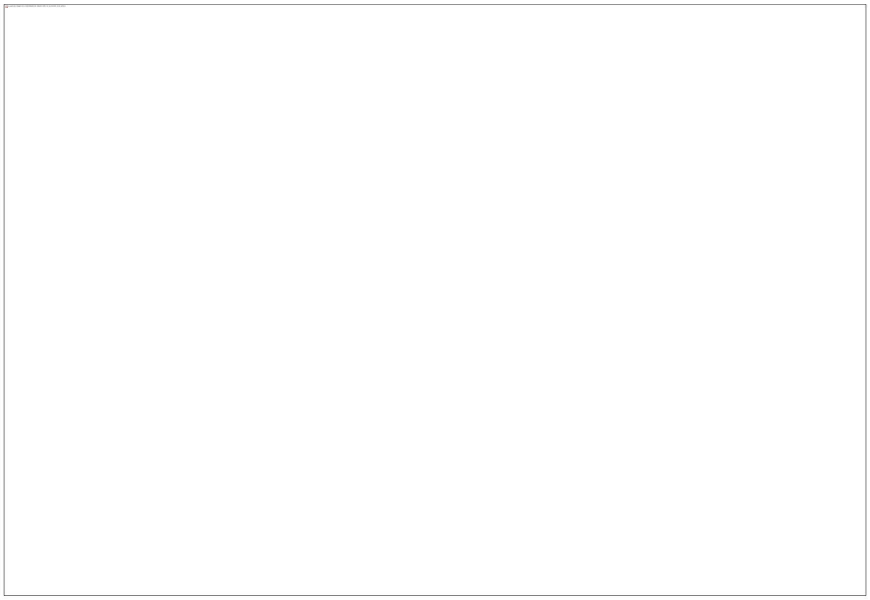


Fig. 8.  Sugar price projections (non-risk neutral).



In order to compare valuation results, the same case was modeled assuming prices followed a GBM process, with the results of the deterministic cases and option value shown in Table 4.

Table 4 Comparison of results under mean reverting process vs. GBM (R$ 000)

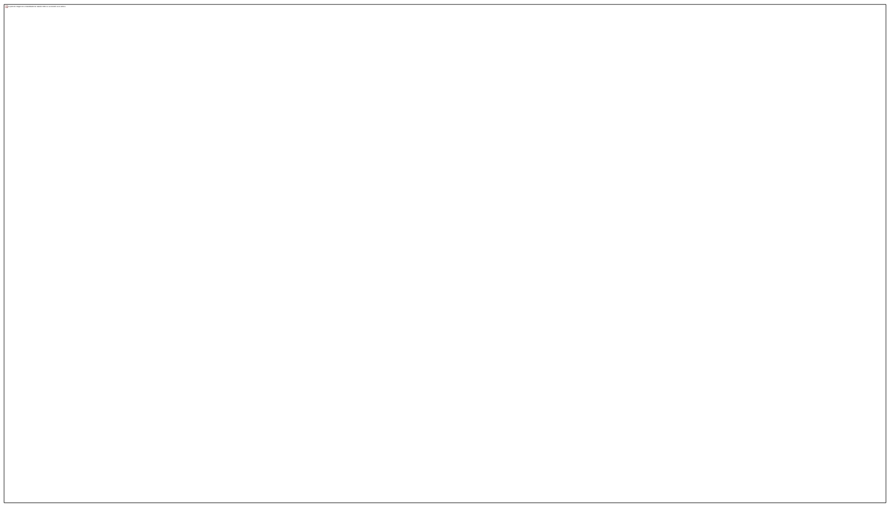
| | Process: | MRM | GBM | Difference |
|---|---|---|---|---|
| Base cases: | Pure Ethanol | 176,584 | 152,405 | -13.7% |
| | Sugar (ethanol byproduct) | 209,716 | 154,376 | -26.4% |
| With option: | Flexible plant | 240,009 | 293,496 | 22.3% |
| | Option Value | 30,293 | 139,120 | |
| Flexible plant compared to base cases: | Pure Ethanol | 35.92% | 92.6% | |
| | Sugar (ethanol byproduct) | 14.44% | 90.1% | |

The bivariate lattice for two GBM's is indeed simpler to implement following the Copeland and Antikarov (2001) framework; however, the base case results in Table 4 show differences of -13.7 % and -26.4 %, respectively, for the two projects, relative to the mean reverting process model, illustrating the effect of the very low or even negative drift in prices resulting from the GBM model. The value for the flexible plant obtained in this way, using the same volatility and price correlation parameters of the mean reverting process case is R$ 293,496,000, and the option value is R$ 139,120,000. These are 92.6% and 90.1% above the base GBM cases of ethanol and sugar, respectively, and 22.3% above the flexible mean reverting process case, which indicates that the use of a GBM in this case significantly overestimates the value of the switching option. The underestimation bias when using a GBM prices process is mostly due to the fact that the starting prices of sugar and ethanol are very low compared to their long term means. Thus, even with a positive drift, the GBM five year projection will still result in undervaluation of the respective projects. On the other hand, the increasing variance of a GBM, which is proportional to *t*, will significantly overvalue the flexible plant and the switching option value.

Sensitivity of results to correlation between price processes

Due to the high correlation between the two uncertain variables (prices of sugar and ethanol) the sensitivity of the option to this parameter was investigated. The results are summarized in Fig. 9, which plots the value of the switching option versus the correlation between price processes. The figure shows that the switching option value increases rapidly as the correlation diminishes, ultimately arriving at an option value of R$ 49,759,000 (24.07% above the base sugar case) when there is no correlation ($\rho$ = 0) used in the bivariate lattice.

Fig. 9. Value of conversion options as a function of correlation.



## Conclusions

Ethanol is currently regarded as one of the most promising automotive fuels of the future. The basic economic case for ethanol has improved significantly in recent years, and ethanol is also viewed as being more environmentally friendly than hydrocarbon based fuels such as gasoline and diesel, since it is derived from renewable sources. Also, since its manufacturing process is relatively labor intensive, it is viewed favorably in developing countries with high unemployment rates. Clearly, ethanol is now a technologically feasible resource with the potential to replace a significant portion of the world's fossil fuel use.

In this paper, we have modeled the prices of ethanol and sugar as mean reverting stochastic processes, using a procedure to estimate the process parameters from empirical market data, and have implemented a computationally efficient, but precise and flexible framework for modeling the option value associated with a flexible ethanol production process. Our results demonstrate that sugar cane based processors do indeed derive additional value from a flexible production process, even under the assumption of mean reverting prices, and benefit from a natural hedge in the market for sugar, a well established commodity. This is an important consideration for potential investors in ethanol's still developing world market. It is also important for policy-makers considering the degree to which ethanol production should be supported with government subsidies in developing markets.

We have also demonstrated that, although a GBM is much simpler to implement as a discrete binomial lattice relative to a mean reverting process, using GBM price models in this problem yielded erroneously higher results relative to the case where we used mean reverting price models, which more accurately depict the price evolution over time for many commodities. Finally, we investigated the sensitivity of the switching option value to the correlation between ethanol and sugar price processes and, as expected, found that the value increased when the two prices moved independently, and that it would continue to increase if they became negatively correlated. This implies that the effect of correlation may become an important dynamic, should the prices of sugar and ethanol begin to decouple as the ethanol market continues to develop.

Appendix 1: Transformation to stochastic process for Log(Price)

Given that *S* follows the geometric mean reversion process:

$$dS = \eta\left[\log\left(\bar{S}\right) - \log\left(S\right)\right]Sdt + \sigma S dz,$$

where $\bar{S}$ is the long term mean price, we can apply Itô's lemma with *Y* = log(*S*):

$$dY = \frac{1}{2}\frac{\partial^2 Y}{\partial S^2}dS^2 + \frac{\partial Y}{\partial S}dS + \frac{\partial Y}{\partial t}$$

Substituting in $\frac{\partial Y}{\partial S} = \frac{1}{S}$, $\frac{\partial^2 Y}{\partial S^2} = -\frac{1}{S^2}$, $\frac{\partial Y}{\partial t} = 0$ and $dS^2 = S^2\sigma^2 dt$ yields

$$dY = -\frac{1}{2}\frac{S^2\sigma^2}{S^2}dt + \frac{1}{S}\left(\eta\left[\log\left(\bar{S}\right) - \log\left(S\right)\right]Sdt + \sigma S dz\right), \text{ or}$$

$$dY = \eta\left[\left(\log\left(\bar{S}\right) - \frac{\sigma^2}{2\eta}\right) - \log\left(S\right)\right]dt + \sigma dz$$

which is the process followed by *Y* = log(*S*), in terms of the same parameters.

By comparing the processes for *Y* and *S*, we can see the relationship between $\bar{Y}$ and $\bar{S}$;

$$\bar{Y} = \log\left(\bar{S}\right) - \frac{\sigma^2}{2\eta},$$

which is an important result for the estimation of stochastic process parameters for the Log(Price) process from empirical price data.

Appendix 2: Adjustment of long-term mean for a risk neutral process

A standard technique in valuation of commodity-related investments is to apply a risk premium in the form of an adjustment to the drift of the stochastic process for the commodity price. If the process can be adjusted so that the drift corresponds to a risk neutral probability measure, then all cash flows can be discounted at the risk free discount rate[32]. This approach is formally justified by assuming that the state variable is priced according to the intertemporal asset pricing models developed by Merton[33] and Cox, Ingersoll, and Ross[34].

In the case of a risk adjusted process, the risk adjusted discount rate is $\mu = \alpha + \delta$ , where $\mu$ is the risk adjusted discount rate, $\alpha$ is the process drift and $\delta$ is the process dividend yield. Thus the drift of the risk adjusted process can be expressed as $\alpha = \mu - \delta$. With a risk-neutral format, the drift $\alpha$ of the process, is replaced by $r - \delta$, where $r$ is the risk free rate.

If we consider the particular case of the single factor Ornstein-Uhlenbeck process, which is given by:

$$dY_t = \eta\left(\overline{Y} - Y_t\right)dt + \sigma dz_t \text{ ,}$$

then the process drift is $\alpha = \eta\left(\overline{Y} - Y\right)$. We note that, in contrast to a GBM, the dividend yield is not constant; rather, it is a function of $Y$. That is, the dividend yield is $\delta = \mu - \alpha$ , or $\delta = \mu - \eta\left(\overline{Y} - Y\right)$.

With this expression we can write the *risk-neutral* drift for the mean reverting process as $r - \delta = r - \mu - \eta\left(\overline{Y} - Y\right)$. Rearranging terms a few times, we have:

$$r - \delta = \eta\left(\overline{Y} - Y\right) - (\mu - r) \quad \text{or}$$

$$r - \delta = \eta\left\{\left(\overline{Y} - \frac{(\mu - r)}{\eta}\right) - Y\right\} .$$

Then finally, using the relationship $\pi = \mu - r$ , the risk-neutral drift becomes:

---

[32] A rigorous development of the risk neutral valuation framework can be found in Duffy, D., 1992. Dynamic asset pricing theory. Princeton: Princeton, NJ.

[33] Merton, R., 1973. An intertemporal capital asset pricing model. Econometrica 41, 867-887.

[34] Cox, J., Ingersoll, J., Ross, S., 1985. An intertemporal general equilibrium model of asset prices. Econometrica 53, 363-384.

$$r - \delta = \eta \left\{ \left( \bar{Y} - \frac{\pi}{\eta} \right) - Y \right\}$$, or

$$r - \delta = \eta \left\{ \bar{Y} - Y \right\} - \pi$$

Note that $\pi = \mu - r$ is the risk-premium. Comparing both drifts (risk-adjusted and risk-neutral) shows that the conversion to a risk-neutral process can be viewed as subtracting the normalized risk-premium $(\mu - r)/\eta$, or $\pi/\eta$, from the long run mean level $\bar{Y}$. In other words, in the risk-neutral process the prices revert toward a lower level than the real long-run level, and the subtracting term is the normalized risk-premium.

Therefore, following the convention used by Schwartz[35,36], we adjust the drift of the process by subtracting $\pi$, where $\pi$ is a parameter called the normalized risk-premium. Thus, the risk-neutral form of the single factor Ornstein-Uhlenbeck process is:

$$dY_t = \left( \eta \left( \bar{Y} - Y_t \right) - \pi \right) dt + \sigma dz$$,

which can in turn be re-written as:

$$dY_t = \eta \left( \left( \bar{Y} - \frac{\pi}{\eta} \right) - Y_t \right) dt + \sigma dz$$

This is the basis for the expressions for the risk-adjusted long-term means shown in Eq. (14a) and (14b) of the paper.

---

[35] Schwartz, E., 1995. Review of investment under uncertainty, A.K. Dixit, R.S. Pindyck. Journal of Finance 50, 1924-1928.

[36] Schwartz, E., 1997. The stochastic behavior of commodity prices: Implications for valuation and hedging. Journal of Finance 52, 923-973.

Appendix 3: Mean reverting model parameter estimation

The simplest form of mean reverting model is the single factor Ornstein-Uhlenbeck process,

$$dY_t = \eta(\bar{Y} - Y_t)dt + \sigma dz_t$$

where:

$Y_t$ is the logarithm of the price $S_t$: $Y_t = \log[S_t]$

$\eta$ is the mean reversion speed

$\sigma$ is the process volatility, and

*dz* is a Weiner process with a normal distribution,

the expected value and variance of the Ornstein-Uhlenbeck process are given in Dixit & Pindyck[37]:

$$E[Y_t] = \bar{Y} + (Y_0 - \bar{Y})e^{-\eta T} \qquad (i)$$

$$Var[Y_t] = \frac{\sigma^2}{2\eta}\left(1 - e^{-2\eta T}\right) \qquad (ii)$$

In order to determine the values for the parameters for the process, we start by writing Eq. (*i*) for a discrete time interval Δ*t*:

$$Y_t = \bar{Y} + \left(Y_{t-1} - \bar{Y}\right)e^{-\eta\Delta t} = \bar{Y}\left(1 - e^{-\eta\Delta t}\right) + Y_{t-1}e^{-\eta\Delta t}$$ , or

$$Y_t - Y_{t-1} = \bar{Y}\left(1 - e^{-\eta\Delta t}\right) + Y_{t-1}\left(e^{-\eta\Delta t} - 1\right)$$

Substituting $Y_t = \log\left[S_t\right]$ and $\bar{Y} = \log\left(\bar{S}\right) - \frac{\sigma^2}{2\eta}$ and rearranging yields[38]:

$$\log\left(S_t/S_{t-1}\right) = \left[\log\left(\bar{S}\right) - \sigma^2/2\eta\right]\left(1 - e^{-\eta\Delta t}\right) + \log\left(S_{t-1}\right)\left(e^{-\eta\Delta t} - 1\right) \qquad (iii)$$

Rewriting this equation in the form:

$$\log\left(S_t/S_{t-1}\right) = \beta_0 + \beta_1 \log\left(S_{t-1}\right), \qquad (iv)$$

---

[37] Dixit, A., Pincyck, R., 1994. Investment under uncertainty. Princeton: Princeton, NJ.

[38] See Appendix 1 for the relationship between $\bar{Y}$ and $\bar{S}$ .

we can the estimate the process parameters by simply performing a linear regression on the price series $S_t$. From the regression output, we can then obtain the parameters needed with the formulas below, which were developed by Dixit and Pindyck and modified by Dias[39].

From Eq. (*iii*) and (*iv*), we have $\beta_1 = e^{-\eta\Delta t} - 1$, or

$$\eta = -\log\left(\beta_1 + 1\right)/\Delta t \qquad (v)$$

We can also determine the volatility parameter $\sigma$ from the variance of errors obtained from the regression, $\sigma_\varepsilon^2$, and Eq. (*ii*). First we equate the two to obtain:

$$\sigma_\varepsilon^2 = \frac{\sigma^2}{2\eta}\left(1 - e^{-2\eta\Delta t}\right)$$

Then re-writing using the relationship $\left(\beta_1 + 1\right)^2 = e^{-2\eta\Delta t}$ and Eq. (*v*), yields

$$\sigma_\varepsilon^2 = -\sigma^2 \Delta t \frac{1 - \left(\beta_1 + 1\right)^2}{2\log\left(\beta_1 + 1\right)},$$ or

$$\sigma = \sigma_\varepsilon \sqrt{\frac{2\log\left(\beta_1 + 1\right)}{\left[\left(\beta_1 + 1\right)^2 - 1\right]\Delta t}} \qquad (vi)$$

Finally, from Eq. (*iii*) and (*iv*), $\beta_0 = \left[\log\left(\bar{S}\right) - \sigma^2/2\eta\right]\left(1 - e^{-\eta\Delta t}\right)$.

With the relationship $-\beta_1 = 1 - e^{-\eta\Delta t}$, we obtain:

$$-\frac{\beta_0}{\beta_1} = \left[\log\left(\bar{S}\right) - \sigma^2/2\eta\right]$$, or

$$\bar{S} = \exp\left[-\frac{\beta_0}{\beta_1} + \frac{\sigma^2}{2\eta}\right]$$

Alternatively, by substituting the value of $\eta$ from Eq. (*v*), we can rewrite this as:

---

[39] Dias, M., 2008. Stochastic processes with focus in petroleum applications, Part 2 – mean reversion models. http://sphere.rdc.puc-rio.br/marco.ind/revers.html#mean-rev

$$\bar{S} = \exp\left[-\frac{\beta_0}{\beta_1} + \frac{\sigma^2 \Delta t}{2\left(-\log[\beta_1 + 1]\right)}\right],$$

and further, using the value of σ from Eq. (*vi*), as:

$$\bar{S} = \exp\left[-\frac{\beta_0}{\beta_1} + \sigma_\varepsilon{}^2 \frac{2\Delta t \log[\beta_1 + 1]}{2\Delta t\left(-\log[\beta_1 + 1]\right)\left([\beta_1 + 1]^2 - 1\right)}\right],$$

so that we have an expression in terms of the regression coefficients:

$$\bar{S} = \exp\left[-\frac{\beta_0}{\beta_1} + \frac{\sigma_\varepsilon{}^2}{1 - (\beta_1 + 1)^2}\right]$$

References

Baker, M., Mayfield, E., Parsons, J., 1998. Alternative models of uncertain commodity prices for use with modern asset pricing models. The Energy Journal 19, 115-148.

Bhattacharya, S., 1978. Project valuation with mean reverting cash flow streams. Journal of Finance 33, 1317-1331.

Black, F., Scholes, M., 1973. The pricing of options and corporate liabilities. Journal of Political Economy 81, 637 – 654.

Boyle, P., 1988. A lattice framework for option pricing with two state variables. Journal of Financial and Quantitative Analysis 23. 1 – 12.

Center for Advanced Studies in Applied Economics (CEPEA), 2007. Indicator of prices. http://www.cepea.esalq.usp.br/.

Copeland, T., Antikarov, V., 2003. Real options: A practitioner's guide. Texere: New York.

Cox, J., Ross, S., Rubinstein, M., 1979. Option pricing: A simplified approach. Journal of Financial Economics 7, 229–263.

Dias, M., 2005. Real options with petroleum applications. Doctoral thesis, Industrial engineering departament, PUC-Rio, Rio de Janeiro, Brazil.

Dias, M., Rocha, K., 1999. Petroleum concessions with extendible options using mean reversion with jumps to model oil prices. 3rd International conference on real options. The Netherlands.

Dixit, A., Pindyck, R., 1994. Investment under uncertainty. Princeton University Press: Princeton, NJ.

Gibson, R., Schwartz, E., 1990. Stochastic convenience yield and the pricing of oil contingent claims. Journal of Finance 45, 959-976.

Goldemberg, J., 2007. Ethanol for a sustainable energy future. Science 315, 9.

Goncalves, D., Neto, J., Brasil, H., 2006. The option of switching an investment project into an agribusiness project. 10th International conference on real options. New York.

Hahn, W., Dyer, J., 2007. Discrete time modeling of mean reverting stochastic processes for real option valuation. European Journal of Operational Research 184 (2), 534-548.

Hull, J., 1999. Options, futures and other derivatives. Prentice Hall: Upper Saddle River, NJ.

Kulatilaka, N., 1993. The value of flexibility: The case of a dual-fuel industrial steam boiler. Financial Management 33, 225-240.

Laughton, D., Jacoby, H., 1993. Reversion, timing options, and long-term decision making. Financial Management 33, 225-240.

Nelson, D., Ramaswamy, K., 1990. Simple binomial processes as diffusion approximations in financial models. The Review of Financial Studies 3 (3), 393-430.

Nelson, J., Siegel, D., and Smith, J., 1988. Option valuation of claims on real assets: The case of offshore petroleum leases." Quarterly Journal of Economics 103, 479-508.

Pindyck, R., 1999. The long run evolution of energy prices. The Energy Journal 20, 1-27.

Pindyck, R., Rubinfeld, D., 1991. Econometric models and economic forecasts. McGraw-Hill: New York.

Pretyman, A., 2005. The growth in the demand of ethanol fuel and its impact on the production mix of a sugar cane mill. Undergraduate dissertation, PUC-Rio de Janeiro, Brazil.

Renewable Fuels Association (RFA), 2007. The industry – Industry statistics." http://www.ethanolrfa.org/.

Schwartz, E., 1997. The stochastic behavior of commodity prices: Implications for valuation and hedging. Journal of Finance 52, 923-973.

Schwartz, E., 1998. Valuing long-term commodity assets. Financial Management 27, 57-66.

Schwartz, E., Smith, J., 2000. Short-term variations and long-term dynamics in commodity prices. Management Science 46, 893-911.

Szwarc, A., 2006. Issues in large scale biofuel production. International seminar on biofuels. MME – OLADE, Brasília, Brazil.

Tseng, C., Lin, K., 2007. A framework using two-factor price lattices for generation asset valuation. Operations Research 55, 234-251.

Union of the Sugar Cane Agroindustry of São Paulo (UNICA), 2007, Portal UNICA., http://www.unica.com.br.

United Nations Conference on Trade and Development (UNCTAD). 2005. Biofuels – Advantages and Trade Barriers. www.unctad.org.

# 8. Flexibility as a source of value in the production of alternative fuels: The ethanol case

**Carlos Bastian-Pintoa, Luiz Brandão [a], Warren J. Hahn[b],**

[a] **Pontifícia Universidade Católica, Rua Marques de São Vicente, 225 – Gávea, Rio de Janeiro, Brazil, tel +55 21 21389304, carlos@bastian.com .**

[b] **Pepperdine University, 24217 Baxter Drive, Malibu, California 90265, USA**

**Keywords: Commodity price models, Option valuation, Renewable fuels**

**Abstract:** There is typically a high degree of flexibility associated with the production of alternative fuels due to the ability to source from different input raw materials or to produce different output products based on market conditions. In this paper, we consider the particular example of ethanol and seek to quantify the incremental value from flexibility in its production from sugarcane in Brazil. We accomplish this by first jointly modeling the stochastic processes for the prices of the two relevant commodities, sugar (a food commodity) and ethanol (an energy commodity) in discrete time as a bivariate lattice. This framework allows us to value the option to switch output products based on the respective price signals of the two commodities. However, unlike the usual assumption of geometric Brownian motion stochastic processes, we use the more realistic case of mean reverting commodity price processes. We estimate the parameters for these processes by applying a regression-based procedure to empirical sugar and ethanol data collected during a period from 1998 through 2007. Our modeling results show that the option to switch outputs has significant value, even under the assumption of mean reverting prices, which has implications for both producers and policy-makers alike.

## Introduction

With the recent rise in oil prices, eventual long term exhaustion of world oil reserves and projected growth in demand for energy in the coming years, alternative sources of renewable energy have become increasingly sought after. One alternative which has gained widespread acceptance in Brazil is sugar cane based ethanol automotive fuel. Development of this market began in the early 1980's, driven by the government's "pro-álcool" program which included production subsidies and a mandatory mix of 20% ethanol to all fuel. After two decades and several initial setbacks, the state subsidies have now been removed and productive capacity has increased dramatically. On the consumption side, the majority of all new auto sales are now flex fuel cars, which can run on any mix of gas and ethanol. As a result, Brazil presently ranks second in the world in terms of total use of bio-fuels, with ethanol currently accounting for 45% of total small vehicle fuel consumption (UNCTAD, 2007; UNICA, 2007).

The main source of ethanol in Brazil is sugar cane, which previously was almost entirely grown to produce sugar, another commodity in which Brazil is a leading world player. Currently, ethanol is also rapidly gaining commodity status in the larger world market. According to the Renewable Fuels Association (RFA, 2007), the largest ethanol producers in 2005 were the United States with 4,265 million gallons, Brazil with 4,227 million gallons, China with 1,004 million gallons, and India with 449 million gallons.

Brazil's ethanol production industry is supported by sugar cane based ethanol's cost advantage relative to corn based ethanol, which is the main source of US production and which is heavily dependent on government subsidies. Many Brazilian sugar cane processors have invested in flexible plants that can produce either sugar or ethanol, since sugar cane can be transformed into sugar in a process that produces a small quantity of ethanol as a byproduct, or processed in an ethanol distillation process to produce ethanol exclusively. Although such plants require a larger up front investment, it appears that the potential for option value is intuitively considered by processors, as most plants currently under construction in Brazil are flexible (sugar/ethanol) facilities.

To value the switching option that is available to the processors, prices of both commodities must be modeled using a joint method that can capture the correlation between the price movements of each commodity. Approaches based on the bivariate lattice introduced by Boyle (1988) for modeling dual geometric Brownian motion (GBM) price processes have been used to value these types of options, however, as noted by Schwartz (1997) and others, prices of most commodities are best modeled by mean reverting processes, and this applies in the case of sugar and ethanol as well.

This paper's main objective is to apply a discrete time lattice based methodology for modeling mean reverting stochastic processes in order to quantify the incremental value due to a flexible production process. We begin the paper with a description of the sugar-ethanol production setting in Brazil in Section 2. Section 3 outlines a bivariate lattice approach to modeling mean reverting stochastic commodity price processes, and Section 4 follows with the empirical data analysis and stochastic process parameter specification, as well as the option value modeling assumptions and methodology utilized. In Section 5 we present our modeling results and compare them to both the results from a simulation model and the results when GBM stochastic processes are used to model the commodity prices. We conclude in Section 6 with a summary of findings and implications.

## The Brazilian sugar/ethanol industry

The ethanol production industry in Brazil today runs without the benefit of government subsidy, and Brazilian sugar cane based ethanol has become by far the world's most competitive bio-fuel (Goldemberg, 2007). Approximately 5.8 million hectares (ha) are currently being used to grow sugar cane in Brazil, of which about 2.9 million hectares are directed for ethanol production (Szwarc, 2006). This number is somewhat variable, due to switching between ethanol and sugar production. Each ha planted with sugar cane can produce approximately 6,800 liters[40] of ethanol.

Sugar-Ethanol producing companies in Brazil are responsible for the processing of sugar cane into the two products. It is both an agricultural and industrial endeavor that includes choosing sugar cane varieties, planting and harvesting at the appropriate time, processing and storage. Industrial investments can either be done directly in a flexible plant (capable of producing sugar, ethanol or both) or in a single product facility (sugar or ethanol), which can later be retrofitted to produce the complementary product.

Sugar cane processing plants are highly energy efficient, since the massive bagasse and straw volumes generated by cane processing are used as fuel for the furnaces that generate the steam necessary for the process. These furnaces typically also generate surplus electrical power which is sold to local power companies. As a result, the energy efficiency ratio (energy output divided by energy input) for sugarcane ethanol production is 8.3, which compares favorably to the ratios for the other major ethanol feedstock (Szwarc, 2006).

A relatively efficient sugar plant can currently produce 107 kg (235 lb)[41] out of every metric ton of sugar cane processed, along with some syrup byproduct

[40] 1 gallon = 3.79 liters
[41] 1 kg = 2.2 lb

which can be converted to 12 liters of ethanol (3.17 gal). The same ton of sugar cane, if processed in an ethanol plant, will produce 80 liters of ethanol (21.14 gal), which is an increase of approximately 14% from 1980s levels, due to productivity gains. Thus, the mass balance for processing one ton of sugar cane is:

1 ton sugar cane = 107 kg sugar + 12 liters ethanol = 80 liters ethanol (1)

With this parity defined, and given the price signals for the two output commodities, processors can decide which mix of products they will output for every crop without switching cost once the industrial investment on a flexible plant has been made.

Stochastic modeling of ethanol and sugar prices

The discrete binomial lattice approach developed by Cox et al. (1979) for modeling the stochastic process of an underlying asset and valuing contingent options has found widespread application, since it generalizes the Black-Sholes-Merton model (1973) and addresses some of that model's restrictions. It is simple to implement, flexible to use, depends on a limited number of parameters, and converges weakly to a GBM as the time interval diminishes. However, there are instances when the underlying prices modeled do not follow a stochastic process similar to a GBM. A common example is the market price of many types of commodities, which may instead follow a mean reverting stochastic process.

Mean reverting processes are a type of Markov process where the sign and degree of the drift are dependent on the current level of a variable, which reverts to a long-term equilibrium level that we typically assume is the long-term mean. Unfortunately, relative to a GBM, a mean reverting process is more complicated to approximate with a probability lattice with binomial chance nodes. As a result, methods employing Monte Carlo simulation and discrete trinomial trees (Hull, 1999) have been developed for modeling mean reverting processes. Unfortunately both methods have drawbacks when used for valuation; simulation-based approaches are computationally intensive, especially for problems with multiple concurrent options, and trinomial trees are more difficult to implement because they require involved methodologies for specifying valid branching probabilities and lattice cell sizes to ensure convergence to the stochastic process.

The simplest form of mean reverting process is the one factor Ornstein-Uhlenbeck process, also called an Arithmetic mean reverting process, which has the form shown in Eq. (2):

$$dY_t = \eta\left(\bar{Y} - Y_t\right)dt + \sigma dz_t \qquad (2)$$

For commodity price modeling, in Eq. (2) $Y_t$ is the log of price, η is the mean reversion coefficient, $\overline{Y}$ is the log of the long term mean price, *σ* is the process volatility and *dz* is a Weiner process. The log of price is commonly used since it is generally assumed that commodity prices are lognormally distributed[42]. This is convenient, because if *Y = log(y)*, then *y* cannot be negative. The expected value and variance of the Ornstein-Uhlenbeck process are given by Eq. (3) and (4):

$$E[Y_t] = \overline{Y} + \left(Y_0 - \overline{Y}\right)e^{-\eta T} \tag{3}$$

$$Var[Y_t] = \frac{\sigma^2}{2\eta}\left(1 - e^{-2\eta T}\right) \tag{4}$$

These expressions show that when $T \to \infty$, then $VAR[Y_t] \to \frac{\sigma^2}{2\eta}$, as opposed to $\infty$, as is the case with a GBM. Other variations of mean reverting processes include the Geometric Mean Reverting model (Dixit and Pindick, 1994), given by $dY_t/Y_t = \eta\left(\overline{Y} - Y_t\right)dt + \sigma dz_t$, and a similar model proposed by Battacharya (1978), which is given by $dY_t = \eta\left(\overline{Y} - Y_t\right)dt + \sigma Y_t dz_t$. The logic of a mean reverting process comes from micro-economics; when prices are low (or below their long-term mean), demand for the product tends to rise while its production tends to diminish. This is because the consumption of a commodity with low prices will typically increase, while the lower revenues for the producing firms will lead them to postpone investments and cease production, reducing the availability of the commodity. The opposite will happen if prices are high (or above their long term-mean). Empirical studies such as Pindyck and Rubinfeld (1991) have confirmed that prices of many commodities follow mean reverting stochastic processes. In the case of oil price modeling, Dias (2005) provides a survey of the different stochastic processes that have been used, most of which have a mean reverting component (Table 1).

Table 1 Classes of models used for oil price

| **Type of Stochastic Model** | **Name of Model** | **Main References** |
|---|---|---|
| Unpredictable Model | Geometric Brownian Motion (GBM) | Paddock, Siegel & Smith (1988) |
| Predictable Model | Pure Mean Reverting Model (Mean reverting process) | Schwartz (1997, model 1) |

[42] See Appendix 1 for the relationship between the processes for Price and Log(Price)

| | | |
|---|---|---|
| More Robust Models | Two and Three Factor Model | Gibson & Schwartz (1990), and Schwartz (1997, models 2 & 3) |
| | Reversion to Uncertain Long-Run Level | Pindick (1999) and Baker, Mayfield & Parsons (1998) |
| | Mean Reversion with Jumps | Dias & Rocha (1999) |

The applicability of these processes to different types of problems is a complicated issue. Although the GBM is extensively used to model a wide range of uncertain variables and offers great ease of use, mean reverting processes are generally considered better-suited to model commodities prices and interest rates. On the other hand, we note that it may still be possible and appropriate to use GBM models in such cases as short duration price series. Another issue is that single factor pure mean reverting models (Ornstein-Uhlenbeck processes) with a fixed long-term equilibrium level can be too simplistic in some instances, and might not perform any better than a GBM model. In such cases, the best approach might be to combine a mean reverting model with a GBM for the equilibrium level, as proposed by Schwartz and Smith (2000), although such process are more difficult to implement for valuation purposes.

Binomial approximation to mean reverting processes

Nelson and Ramaswamy (1990) developed a general approach for discrete time approximations of stochastic processes which is applicable to mean reverting Ornstein-Uhlenbeck processes. Their approach is a simple binomial sequence of *n* periods of length $\Delta t$ with a time horizon $T = n\Delta t$ that models the general form stochastic differential equation $dY = \mu(Y,t)dt + \sigma(Y,t)dz$ as:

$Y_t^+ \equiv Y + \sqrt{\Delta t}\sigma(Y,t)$ (up move) (5a)

$Y_t^- \equiv Y - \sqrt{\Delta t}\sigma(Y,t)$ (down move) (5b)

$q_t \equiv 1/2 + 1/2\sqrt{\Delta t}\dfrac{\mu(Y,t)}{\sigma(Y,t)}$ (probability of up move) (5c)

$1-q_t$ (probability of down move) (5d)

Substituting in the Ornstein-Uhlenbeck parameters from Eq. (2) into Eq. (5a-d) yields:

$Y_t^+ \equiv Y + \sqrt{\Delta t}\sigma$ (up move) (6a)

$$Y_t^- \equiv Y - \sqrt{\Delta t}\sigma \qquad \text{(down move)} \qquad (6b)$$

$$q_t \equiv 1/2 + 1/2\sqrt{\Delta t}\,\frac{\eta\left(\bar{Y} - Y_t\right)}{\sigma} \qquad \text{(probability of up move)} \qquad (6c)$$

$$1\text{-}q_t \qquad \text{(probability of down move)} \qquad (6d)$$

Since the calculated probabilities cannot be negative or greater than 1, it is necessary to censor the values of $q_t$ to the range between 0 and 1, as shown in Eq. (7):

$$q_t = \begin{cases} 1/2 + 1/2\eta\left(\bar{Y} - Y_t\right)\sqrt{\Delta t}/\sigma & 0 \le q_t \le 1 \\ 0 & q_t \le 0 \\ 1 & q_t \ge 1 \end{cases} \qquad (7)$$

This can be summarized in the following nested formula:

$$q_t = \max\left(0, \min\left(1, 1/2 + 1/2\sqrt{\Delta t}\,\frac{\eta\left(\bar{Y} - Y_t\right)}{\sigma}\right)\right). \qquad (8)$$

In the branching of the binomial lattice, the up and down state space increments are $\Delta Y^+ = \sigma\sqrt{\Delta t}$ and $\Delta Y^- = -\sigma\sqrt{\Delta t}$, respectively. If *Y* is the log of the price *y*, then the increments are $\Delta y^+ = e^{\sigma\sqrt{\Delta t}}$ and $\Delta y^- = e^{-\sigma\sqrt{\Delta t}}$. These are the familiar forms utilized in the GBM lattice modeling, and result in a binomial value lattice similar to the one obtained from a GBM (Cox et al., 1979). The calculated probabilities and censoring of these probabilities will yield a model that converges weakly to a mean reverting process, as was shown by Nelson and Ramaswamy (1990). It is important to note that at each node of the lattice, the probability of an up move ($q_t$) will change depending on $Y_t$ according to Eq. (8), which is what allows the mean reverting behavior to be modeled.

Converting to a risk neutral process

There are two ways of discounting cash flows for the purpose of valuation: 1) directly using the risk adjusted rate and 2) using a Martingale probability measure with the risk-free rate. The second approach is typically used in valuing options because it is difficult to determine the appropriate risk-adjusted rate when real options are present.

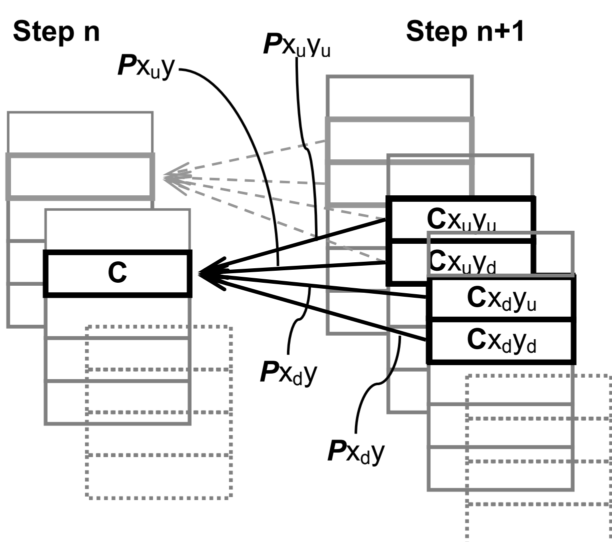
In the Martingale probability approach, the stochastic process used for the value of the underlying asset is adjusted according to the risk level so that future payoffs can be discounted at the risk free rate. As an example, when a discrete model of a GBM stochastic process is used, the probability of an up move in the lattice is set to $p = \frac{1+r-d}{u-d}$, where *r* is the risk-free discount rate, *u* is the factor for a upward movement in the lattice and $d = \frac{1}{u}$ is the corresponding factor for a downward move (Cox et al., 1979).

With a mean reverting process, a similar adjustment is made to the probability calculations. To do this, we substitute $\bar{Y}' = \bar{Y} - \frac{\pi}{\eta}$ for $\bar{Y}$ in Eq. (8), where $\bar{Y}'$ is the risk-adjusted long term mean, $\bar{Y}$ is the un-adjusted long term mean, $\pi$ is the project risk premium, and $\eta$ is the mean reversion speed coefficient (Dixit and Pindyck, 1994 and Schwartz, 1997). More detailed discussion of the basis for the risk adjustment can be found in Appendix 2.

Bivariate discrete modeling of mean reverting processes

The modeling approach used in this paper is based on a bivariate lattice combining two uncertain variables. The notion of a bivariate lattice was first introduced by Boyle (1988) and was also later discussed by Copeland and Antikarov (2003), who proposed a "quadranomial" lattice model with two correlated uncertainties, each following a GBM. In order to construct a bivariate lattice, the joint probabilities of each of the four outgoing branches at each node must be determined (Fig. 1). As shown in the figure, to value an option *C* at time step *n* in such a lattice, we sum of the values at the four subsequent nodes at time step *n+1* multiplied by their respective risk-neutral probabilities, discounted at the risk free rate *r*.

Fig.1. Option value in a bivariate lattice.



It follows that this dual variable approach is particularly useful for valuing real options to switch. Gonçalves et al. (2005) analyze a production switching option available to a Brazilian flexible sugar-ethanol plant, and model the underlying uncertainties using two distinct GBM diffusion processes. However, as noted by Schwartz (1998), Laughton and Jacoby (1993), and others, if commodity prices are indeed mean reverting, then a lognormal geometric Brownian diffusion model can significantly overestimate uncertainty in the resultant cash flows from a project, and result in overstated option values. Therefore, the Copeland and Antikarov quadranomial model cannot be directly used for modeling two one factor mean reverting processes, since the probabilities at each branch must change throughout the lattice. Kulatilaka (1993) provides an approach for valuing a switching option where the two input variables are modeled as a single mean reverting process for relative price; however, this approach is limited to cases with relatively simple value functions that can be written in terms of this type of variable.

To value switching options in more general cases we need to jointly model two variables, such the log of two commodity prices, $X = \ln(x)$ and $Y = \ln(y)$, each following a different mean reverting stochastic process:

$$dX = \eta_x\left(\overline{X} - X\right)dt + \sigma_x dz \quad (9a)$$

$$dY = \eta_y\left(\overline{Y} - Y\right)dt + \sigma_y dz \quad (9b)$$

with increments:

$$\Delta_X = \sigma_x\sqrt{\Delta t} \quad (10a)$$

$$\Delta_Y = \sigma_y\sqrt{\Delta t}\,. \quad (10b)$$

For these two processes, we can specify the joint probabilities for both *X* and *Y* moving up ($p_{uu}$), *X* moving up and *Y* moving down ($p_{ud}$), *X* moving down and *Y* moving up ($p_{du}$), and both *X* and *Y* moving down ($p_{dd}$), respectively as:

$$p_{uu} = \frac{\Delta_X\Delta_Y + \Delta_Y\nu_X\Delta t + \Delta_X\nu_Y\Delta t + \rho\sigma_X\sigma_Y\Delta t}{4\Delta_X\Delta_Y} \quad (11a)$$

$$p_{ud} = \frac{\Delta_X\Delta_Y + \Delta_Y\nu_X\Delta t - \Delta_X\nu_Y\Delta t - \rho\sigma_X\sigma_Y\Delta t}{4\Delta_X\Delta_Y} \quad (11b)$$

$$p_{du} = \frac{\Delta_X\Delta_Y - \Delta_Y\nu_X\Delta t + \Delta_X\nu_Y\Delta t - \rho\sigma_X\sigma_Y\Delta t}{4\Delta_X\Delta_Y} \quad (11c)$$

$$p_{dd} = \frac{\Delta_X \Delta_Y - \Delta_Y \nu_X \Delta t - \Delta_X \nu_Y \Delta t + \rho \sigma_X \sigma_Y \Delta t}{4 \Delta_X \Delta_Y} \tag{11d}$$

where $p_{uu} + p_{ud} + p_{du} + p_{dd} = 1$.

These probabilities are dependent on the drift for each process as well as the correlation $\rho$ between the increments of the two processes. The drifts of the respective processes are given by: $\nu_X = \eta_x \left(\overline{X} - X_t\right) - 1/2\,\sigma_x^2$ and $\nu_Y = \eta_y \left(\overline{Y} - Y_t\right) - 1/2\,\sigma_y^2$.

Unfortunately, a four branch node of such a joint process cannot be directly censored when necessary, as the mean reverting model requires. Hahn and Dyer (2006) solve this issue by applying Baye's Rule to decompose the joint probabilities into the products of marginal and conditional probabilities. To obtain the conditional probabilities, the joint probabilities are divided by the marginal probabilities for $X$,

$$p_u = \frac{1}{2} + \frac{1}{2}\frac{\nu_X \Delta t}{\Delta_X} \tag{12a}$$

$$p_d = \frac{1}{2} - \frac{1}{2}\frac{\nu_X \Delta t}{\Delta_X}, \tag{12b}$$

which yields the following conditional probabilities for $Y$:

$$p_{u|u} = \frac{\Delta_X \left(\Delta_Y + \Delta t \nu_Y\right) + \Delta t\left(\Delta_Y \nu_X + \rho \sigma_X \sigma_Y\right)}{2\Delta_Y \left(\Delta_X + \Delta t \nu_X\right)} \tag{13a}$$

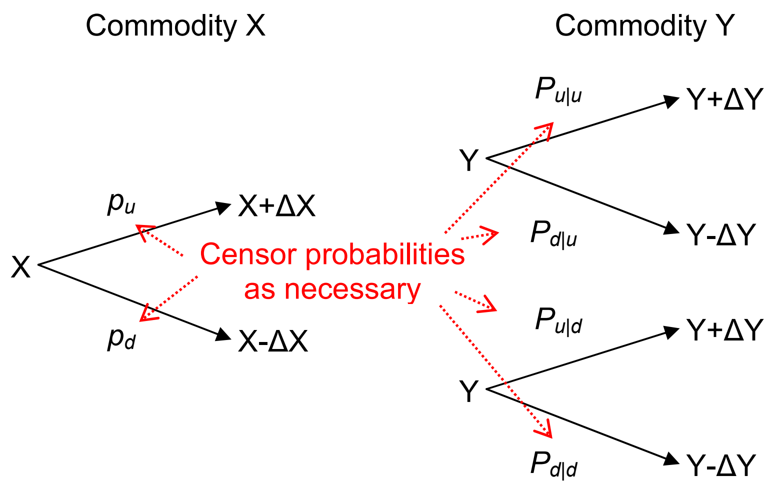
$$p_{d|u} = \frac{\Delta_X \left(\Delta_Y - \Delta t \nu_Y\right) + \Delta t\left(\Delta_Y \nu_X - \rho \sigma_X \sigma_Y\right)}{2\Delta_Y \left(\Delta_X + \Delta t \nu_X\right)} \tag{13b}$$

$$p_{u|d} = \frac{\Delta_X \left(\Delta_Y + \Delta t \nu_Y\right) - \Delta t\left(\rho \sigma_X \sigma_Y + \Delta_Y \nu_X\right)}{2\Delta_Y \left(\Delta_X + \Delta t \nu_X\right)} \tag{13c}$$

$$p_{d|d} = \frac{\Delta_X \left(\Delta_Y - \Delta t \nu_Y\right) - \Delta t\left(\Delta_Y \nu_X - \rho \sigma_X \sigma_Y\right)}{2\Delta_Y \left(\Delta_X + \Delta t \nu_X\right)}. \tag{13d}$$

Note that in this formulation, $p_{u|u} + p_{d|u} = 1$ and $p_{u|d} + p_{d|d} = 1$. These probabilities allow the four branch node with joint probabilities to be split into a marginal-conditional sequence (Fig. 2) where all probabilities can again be censored in the manner of Eq. (8).

Fig. 2. Marginal-conditional node sequence for two commodities.




Switching option valuation methodology

In this section, we analyze the incremental value due to the flexibility afforded sugar cane processors to switch production from ethanol to sugar/ethanol or vice-versa in any given time period.

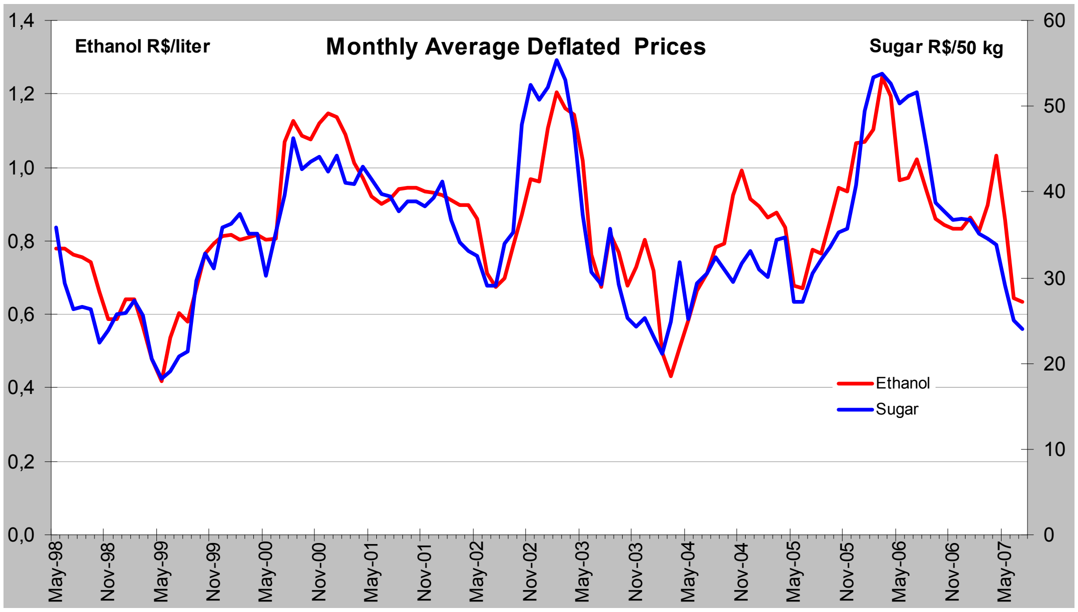
Data collection

Data based on daily observations of sugar and ethanol prices directly paid to processors was obtained from CEPEA (2007) and are available online. For ethanol, prices are a mean between anhydrous and hydrated alcohol (70% of the former, and 30% of the latter, both produced in the facilities in these proportions). Although we only used prices paid in the state of São Paulo, they were assumed to be representative of the general case due to the fact that this state produces about 64% of these commodities in Brazil and they are a reference widely utilized in research on the ethanol-sugar sector (Pretyman, 2005). Prices are in local currency, R$ (Reais)[43], and for ethanol are given per liter (R$/l), whereas for sugar they are in 50 Kg bags (R$/50 kg), which is the standard unit in the sector.

Both series of prices were collected from May 1998 to July 2007 on a monthly average basis, resulting in 112 data periods (almost 10 years), and were deflated by the most widely used Brazilian inflation indicator, IGP-DI (FGV), also on a monthly basis. In Fig. 3 they are plotted together on different scales for visual comparison. All prices shown in the figure are in local currency, R$ (Real), which currently trades for about $R\$1.00 \cong US\$0.55$.

[43] As of November 2007, the going exchange rate was R$ 1.8 / USD.

Fig. 3. Ethanol and sugar price data series.




Source: CEPEA (2007), UNICA (2007).

The model parameters were estimated using a procedure based on the methodology outlined by Dixit and Pindick (1994) which allows simultaneous estimation of all parameters from discrete time series.44 From these series we were able to calculate the parameters needed for the mean reverting processes used in the model. For both series, a simple linear regression was run with $\log(P_t) - \log(P_{t-1})$ as the dependent variable and $\log(P_{t-1})$ as the independent variable. The resulting regression equation is therefore $\log\left(P/P_{t-1_t}\right) = \beta_0 + \beta_1 \log\left(P_{t-1}\right) + \varepsilon$.

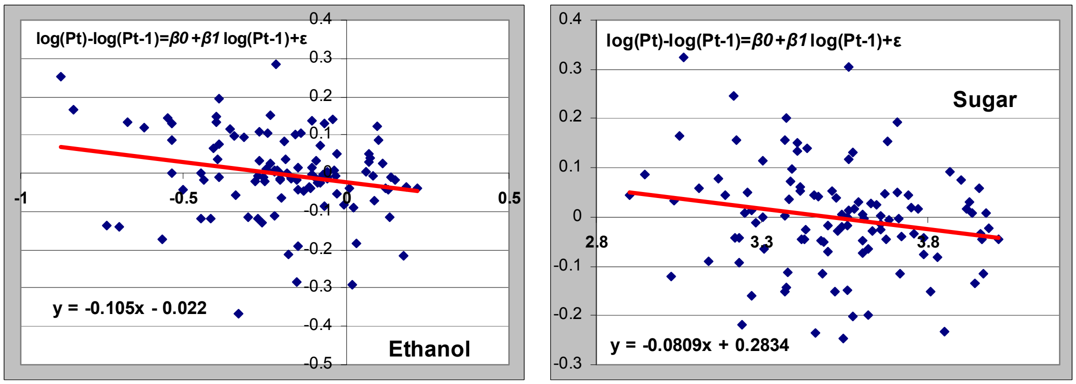
The mean reverting coefficients $\eta$ can then be obtained from the regression output as $\eta = \dfrac{-\log(\beta_1 + 1)}{\Delta t}$ and the volatility of the series and long term mean are given by $\sigma = \sigma_\varepsilon \sqrt{\dfrac{2\log\left(\beta_1 + 1\right)}{\Delta t\left[\left(\beta_1 + 1\right)^2 - 1\right]}}$, where $\sigma_\varepsilon^2$ is the variance of the

---

[44] See Appendix 3 for details on the parameter estimation procedure

regression's errors, and $\overline{P} = \exp\left[ -\frac{\beta_0}{\beta_1} + \frac{\sigma^2}{2\eta} \right]$, respectively. Plotted regression lines and their corresponding equations for our data can be seen in Fig. 4.

Fig. 4. Regression to determine stochastic process parameters.




The correlation calculated between the return of the two series (sugar and ethanol) was found to be ρ = 0.5786. All stochastic process parameters are summarized in Table 2. As can be observed, prices for both commodities are currently below their long-term means.

Table 2 Stochastic process parameters for ethanol and sugar

| | **Sugar** | | | **Ethanol** | | |
|---|---|---|---|---|---|---|
| **Initial Price** | 24.29 R$ / 50 kg bag | | | 0.643 R$ / liter | | |
| **Long-term mean** | 35.74 R$ / 50 kg bag | | | 0.8526 R$ / liter | | |
| | Month | Semester | Year | Month | Semester | Year |
| **Volatility ($\sigma$)** | 11.02% | 27.00% | 38.18% | 10.52% | 25.77% | 36.45% |
| **Mean reversion coefficient ($\eta$)** | 0.1109 | 0.6657 | 1.3314 | 0.0843 | 0.5060 | 1.0120 |

Option value model methodology

The model we use measures the present value of cash flows generated from processing 2,600,000 tons of sugar cane annually, either as ethanol or as sugar, with some ethanol as a by product (Gonçalves, 2006). This represents a relatively large processing plant, equivalent to 1% of the total Brazilian sugar cane processing capacity. The time horizon chosen is five years, in half year periods ($T$ = 5, $n$ = 10, $\Delta t$ = 0.5). The project risk premium ($\pi$) of 6% was estimated as the ethanol-sugar sector deflated risk premium, calculated from listed companies in the Sao Paulo stock exchange. It is coincidentally very close to the present deflated risk free rate ($r$) of 6% in Brazil, a figure which is based on the real interest rate of Brazilian government bonds, as well as the risk free rates used in similar works (Dias, 2005 and Gonçalves, 2005).

With these parameter values, the risk adjusted long term means are:

$$\overline{x}' = e^{\left(\overline{X} - \frac{\pi}{\eta}\right)} = e^{\left(\ln(0.8526) - \frac{6\%}{1.012}\right)} = 0.8150 \text{ R\$/liter for Ethanol} \tag{14a}$$

$$\overline{y}' = e^{\left(\overline{Y} - \frac{\pi}{\eta}\right)} = e^{\left(\ln(35.74) - \frac{6\%}{1.3314}\right)} = 33.687 \text{ R\$/50 kg for Sugar} \tag{14b}$$

Project cash flow values are calculated as follows:

For pure ethanol processing, the projected ethanol price (R$/liter) is multiplied by 80 (liters per ton of sugar cane) and then by 0.96% (4% discount due sales tax). This result, minus 29.67 R$/ton (variable cost), is then multiplied by 2,600 (yearly sugar cane tons processed/1,000). The final result is obtained by subtracting fixed costs of R$ (1,000) 28,726, and multiplying by 81% to reflect the income tax.

For sugar processing, sugar price (in R$/50 Kg bags) is multiplied by 2.14 (107 kg of sugar from one ton of sugar cane, in 50 Kg bags) and then by 0.84 (16% discount due sales tax), plus 12 (liters of by-product of ethanol per ton of sugar cane) multiplied by ethanol price (R$/liter), and then by 0.96 (4% discount due sales tax). This result, minus 31.94 R$/ton (variable cost), is then multiplied by 2,600 (yearly sugar cane tons processed/1,000). The final result is again obtained by subtracting fixed costs of R$ (1,000) 28,726, and multiplying by 81% to reflect the income tax.

For a flexible plant, the higher of these two values is chosen. This follows, because even with the flexibility of choosing any mix between the two outputs, a corner solution is always the optimal one due to the linear relationship between cash flow and product prices.

Fixed and variable costs account not only for industrial, but also for agricultural costs, and the latter is the same for both processes (Gonçalves et al., 2006). These algorithms are summarized in Eq. (15) and (16).

$$CF_{Eth} = \left(\left[\left(80P_{Eth}[1-4\%]\right) - 29.67\right]2{,}600 - 28{,}726\right)\left(1-19\%\right) \tag{15}$$

$$CF_{Sug} = \left(\left[\left(2.14P_{Sug}[1-16\%] + 12P_{Eth}[1-4\%]\right)2{,}600 - 31.94\right] - 28{,}726\right)\left(1-19\%\right) \tag{16}$$

The deterministic cases using these equations and expected values for the two commodity prices are listed in Table 3.

Table 3 Deterministic base case economics

| | Process: | MRM (R$ 000) |
|---|---|---|
| Base cases: | Pure Ethanol | 176,584 |
| | Sugar (ethanol byproduct) | 209,716 |

To model the variability in project value, lattices for both commodities were constructed using the approach described in Section 3.1, with the results shown in Fig. 5 and Fig. 6. These two lattices were then jointly modeled according to their correlation using the approach described in Section 3.3. The marginal probabilities of an up move in the lattice are dependent on the log of the price value at each node, according to Eq. (8). Then, as we have split the price movement into marginal and conditional steps, as in Fig. 3, we generate the conditional probabilities using the expressions given in Eq. (13a-d). Although this approach is numerically intensive, it is relatively straightforward to implement in an Excel worksheet.

Fig. 5. Risk neutral process lattice for sugar.

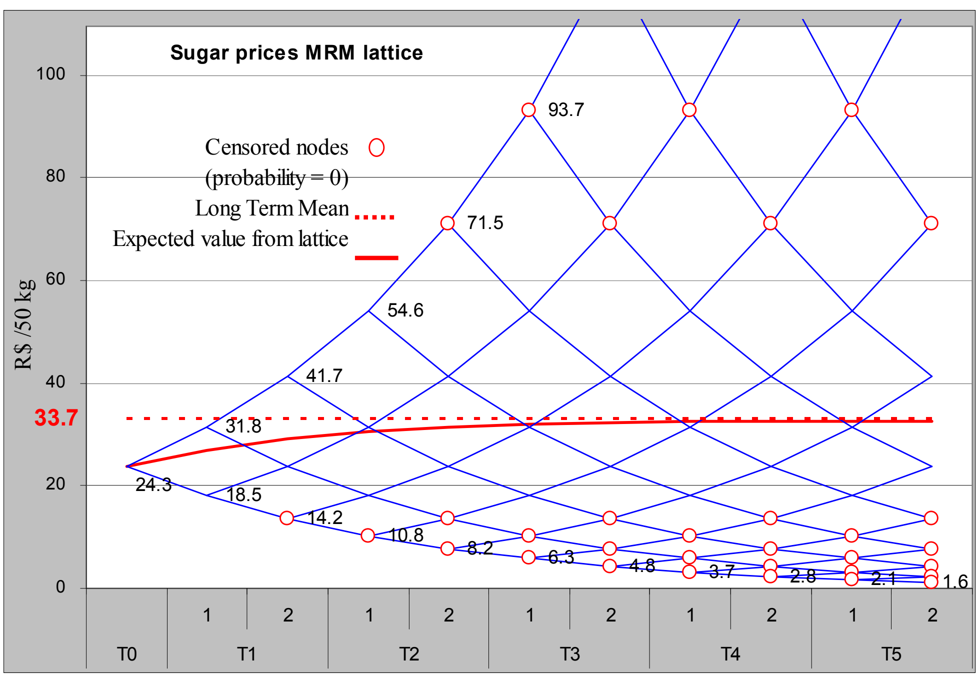
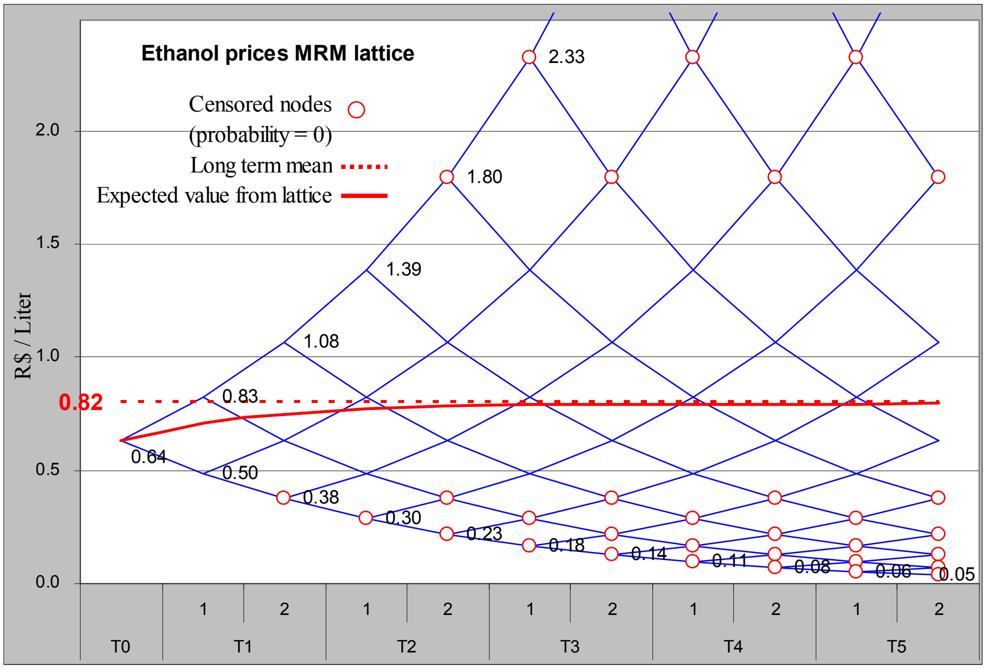



Fig. 6. Risk neutral process lattice for ethanol.




With the resulting bivariate price lattice, an algorithm is applied to each node to produce an optimal decision regarding the option available to the producer; either to produce ethanol or to produce sugar and some ethanol as a by-product during the semester. The algorithm is outlined in the following equation:

$$Max\left[CF_{Ethanol}, CF_{Sugar}\right]\left(0.5\frac{semester}{year}\right) \qquad (17)$$

Beginning one time period from the end of the bivariate lattice (in period 9 out of 10), we then apply Eq. (17) and work backwards recursively to period 0, calculating the value at each node as the discounted sum, at the risk free rate, of the four subsequent nodes in the lattice weighted by the joint probabilities, which are in turn the result of multiplying the marginal probabilities of ethanol (which was chosen to be the first variable) by the conditional probabilities for sugar at each node, and adding the value of the cash flow at the node considered. We end up at period 0 with the present value of 1 ton of processed sugar cane per month, during five years, with the semester option of choosing between to two possible outputs.

## Results

### Results from bivariate lattice model

Using the method described in the previous section, we obtained a result of R$ 240,009,000 for the present value of a flexible plant processing 2,600,000 tons of sugar cane every year during five years. This can then be compared to the values of R$ 176,584,000 for an ethanol only producing plant and R$

209,716,000 for a sugar producing plant (which produces some ethanol as by product) that are shown in Table 3. These results represent increases of 35.9%and 14.4% in value, respectively, relative to the non-flexible plants. Thus, the percent value of the switching option is 14.4% (flexible production compared with the highest value base case) relative to the case with no flexibility, and the absolute incremental value of the switching option is R$ 30,293,000. It is interesting to note that even with the sugar producing plant having a higher present value than the ethanol plant, the average mix of the Brazilian industry was about 51% ethanol and 49% sugar in 2005, with the ethanol fraction increasing (Pretyman, 2005). We can conclude that even if it is only based on intuition, processors are well aware of the value of flexibility, and are therefore investing in flexible plants.

Comparison with results from a simulation model

Simulation models can be difficult to implement for more complex options, particularly where early exercise is possible, however they can be used for relatively simple call, put, or switching options. Since the sugarcane processing switching option can be exercised in each period without costs (after the initial cost of investment in a flexible plant) and since the option is also independent of all decisions made before or after a particular point, we can reconstruct the valuation problem as a bundle of European options. Thus, we have an alternative means of obtaining the value of the switching option. Although the computational disadvantages of simulation based approaches for these types of problems are well-documented (Tseng and Lin, 2007), we can nonetheless obtain results via simulation with the same input data and then use those results to validate the results obtained with the bivariate mean reverting lattice approach.

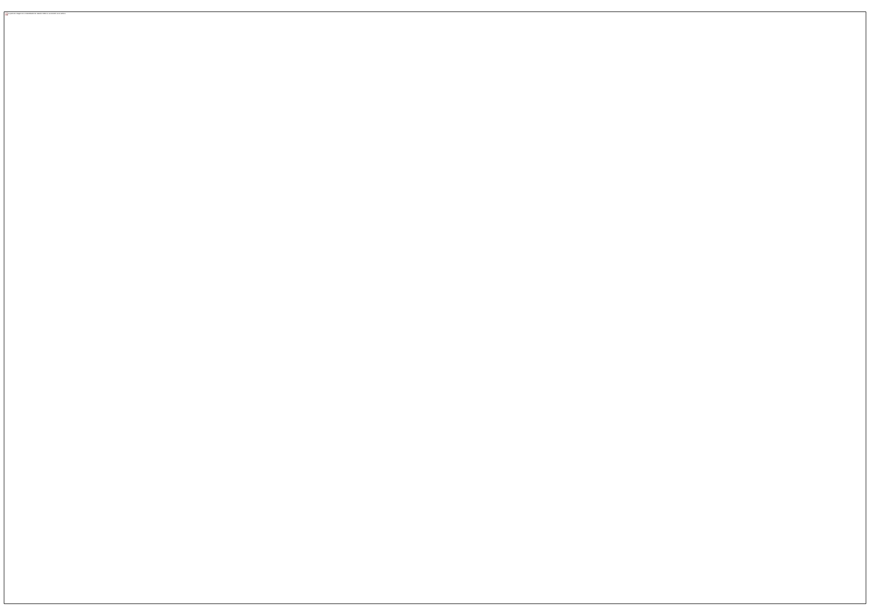
The value obtained from a simulation with 100,000 iterations using @RISK® was R$ 235,109,000 for the flexible plant, which is -2.04% different from the result from the bivariate lattice method. This difference is due to the discrete increment in the bivariate lattice of $\Delta T = 0.5$, which may still be considered relatively large; however, we could decrease the difference further by simply decreasing $\Delta T$.

Comparison with results when GBM price processes are assumed

*As we mentioned previously, the GBM diffusion process is very simple and straightforward to model and implement, but its drawback is that it may not fit the empirical data. We have shown that for the two commodities analyzed in this paper, the mean reverting diffusion process provides a reasonable fit, whereas a GBM may not be as appropriate. To illustrate, in Fig. 7 and Fig. 8 we show the projections of ethanol and sugar mean prices, respectively, as well as the 90% confidence intervals derived from both the mean reverting process and GBM.*

Fig. 7.  Ethanol price projections (non-risk neutral).


Fig. 8.  Sugar price projections (non-risk neutral).



In order to compare valuation results, the same case was modeled assuming prices followed a GBM process, with the results of the deterministic cases and option value shown in Table 4.

Table 4 Comparison of results under mean reverting process vs. GBM (R$ 000)

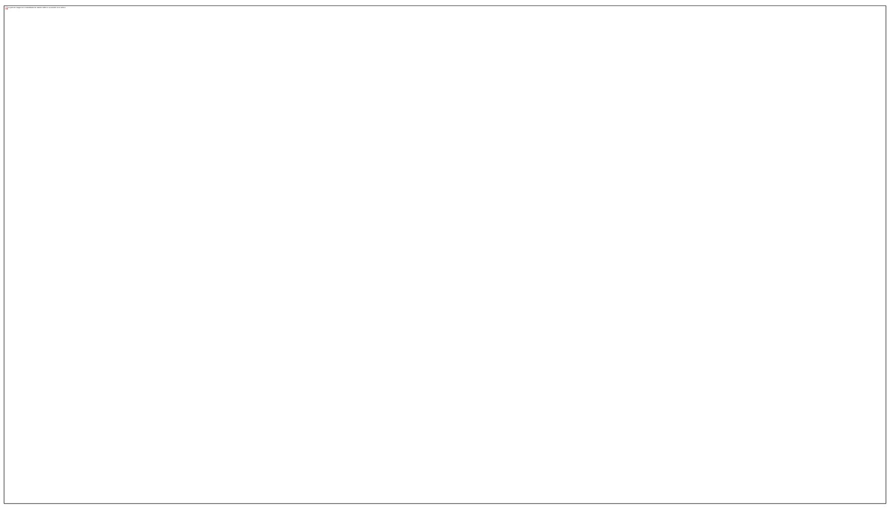
| | **Process:** | **MRM** | **GBM** | Difference |
|---|---|---|---|---|
| Base cases: | Pure Ethanol | 176,584 | 152,405 | -13.7% |
| | Sugar (ethanol byproduct) | 209,716 | 154,376 | -26.4% |
| With option: | Flexible plant | 240,009 | 293,496 | 22.3% |
| | Option Value | 30,293 | 139,120 | |
| Flexible plant compared to base cases: | Pure Ethanol | 35.92% | 92.6% | |
| | Sugar (ethanol byproduct) | 14.44% | 90.1% | |

The bivariate lattice for two GBM's is indeed simpler to implement following the Copeland and Antikarov (2001) framework; however, the base case results in Table 4 show differences of -13.7 % and -26.4 %, respectively, for the two projects, relative to the mean reverting process model, illustrating the effect of the very low or even negative drift in prices resulting from the GBM model. The value for the flexible plant obtained in this way, using the same volatility and price correlation parameters of the mean reverting process case is R$ 293,496,000, and the option value is R$ 139,120,000. These are 92.6% and 90.1% above the base GBM cases of ethanol and sugar, respectively, and 22.3% above the flexible mean reverting process case, which indicates that the use of a GBM in this case significantly overestimates the value of the switching option. The underestimation bias when using a GBM prices process is mostly due to the fact that the starting prices of sugar and ethanol are very low compared to their long term means. Thus, even with a positive drift, the GBM five year projection will still result in undervaluation of the respective projects. On the other hand, the increasing variance of a GBM, which is proportional to $t$, will significantly overvalue the flexible plant and the switching option value.

Sensitivity of results to correlation between price processes

Due to the high correlation between the two uncertain variables (prices of sugar and ethanol) the sensitivity of the option to this parameter was investigated. The results are summarized in Fig. 9, which plots the value of the switching option versus the correlation between price processes. The figure shows that the switching option value increases rapidly as the correlation diminishes, ultimately arriving at an option value of R$ 49,759,000 (24.07% above the base sugar case) when there is no correlation ($\boldsymbol{\rho}$ = 0) used in the bivariate lattice.

Fig. 9. Value of conversion options as a function of correlation.



## Conclusions

Ethanol is currently regarded as one of the most promising automotive fuels of the future. The basic economic case for ethanol has improved significantly in recent years, and ethanol is also viewed as being more environmentally friendly than hydrocarbon based fuels such as gasoline and diesel, since it is derived from renewable sources. Also, since its manufacturing process is relatively labor intensive, it is viewed favorably in developing countries with high unemployment rates. Clearly, ethanol is now a technologically feasible resource with the potential to replace a significant portion of the world's fossil fuel use.

In this paper, we have modeled the prices of ethanol and sugar as mean reverting stochastic processes, using a procedure to estimate the process parameters from empirical market data, and have implemented a computationally efficient, but precise and flexible framework for modeling the option value associated with a flexible ethanol production process. Our results demonstrate that sugar cane based processors do indeed derive additional value from a flexible production process, even under the assumption of mean reverting prices, and benefit from a natural hedge in the market for sugar, a well established commodity. This is an important consideration for potential investors in ethanol's still developing world market. It is also important for policy-makers considering the degree to which ethanol production should be supported with government subsidies in developing markets.

We have also demonstrated that, although a GBM is much simpler to implement as a discrete binomial lattice relative to a mean reverting process, using GBM price models in this problem yielded erroneously higher results relative to the case where we used mean reverting price models, which more accurately depict the price evolution over time for many commodities. Finally, we investigated the sensitivity of the switching option value to the correlation between ethanol and sugar price processes and, as expected, found that the value increased when the two prices moved independently, and that it would continue to increase if they became negatively correlated. This implies that the effect of correlation may become an important dynamic, should the prices of sugar and ethanol begin to decouple as the ethanol market continues to develop.

**Appendix 1: Transformation to stochastic process for Log(Price)**

Given that *S* follows the geometric mean reversion process:

$$dS = \eta\left[\log\left(\bar{S}\right) - \log\left(S\right)\right]Sdt + \sigma Sdz \text{ ,}$$

where $\bar{S}$ is the long term mean price, we can apply Itô's lemma with $Y = \log(S)$:

$$dY = \frac{1}{2}\frac{\partial^2 Y}{\partial S^2}dS^2 + \frac{\partial Y}{\partial S}dS + \frac{\partial Y}{\partial t}$$

Substituting in $\frac{\partial Y}{\partial S} = \frac{1}{S}$, $\frac{\partial^2 Y}{\partial S^2} = -\frac{1}{S^2}$, $\frac{\partial Y}{\partial t} = 0$ and $dS^2 = S^2\sigma^2 dt$ yields

$$dY = -\frac{1}{2}\frac{S^2\sigma^2}{S^2}dt + \frac{1}{S}\left(\eta\left[\log\left(\bar{S}\right) - \log\left(S\right)\right]Sdt + \sigma Sdz\right) \text{, or}$$

$$dY = \eta\left[\left(\log\left(\bar{S}\right) - \frac{\sigma^2}{2\eta}\right) - \log\left(S\right)\right]dt + \sigma dz$$

which is the process followed by $Y = \log(S)$, in terms of the same parameters.

By comparing the processes for *Y* and *S*, we can see the relationship between $\bar{Y}$ and $\bar{S}$;

$$\bar{Y} = \log\left(\bar{S}\right) - \frac{\sigma^2}{2\eta} \text{ ,}$$

which is an important result for the estimation of stochastic process parameters for the Log(Price) process from empirical price data.

## Appendix 2: Adjustment of long-term mean for a risk neutral process

A standard technique in valuation of commodity-related investments is to apply a risk premium in the form of an adjustment to the drift of the stochastic process for the commodity price. If the process can be adjusted so that the drift corresponds to a risk neutral probability measure, then all cash flows can be discounted at the risk free discount rate[45]. This approach is formally justified by assuming that the state variable is priced according to the intertemporal asset pricing models developed by Merton[46] and Cox, Ingersoll, and Ross[47].

In the case of a risk adjusted process, the risk adjusted discount rate is $\mu = \alpha + \delta$, where $\mu$ is the risk adjusted discount rate, $\alpha$ is the process drift and $\delta$ is the process dividend yield. Thus the drift of the risk adjusted process can be expressed as $\alpha = \mu - \delta$. With a risk-neutral format, the drift $\alpha$ of the process, is replaced by $r - \delta$, where $r$ is the risk free rate.

If we consider the particular case of the single factor Ornstein-Uhlenbeck process, which is given by:

$$dY_t = \eta\left(\overline{Y} - Y_t\right)dt + \sigma dz_t ,$$

then the process drift is $\alpha = \eta\left(\overline{Y} - Y\right)$. We note that, in contrast to a GBM, the dividend yield is not constant; rather, it is a function of $Y$. That is, the dividend yield is $\delta = \mu - \alpha$, or $\delta = \mu - \eta\left(\overline{Y} - Y\right)$.

With this expression we can write the *risk-neutral* drift for the mean reverting process as $r - \delta = r - \mu - \eta\left(\overline{Y} - Y\right)$. Rearranging terms a few times, we have:

$$r - \delta = \eta\left(\overline{Y} - Y\right) - \left(\mu - r\right) \text{ or}$$

$$r - \delta = \eta\left\{\left(\overline{Y} - \frac{\left(\mu - r\right)}{\eta}\right) - Y\right\} .$$

Then finally, using the relationship $\pi = \mu - r$, the risk-neutral drift becomes:

---

[45] A rigorous development of the risk neutral valuation framework can be found in Duffy, D., 1992. Dynamic asset pricing theory. Princeton: Princeton, NJ.

[46] Merton, R., 1973. An intertemporal capital asset pricing model. Econometrica 41, 867-887.

[47] Cox, J., Ingersoll, J., Ross, S., 1985. An intertemporal general equilibrium model of asset prices. Econometrica 53, 363-384.

$$r - \delta = \eta \left\{ \left( \bar{Y} - \frac{\pi}{\eta} \right) - Y \right\}, \text{ or}$$

$$r - \delta = \eta \left\{ \bar{Y} - Y \right\} - \pi$$

Note that $\pi = \mu - r$ is the risk-premium. Comparing both drifts (risk-adjusted and risk-neutral) shows that the conversion to a risk-neutral process can be viewed as subtracting the normalized risk-premium $\left(\mu - r\right)/\eta$, or $\pi/\eta$, from the long run mean level $\bar{Y}$. In other words, in the risk-neutral process the prices revert toward a lower level than the real long-run level, and the subtracting term is the normalized risk-premium.

Therefore, following the convention used by Schwartz[48,49], we adjust the drift of the process by subtracting $\pi$, where $\pi$ is a parameter called the normalized risk-premium. Thus, the risk-neutral form of the single factor Ornstein-Uhlenbeck process is:

$$dY_t = \left( \eta \left( \bar{Y} - Y_t \right) - \pi \right) dt + \sigma dz,$$

which can in turn be re-written as:

$$dY_t = \eta \left( \left( \bar{Y} - \frac{\pi}{\eta} \right) - Y_t \right) dt + \sigma dz$$

This is the basis for the expressions for the risk-adjusted long-term means shown in Eq. (14a) and (14b) of the paper.

---

[48] Schwartz, E., 1995. Review of investment under uncertainty, A.K. Dixit, R.S. Pindyck. Journal of Finance 50, 1924-1928.

[49] Schwartz, E., 1997. The stochastic behavior of commodity prices: Implications for valuation and hedging. Journal of Finance 52, 923-973.

**Appendix 3: Mean reverting model parameter estimation**

The simplest form of mean reverting model is the single factor Ornstein-Uhlenbeck process,

$$dY_t = \eta(\overline{Y} - Y_t)dt + \sigma dz_t$$

where:

$Y_t$ is the logarithm of the price $S_t$: $Y_t = \log[S_t]$

$\eta$ is the mean reversion speed

$\sigma$ is the process volatility, and

*dz* is a Weiner process with a normal distribution,

the expected value and variance of the Ornstein-Uhlenbeck process are given in Dixit & Pindyck[50]:

$$E[Y_t] = \overline{Y} + (Y_0 - \overline{Y})e^{-\eta T} \quad (i)$$

$$Var[Y_t] = \frac{\sigma^2}{2\eta}\left(1 - e^{-2\eta T}\right) \quad (ii)$$

In order to determine the values for the parameters for the process, we start by writing Eq. (*i*) for a discrete time interval $\Delta t$:

$$Y_t = \overline{Y} + \left(Y_{t-1} - \overline{Y}\right)e^{-\eta\Delta t} = \overline{Y}\left(1 - e^{-\eta\Delta t}\right) + Y_{t-1}e^{-\eta\Delta t}, \text{ or}$$

$$Y_t - Y_{t-1} = \overline{Y}\left(1 - e^{-\eta\Delta t}\right) + Y_{t-1}\left(e^{-\eta\Delta t} - 1\right)$$

Substituting $Y_t = \log\left[S_t\right]$ and $\overline{Y} = \log\left(\overline{S}\right) - \dfrac{\sigma^2}{2\eta}$ and rearranging yields[51]:

$$\log\left(S_t/S_{t-1}\right) = \left[\log\left(\overline{S}\right) - \sigma^2/2\eta\right]\left(1 - e^{-\eta\Delta t}\right) + \log\left(S_{t-1}\right)\left(e^{-\eta\Delta t} - 1\right) \quad (iii)$$

Rewriting this equation in the form:

$$\log\left(S_t/S_{t-1}\right) = \beta_0 + \beta_1 \log\left(S_{t-1}\right), \quad (iv)$$

---

[50] Dixit, A., Pincyck, R., 1994. Investment under uncertainty. Princeton: Princeton, NJ.

[51] See Appendix 1 for the relationship between $\overline{Y}$ and $\overline{S}$.

we can the estimate the process parameters by simply performing a linear regression on the price series $S_t$. From the regression output, we can then obtain the parameters needed with the formulas below, which were developed by Dixit and Pindyck and modified by Dias[52].

From Eq. (*iii*) and (*iv*), we have $\beta_1 = e^{-\eta\Delta t} - 1$, or

$$\eta = -\log\left(\beta_1 + 1\right)/\Delta t \qquad (v)$$

We can also determine the volatility parameter $\sigma$ from the variance of errors obtained from the regression, $\sigma_\varepsilon^2$, and Eq. (*ii*). First we equate the two to obtain:

$$\sigma_\varepsilon^2 = \frac{\sigma^2}{2\eta}\left(1 - e^{-2\eta\Delta t}\right)$$

Then re-writing using the relationship $\left(\beta_1 + 1\right)^2 = e^{-2\eta\Delta t}$ and Eq. (*v*), yields

$$\sigma_\varepsilon^2 = -\sigma^2 \Delta t \frac{1 - \left(\beta_1 + 1\right)^2}{2\log\left(\beta_1 + 1\right)}, \quad \text{or}$$

$$\sigma = \sigma_\varepsilon \sqrt{\frac{2\log\left(\beta_1 + 1\right)}{\left[\left(\beta_1 + 1\right)^2 - 1\right]\Delta t}} \qquad (vi)$$

Finally, from Eq. (*iii*) and (*iv*), $\beta_0 = \left[\log\left(\bar{S}\right) - \sigma^2/2\eta\right]\left(1 - e^{-\eta\Delta t}\right)$.

With the relationship $-\beta_1 = 1 - e^{-\eta\Delta t}$, we obtain:

$$-\frac{\beta_0}{\beta_1} = \left[\log\left(\bar{S}\right) - \sigma^2/2\eta\right], \text{ or}$$

$$\bar{S} = \exp\left[-\frac{\beta_0}{\beta_1} + \frac{\sigma^2}{2\eta}\right]$$

Alternatively, by substituting the value of $\eta$ from Eq. (*v*), we can rewrite this as:

$$\bar{S} = \exp\left[-\frac{\beta_0}{\beta_1} + \frac{\sigma^2 \Delta t}{2\left(-\log\left[\beta_1 + 1\right]\right)}\right],$$

---

[52] Dias, M., 2008. Stochastic processes with focus in petroleum applications, Part 2 – mean reversion models. http://sphere.rdc.puc-rio.br/marco.ind/revers.html#mean-rev

and further, using the value of σ from Eq. (*vi*), as:

$$\bar{S} = \exp\left[ -\frac{\beta_0}{\beta_1} + \sigma_\varepsilon{}^2 \frac{2\Delta t \log[\beta_1 + 1]}{2\Delta t\left(-\log[\beta_1 + 1]\right)\left([\beta_1 + 1]^2 - 1\right)} \right],$$

so that we have an expression in terms of the regression coefficients:

$$\bar{S} = \exp\left[ -\frac{\beta_0}{\beta_1} + \frac{\sigma_\varepsilon{}^2}{1 - (\beta_1 + 1)^2} \right]$$

References

Baker, M., Mayfield, E., Parsons, J., 1998. Alternative models of uncertain commodity prices for use with modern asset pricing models. The Energy Journal 19, 115-148.

Bhattacharya, S., 1978. Project valuation with mean reverting cash flow streams. Journal of Finance 33, 1317-1331.

Black, F., Scholes, M., 1973. The pricing of options and corporate liabilities. Journal of Political Economy 81, 637 – 654.

Boyle, P., 1988. A lattice framework for option pricing with two state variables. Journal of Financial and Quantitative Analysis 23. 1 – 12.

Center for Advanced Studies in Applied Economics (CEPEA), 2007. Indicator of prices. http://www.cepea.esalq.usp.br/.

Copeland, T., Antikarov, V., 2003. Real options: A practitioner's guide. Texere: New York.

Cox, J., Ross, S., Rubinstein, M., 1979. Option pricing: A simplified approach. Journal of Financial Economics 7, 229–263.

Dias, M., 2005. Real options with petroleum applications. Doctoral thesis, Industrial engineering departament, PUC-Rio, Rio de Janeiro, Brazil.

Dias, M., Rocha, K., 1999. Petroleum concessions with extendible options using mean reversion with jumps to model oil prices. 3rd International conference on real options. The Netherlands.

Dixit, A., Pindyck, R., 1994. Investment under uncertainty. Princeton University Press: Princeton, NJ.

Gibson, R., Schwartz, E., 1990. Stochastic convenience yield and the pricing of oil contingent claims. Journal of Finance 45, 959-976.

Goldemberg, J., 2007. Ethanol for a sustainable energy future. Science 315, 9.

Goncalves, D., Neto, J., Brasil, H., 2006. The option of switching an investment project into an agribusiness project. 10th International conference on real options. New York.

Hahn, W., Dyer, J., 2007. Discrete time modeling of mean reverting stochastic processes for real option valuation. European Journal of Operational Research 184 (2), 534-548.

Hull, J., 1999. Options, futures and other derivatives. Prentice Hall: Upper Saddle River, NJ.

Kulatilaka, N., 1993. The value of flexibility: The case of a dual-fuel industrial steam boiler. Financial Management 33, 225-240.

Laughton, D., Jacoby, H., 1993. Reversion, timing options, and long-term decision making. Financial Management 33, 225-240.

Nelson, D., Ramaswamy, K., 1990. Simple binomial processes as diffusion approximations in financial models. The Review of Financial Studies 3 (3), 393-430.

Nelson, J., Siegel, D., and Smith, J., 1988. Option valuation of claims on real assets: The case of offshore petroleum leases." Quarterly Journal of Economics 103, 479-508.

Pindyck, R., 1999. The long run evolution of energy prices. The Energy Journal 20, 1-27.

Pindyck, R., Rubinfeld, D., 1991. Econometric models and economic forecasts. McGraw-Hill: New York.

Pretyman, A., 2005. The growth in the demand of ethanol fuel and its impact on the production mix of a sugar cane mill. Undergraduate dissertation, PUC-Rio de Janeiro, Brazil.

Renewable Fuels Association (RFA), 2007. The industry – Industry statistics." http://www.ethanolrfa.org/.

Schwartz, E., 1997. The stochastic behavior of commodity prices: Implications for valuation and hedging. Journal of Finance 52, 923-973.

Schwartz, E., 1998. Valuing long-term commodity assets. Financial Management 27, 57-66.

Schwartz, E., Smith, J., 2000. Short-term variations and long-term dynamics in commodity prices. Management Science 46, 893-911.

Szwarc, A., 2006. Issues in large scale biofuel production. International seminar on biofuels. MME – OLADE, Brasília, Brazil.

Tseng, C., Lin, K., 2007. A framework using two-factor price lattices for generation asset valuation. Operations Research 55, 234-251.

Union of the Sugar Cane Agroindustry of São Paulo (UNICA), 2007, Portal UNICA., http://www.unica.com.br.

United Nations Conference on Trade and Development (UNCTAD). 2005. Biofuels – Advantages and Trade Barriers. www.unctad.org.

# 9. Economic Aspects of Biofuels: A Comparison between Europe and Latin America♦

**Amela Ajanovic, Reinhard Haas**

Energy Economics Group, Technische Universität Wien

Gußhausstraße 27-29/373-2, A-1040 Wien, Austria.

Telefon: +431/58801-37364, Fax: +431/58801-37397

e-mail: ajanovic@eeg.tuwien.ac.at

Key words: Biofuels, Costs, Scenarios

Abstract: Over the last decades, biofuels have been more expensive than petroleum fuels, so that government incentive programs have been and still are necessary to allow biofuels to play a role in the marketplace. The production of biofuels is relatively small in almost all countries with the exceptions of USA and Brazil. The share of biofuels in total transport fuels demand in 2007 was about 20% in Brazil, 3% in the US and less than 2% in the EU.

The interest in alternative fuels is rapidly increasing all over the world, mostly because of energy supply security and environmental reasons. Currently, the most important alternative fuels are bioethanol and biodiesel.

The core objective of this paper is to investigate the possible future potential up to 2030 and the economic market prospects of biofuels for transport in different regions. The focus of this paper is a compare between Europe and Latin America.

The analysis of costs and potential is conducted in a dynamic framework till 2030. Regarding economics many factors have an impact on biofuels costs. The most important are: investment costs, fixed and variable O&M costs, feedstock costs and policies (subsidies, taxation of fuels).

Due to favorable climate conditions feedstock costs as well as total biofuels production costs are much lower in Latin America than in Europe.

---

♦ This analysis is a follow-up of our contribution on biofuels to the World Energy Outlook (WEO 2006).

In the future, through technical improvements and optimisation, biofuels cost will continue to decline. In 2030 biofuels production costs in Europe are expected to be about 33% lower than now – mainly due to technological learning and scale-effects of production, but Brazil will remain the cheapest bioethanol producer with about 40% lower costs than today.

Biofuels can provide a significant contribution especially when accompanied by comprehensive efficiency improvements and continues development towards using whole plants (2nd generation biofuels), but biofuels will not be the one and only solution for GHG reduction in the transport sector.

1.- Introduction

Interest in biofuels is increasing in many countries worldwide. Biofuels have potential to reduce fossil fuel consumption, to increase energy diversity in the transport sector, to enhance energy supply security and to reduce greenhouse-gas emissions.

Over the last decades, biofuels have been more expensive than petroleum fuels, so that government incentive programs have been and are still necessary to allow biofuels to play a role in the market place. Currently, the share of biofuels is relatively small in almost all countries with the exceptions of USA and Brazil. The share of biofuels in total transport fuels demand in 2007 was about 20% in Brazil, 3% in the US and less than 2% in the EU, see Fig.1. Many countries have set the goal to replace a significant part of fossil fuels by biofuels. In the European Union by the year 2010 5,75 percent of the energy used for transportation should be biofuels.

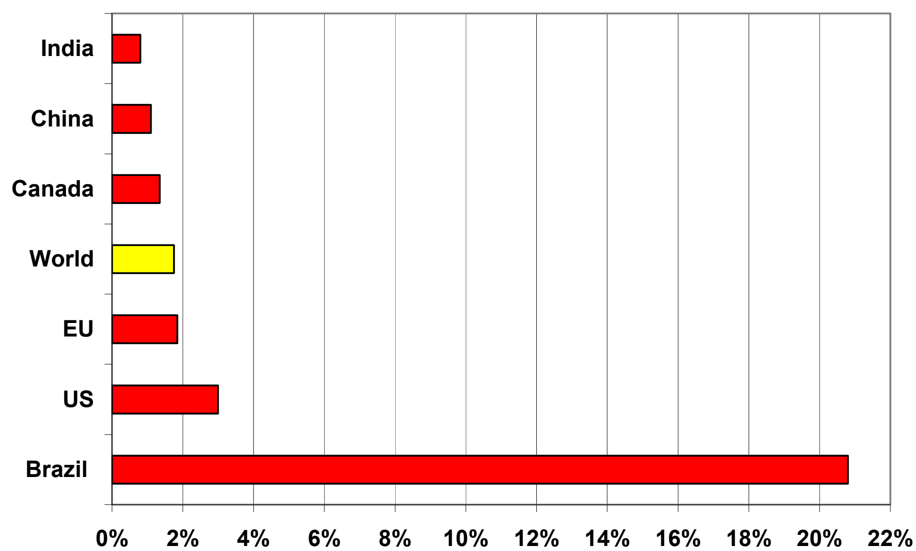



Figure 1: Share of biofuels in total road-fuel consumption in energy terms, 2007

(Source: F.O.Licht,IEA)

There are several feedstocks which have great potential for biofuels production. Prefered feedstocks for ethanol are corn, wheat, barley, sugarcane, sugar beet, sorghum, cellulosic crops and waste biomass. Depending on climatic factors different feedstocks are used in different regions. Main feedstock for bioethanol production in USA is corn and in Brazil sugarcane. Appropriate feedstocks for biodiesel production are rapeseed, soybean, sunflower, oil palm, coconut, jatropha and waste oil.

There are several biofuels production options with different limiting factors. Some of conversion processes have a very long tradition, which has been improved significantly during the past few years. Ethanol production from sugar crops is a well developed and commercial technology in Brazil. In the future, according to many studies, ethanol production from lignocellulosic sources should play a significant role because of lower feedstock costs.

The core objective of this paper is to investigate the possible future potential up to 2030 and the economic market prospects of biofuels for transport in different regions. The focus of this paper is a compare between Europe and Latin America.

The analysis of costs and potential is conducted in a dynamic framework till 2030. Regarding economics many factors have an impact on biofuels costs. The most important are: investment costs, fixed and variable O&M costs, feedstock costs and policies (subsidies, taxation of fuels).

## 2.- Biofuels production

Global production of biofuels amounted to 62 billion litres (or 36 million tonnes of oil equivalent (Mtoe)) in 2007, what is equal to about 1.8% of total global transport fuel consumption in energy terms. Brazil and the United States together account for almost three-quarters of global biofuels supply. For a long time Brazil was the world's largest producer of biofuels, but recently it has been overtaken by the United States. In Brazil, ethanol accounts for almost all biofuel output.

Ethanol production is rising rapidly in many parts of the world in response to climate change and higher oil price, which are making ethanol more competitive, especially in combination with government incentives.

Recent trends in ethanol production are shown in Fig.2. As shown, global production tripled from its 2000 level and reached 52 billion litres (28.6 Mtoe) in 2007.

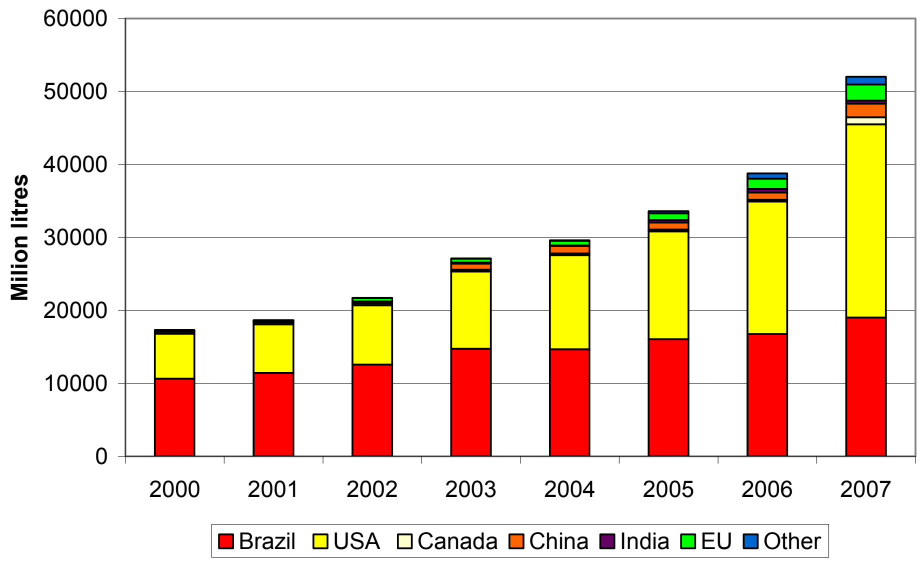



Figure 2: Recent trends in ethanol production (Source: F.O.Licht,IEA)

Total production of biodiesel worldwide was about 10.2 billion litres (7.6 Mtoe) in 2007. This is very small compared with that of ethanol production. The largest part of biodiesel, about 60% is produced in the European Union. Recently, Brazil has also started to produce biodiesel.

Recent trends in biodiesel production are shown in Fig.3.

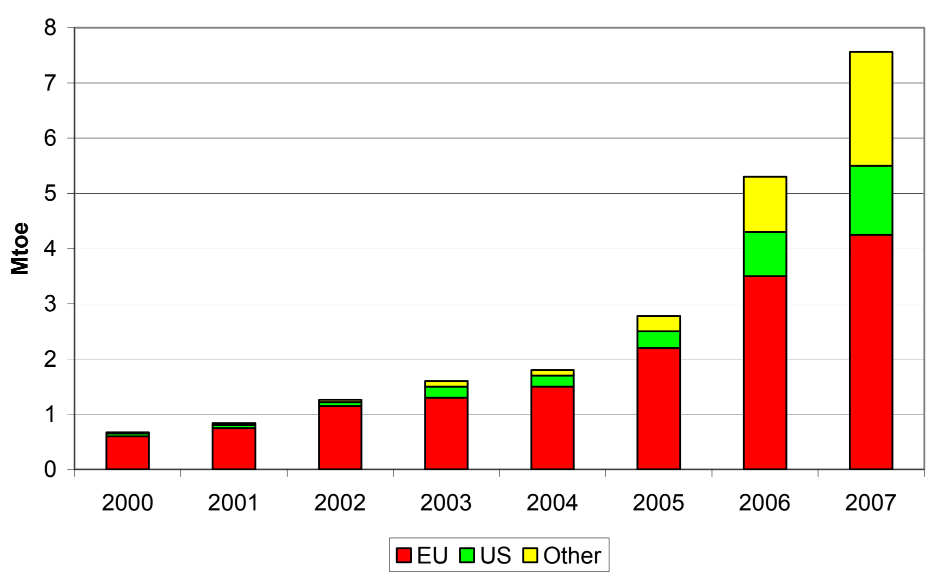



Figure 3: Recent trends in biodiesel production (Source: F.O.Licht,IEA)

Beside Brazil some other Latin American's countries are also active in biofuels production, such as Argentina, Bolivia, Columbia, but this production is very low compared to Brazil, see Fig.4. Due to this reason in this paper Brazil is considered as the main representative of Latin America.

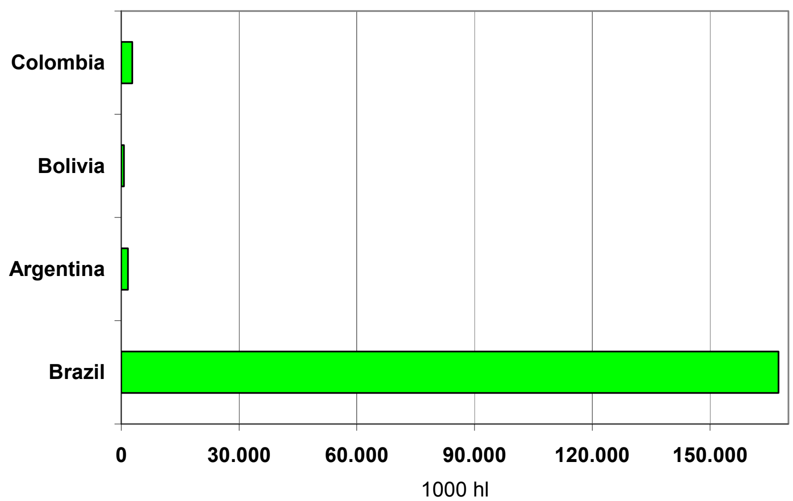



Figure 4: Ethanol production in South American countries in 2006 (Source: F.O.Licht)

Currently worldwide bioethanol production is much higher than biodiesel production. Only in Europe is biodiesel production considerably higher than ethanol production. In last few years Brazil has started biodiesel production and also in USA is biodiesel production rapidly increasing. The share of bioethanol on total biofuels will be changed in almost all regions, see Fig.5.

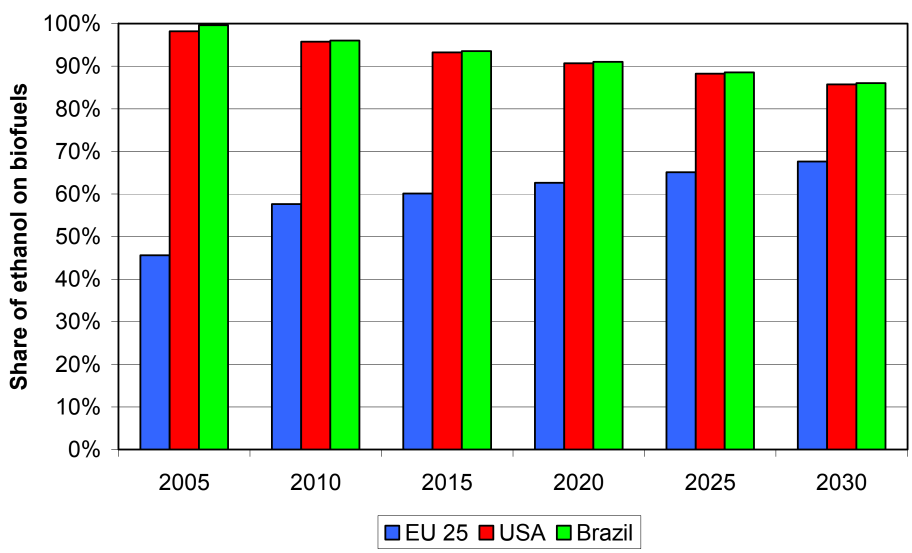


Figure 5: Share of bioethanol on total biofuels

## 3.- Biomass potentials and land needs for biofuels production

Biomass is abundant in almost all parts of the world, but some world regions have a much larger biomass production potential. Currently, use of biomass covers about 13%of the global energy demand. Biomass supply potential is very dependent on the land availability, crop yields, population growth, food demand, economic development, food production efficiency and competing biomaterial products [Regettli, 2007].

According to the FAO, a lack of land is not forecasted for the time period until 2030. Suitable land for rain fed crop production is almost three times larger then currently used capacities (FAO, 2002).

Generally Latin America, Eastern Europe, Southeast Asia, China and Sub-Saharan Africa are seen as the most potential biomass suppliers.

Currently about 14 million hectares of land (about 1% of the world's available arable land) are used for the production of biofuels and by-products. Given that 1% of global transportation fuels are currently derived from biomass, increasing the share to 100% is clearly impossible unless fuel demand is reduced, land productivity is dramatically increased, large areas of pasture are converted to arable land or production is shifted from conventional sources of biomass to new ones, such as crop residues or trees and grasses that can be grown on non-arable land. The large-scale use of biofuels will probably not be possible unless second-generation technologies based on lingo-cellulosic biomass that requires less arable land can be developed commercially [WEO,2006].

According to the IEA, biomass potential from all sources in 2050 could be between 1000 and 26200 Mtoe. The share of the world's arable land used to grow biomass for biofuels is projected to rise from 1% at present to 2,5% in 2030 in the Reference Scenario and 3,8% in the Alternative Policy Scenario, on the assumption that biofuels are derived solely from conventional crops [WEO,2006].

The future land requirements for biofuels production in Reference (RS) and Alternative Scenario (AS), as well as in Second-Generation biofuels case (SG) are shown in the Fig. 6.

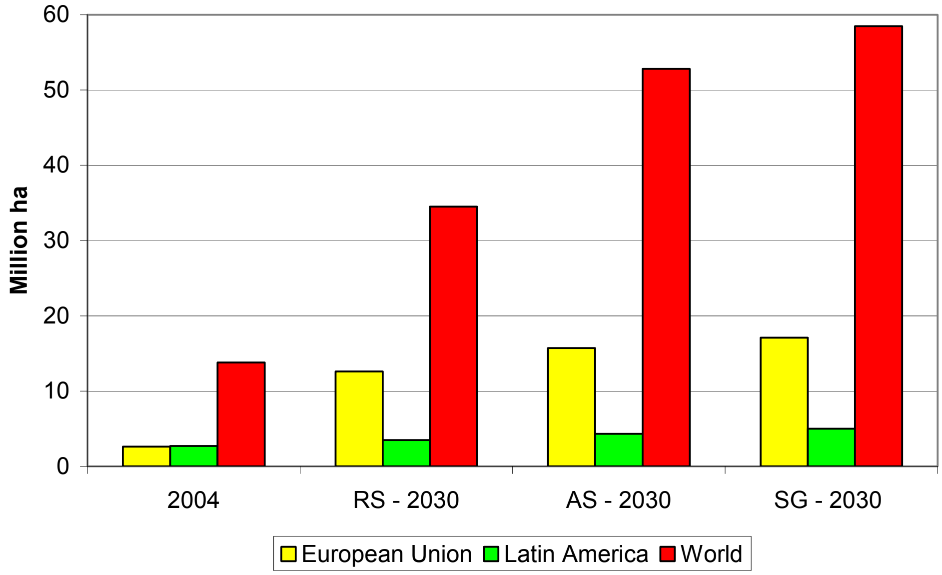



Figure 6: Land requirements for biofuels production (Source: WEO,2006)

4.- Methods of approach: Economic analysis

Lots of factors, such as feedstock price, conversion costs, and different promotion policies, have an impact on biofuels costs. The largest part of the biofuels costs are feedstock costs and these are currently largely dependent on prices on agricultural markets. Feedstock costs are different by the type of crop used, harvesting technologies, and agricultural subsidies for crops and regions and currently very volatile.

Producer prices for maize, rapeseed, sugar cane, sugar beet, sunflower seed and wheat in some European and Latin American countries are shown in Fig.7. Price differences in some cases are higher then 100%. The mostly used feedstock in South America for ethanol production is sugar cane. Sugar cane price in this region in 2006 was between 14 and 37 US $ per tonne. In Europe wheat is mostly used for ethanol, and rapeseed for diesel production. Wheat price in Europe is lower than in South American countries, between 130 and 145 US $ per tonne.

Besides feedstock costs the size and scale of the conversion facility have a considerable impact on biofuels production costs.

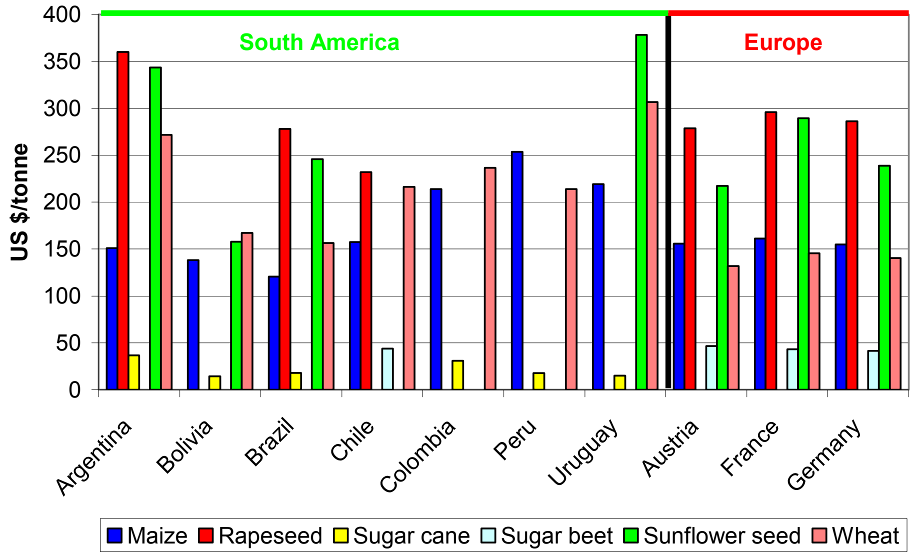



Figure 7: Feedstock - Producer price in 2006 (Source: FAO,2006)

In this study three system components are considered in order to calculate the costs of biofuels:

Net feedstock costs (FC)

Average gross conversion costs (ACC)

Subsidy for biofuels (Sub)

Net feedstock costs are calculated as:

$$FC = FP - ASub - C_{by-product}$$

Where:

FP...............Feedstock price

ASub............Agricultural subsidy

$C_{by\text{-}product}$...... Credits for by-product

Average gross conversion costs are calculated as:

$$ACC = CC + LC + EC + MC$$

Where:

CC…………. Capital costs

LC…………..Labour costs

EC…………Chemicals, energy costs

MC………… Costs for maintenance, insurance, taxes

At the end total biofuels costs (BFC) are calculated as followed:

$$BFC = FC + ACC - Sub$$

Capital costs are dependent on specific investment costs (SC) and capital recovery factor (CRF) and specific investment costs are calculated as a sum of national and international investments costs. It is assumed that 60% of the investment costs (IC) are same in all regions and 40% of investment costs (NC) are dependent on countries' or regions' specific circumstance.

$$CC = SC * CRF = (IC + NC) * CRF$$

Future biofuel production costs could be reduced through technological learning. Technological learning can be illustrated for many technologies by so-called experience or learning curves, and the usual formula to express an experience curve is using an exponential regression:

$$C(x) = a \cdot x^{-b}$$

Where:

C(x): Specific cost

x: Cumulative capacity

b: Learning index

a: Specific cost of the first unit

The learning index b defines the effectiveness with which the learning process takes place. It constitutes one of the key parameters in the expression above.

By national costs the calculation has been done with the learning rate of 15% and by international costs with the learning rate of 20%.

The analysis of the future costs are based on two scenarios: Referent scenario and Alternative scenario. The basic difference in these two scenarios is development of biofuels demand till 2030.

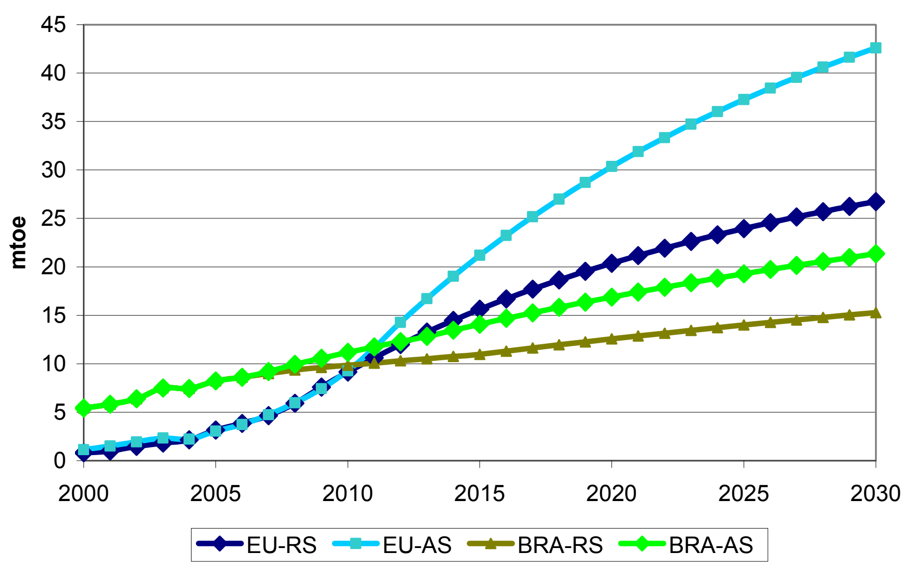


Figure 8: Biofuels demand in Brazil and EU

## 5.- Results

European ethanol production is more expensive then production in Brazil and United States, see Fig.9. Production costs for ethanol are at present lower in Brazil, less than half of the costs in Europe.  Reasons for this are higher feedstock and energy costs in Europe.

The main raw material for bioethanol production in Brazil is sugar cane, in United States corn and in Europe wheat and sugar beet. In Germany bioethanol production from wheat is slightly cheaper than from sugar beet.

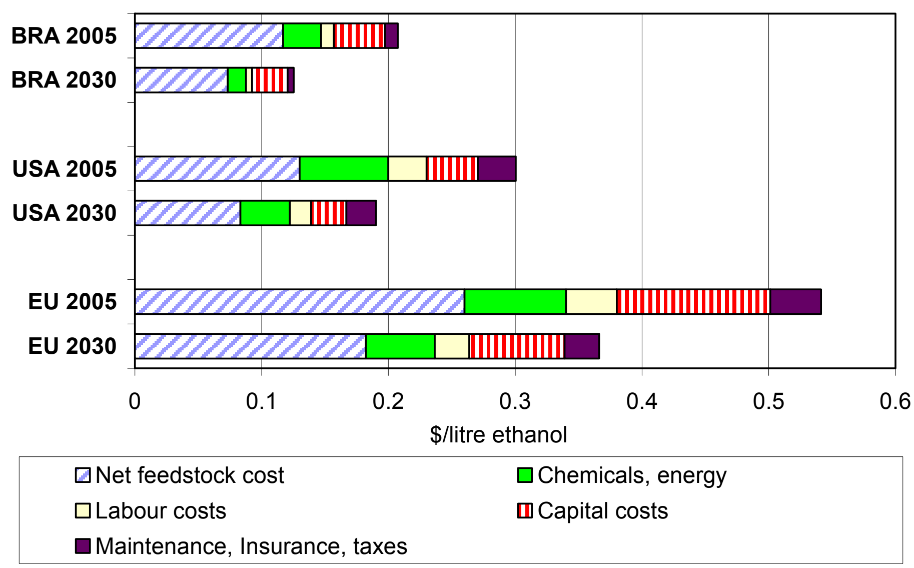



Figure 9: Cost structure of bioethanol

The feedstock costs are the largest part of the bioethanol production costs in all regions, between 43 and 59 percent of the total cost (see Fig. 9). This part is higher or lower in different regions depending on land availability, energy crop yield and agricultural subsidies.

Capital costs for a bioethanol conversion plants are between 13 and 23 percent of total production costs. The rest are labour costs, 3-10 percent, and other operating and energy costs.

In the future, through technical improvements and optimisation, bioethanol cost will continue to decline. In 2030 bioethanol production costs in Europe are expected to be about 33% lower than now – mainly due to technological learning and scale-effects of production, but Brazil will remain the cheapest bioethanol producer with about 40% lower costs than today.

The production costs for biodiesel are more dependent on feedstock prices than bioethanol production costs. The share of feedstock costs in the total production costs lies between 54 and 67 percent. Appropriate feedstocks for biodiesel production are rapeseed, soybean, sunflower, oil palm, coconut, jatropha and waste oil.

The cost structure of the biodiesel costs in two largest regions of biodiesel production, USA and EU, are shown in Fig.10.

Note to some extent the differences in costs are due to fluctuations in the conversion of currencies.

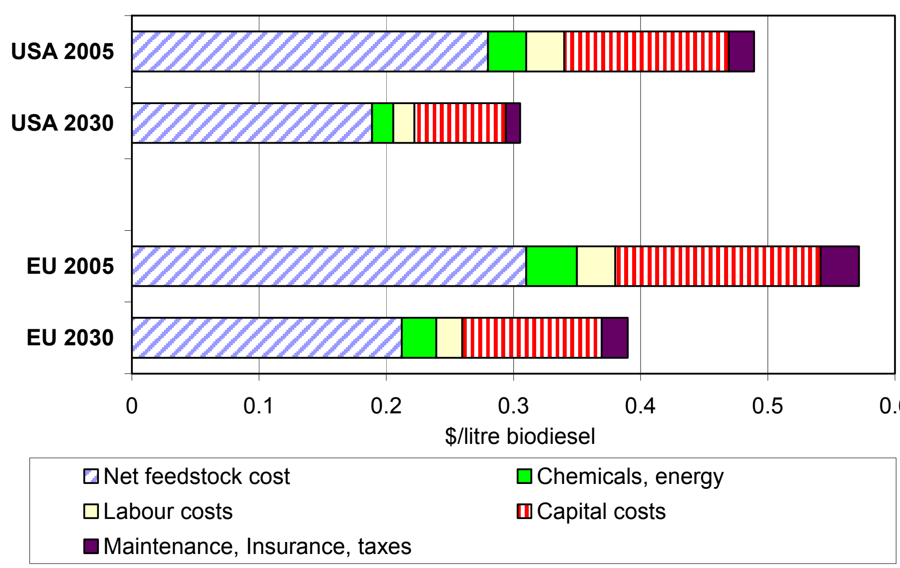



Figure 10: Cost structure of biodiesel

6.- Conclusions

Currently, the three most important regions for biofuels production are Latin America, USA and Europe. These regions contribute with more than 90% to total world-wide biofuels production in 2007.

At present only Brazil is able to produce market competitive bioethanol. In all other regions biofuels costs are higher than fossil fuels costs, and this gap has to be covered through different subsidies to make biofuels competitive in the market.

Conventional production technologies for ethanol based on starchy and sugar crops, as well as for biodiesel based on oil seed are relatively mature, but all current conversion technologies need to be optimised. Further incremental cost reductions can be expected, particularly through large-scale processing plants. Crop prices will remain a major factor in future production cost trends, between 43% and 67% of the total biofuels costs. Higher crop yields, through the use of better fertilizers, plant breeding and agricultural management could help to lower prices, but the largest expectations are from advanced ethanol production from lignocellulosic materials. This production technology should enable the use of wide range of new feedstocks such as waste cellulosic materials, grasses and trees.

Biofuels production is very land intensive. In regions with high population density the biofuels production capacity is very limited. Other important factor is climate conditions. Future biofuels costs depend on land availability for biofuels crops production, agricultural productivity and conversion efficiency over time, but also on the political will to support biofuels for transport until they are able to be competitive with conventional fuels.

Biofuels can provide a significant contribution especially when accompanied by comprehensive efficiency improvements and continues development towards using whole plants (2nd generation biofuels), but biofuels will not be the one and only solution for GHG reduction in the transport sector.

## 7.- References

IEA, 2006: “World Energy Outlook 2006”, IEA 2006

F.O. Lichts, 2006: “World Ethanol Markets, The Outlook to 2015”, An F.O. Licht Special Study, 2006

Ajanovic A.,Haas R.: “Renewable Energies in the Transport Sector: Costs and Possibilities”, eceee 2007

Regettli, M.:"Cost outlook for the production of biofuels", Environmental Sciences ETH, 2007

FAO, World agriculture: "Towards 2015/2030", Food and Agriculture Organization: Rome, 2002

Worldwatch Institute, 2006: "Biofuels for Transport – Global Potential and Implications for Sustainable Agriculture and Energy in the 21st Century", Worldwatch Institute, May 2006

# 10. Innovation Strategies in Ethanol: Industry Dynamics and the Brazilian Case.

José Vitor Bomtempo – Amir Szuster

**Energy Economics Group – IE – UFRJ**

**Technology Innovation Management – EQ – UFRJ**

Av. Pasteur 250, Sala 123
CEP 22290-240
Rio de Janeiro - RJ, Brasil.
Tel: (21) 3873.5269 or 3873.5270

Email: vitor@eq.ufrj.br

**Amir Szuster**

**Energy Economics Group – IE – UFRJ**

**Email** amir.szuster@gmail.com

**Key words: biofuel, innovation strategy, ethanol**

This paper examines the evolution of the Brazilian ethanol industry and the challenges it will probably face in the next years. Ethanol technology has been improved for the last 30 years in Brazil and Brazilian industry has presently a very high productivity level compared to other producers around the world. Nevertheless, some challenges seem to present to the industry as a called biofuel second generation comes to age.

This paper examines these challenges and based on fundamental concepts in innovation economics, in particular technology life cycle (Abernathy and Utterback, 1978) and technological trajectories (Rosenberg, 1976; Dosi, 1982), tries to elaborate on the nature of changes and its consequences for the ethanol

industry at the world level. First, we identify the second generation ethanol as a technological innovation with three related possible dimensions: new raw materials (cellulosic materials, for ex), new processes (hydrolysis, gasification, etc.) and new products (biobutanol and others). In the second part of the paper, reviewing the most relevant papers and studies, we analyze the possible repercussions to the Brazilian industry. These repercussions in the case of raw material innovations could displace positions now concentrated on agronomical advantage. In the cases of new processes and new products, the critical point is the possible entry of new players, like Shell, for example, with proprietary technologies that could become industry leaders.

The implications of the paper concern the technological strategies at firm level and technological and innovation policy at government agencies level, not to mention the research programs at the university centers. Which strategies institutions should design and implement in order to mitigate the risks of rupture of the present competitive position of Brazilian ethanol industry?

# 11. The High Temperature Reactor with Pebble Fuel for Future Energy Production

**Allelein, H.J.- Barnet, H.- Beckers, K.- Michael J. Will**

Professor Ricardo Raineri
President of the Conference

October 31, 2008

# Second American Meeting on Energy Economics, Energy Security, Integration and Development in Latin America,

Santiago de Chile March 22-24, 2009


Allelein, H.-J. 2); Barnert, H. 3); Beckers, K.-A. 1); Odoj, R. 2)

1): PhysD Dr., Ministry of Environment and Climate Protection of Lower Saxony NMU, Hanover
2): Professor Dr., Research Center Juelich FZJ, Head of Institute for Energy Research-6: Safety Research and Reactor Technology
3): Professor Dr., Joint Working Group Nuclear Energy - FZJ


Abstract

## The High Temperature Reactor with Pebble Fuel for Future Energy Production


The objectives and achievements of the German HTR Program with the special pebble type fuel are described (it operates with continuous fuelling), including electricity production as well as process heat application up to high application temperatures, and including waste management.
The experimental reactor AVR operated 21 years and was used for development of the pebble type fuel testing as well as for the demonstration of a mean outlet temperature of 950°C. An interesting result of the German program is the concept of the modularization of larger cores into moduls for safety and economic reasons: The HTR-Modul with 200 MWt has the safety advantage that core melt downs are deterministically nearly excluded. A site independent licensing procedure by German Atomic Law was successfully conduced at NMU in the late 1980th, the main results would be shortly mentioned.
Modern HTR designs in the world have adopted that concept, because of flexibility and because series production promises cost reduction. The commercialisation of the HTR in Germany failed in 1991/92 mainly for political reasons, the German industry went into "hibernation", which last on. But a few years later a new interest developed in South Africa and in China, leading to a technology transfer from German industries organisations and the Research Center Juelich with permission of Governmental institutions into these countries. This technology transfer still goes on. The South African goal is a Demonstration power station with an HTR Modul (pebble fuel) of 400 MWt with helium turbine and the Chinese goal is an HTR Twin Modul (pebble fuel) of 2x250 MWt with steam turbine.
Waste Management of burned HTR pebble fuel would be easier performed as in case of conventional LWR fuel elements namely by Direct Disposal without reprocessing.

The expected renaissance of nuclear energy world-wide and the identified large variety of applications offers a good chance for development of this technology also in Latin America, especially in the arid regions in the North of Chile. Electricity generation could efficiently be combined with drinking-water production from sea water. Long distance heat delivery could for example be of interest for the southern til antarctic regions of the continent.

# 12. Challenges and Achievements of Coal-Based Power Generation: Moving Towards a Holistic and Sustainable Approach

**Vinio V. Floris**

Vinio V. Floris, Ph.D., P.E.

Senior Managing Consultant, Exponent Inc.

10850 Richmond Avenue, Suite 175
Houston, TX 77042

USA

Phone: (832) 325-5700

Email: vfloris@exponent.com

Key words: coal, economics, $CO_2$

Abstract

Coal is an abundant, reliable and inexpensive energy source around the globe. Yet, when burned (specially for power generation) it is also one of the main producers of massive amounts of Carbon Dioxide ($CO_2$), a greenhouse gas that is negatively affecting the temperature of the Earth and, therefore threatening the functioning of natural processes. The challenge is to reduce global emissions in a sustainable, energy-efficient and cost-effective manner.

This paper starts with a discussion of the world-wide dynamics of supply and demand for coal, coal-based power generation and $CO_2$ emissions. It continues with an analysis of the options for sustainable coal power plants including the implementation of conventional and advanced coal power generation technologies (including **Integrated Gasification and Combined Cycle with** carbon dioxide capture and storage **techniques)** with their costs and benefits. It

also reviews the use of coal combustion products as a way of mitigating $CO_2$ emissions from conventional power plants, and reviews regulatory initiatives in the US. The paper concludes with a discussion of a holistic approach for managing coal power generation, and the economic impacts to coal-based power generation in a carbon-constrained world.

Introduction.

Coal is a relatively abundant, reliable and inexpensive energy source of power generation around the globe. However, it is also one of the main producers of Carbon Dioxide ($CO_2$) and other noxious pollutants like Mercury, particulate matter, Nitrogen Oxide and Sulphur Dioxide. Economically speaking, viable mitigation technologies exist for the above mentioned pollutants with the exception of $CO_2$[53].

Extensive research is underway to find more economically feasible alternatives for carbon dioxide capture and storage (CCS). However, until financially and environmentally sustainable alternatives are found, the toxic byproducts of pulverized coal-based power generation (conventional) will be an issue for decades to come. A successful $CO_2$ mitigation process (through time) lies in a private-public strategy that combines existing power plants (revamped to capture, geologically store and/or enhance oil recovery), and new ones using more advanced coal power generation technologies like the Integrated Coal Gasification Combined Cycle (IGCC). These approaches alongside proactive regulation could build a relatively sustainable alternative for the future.

Not all current power plants will be refurbished as mentioned above; yet Coal Combustion Products (CCP) from plants that do not convert to CCS technologies could still be put to good use through innovative ways in order to assist in the decrease of greenhouse gases. For instance, fly ash (a by-product of coal burning in power generation that usually ends up in landfills) can substitute cement without posing structural changes to the end product (concrete and others). The use of one unit of fly ash could reduce approximately one unit of $CO_2$ emitted by a cement kiln. Fly ash and other CCP

---

[53] The US alone produces approximately 1.5 billion tons of $CO_2$ annually; globally, one third of all CO2 emissions are attributed to coal.

in the cement-making process could also avoid the use of intense energy sources and significantly reduce the volume of debris taken to already overwhelmed waste management sites.

The World of Coal and Coal-based Power Generation.

Around the world, coal is primarily used as a solid fuel to produce electricity and heat through combustion. Globally, 25% of total energy sources come from coal while in the US it is about 50%.

Approximately, 81% of coal reserves (data of 2006) were concentrated in six countries (in descending order: USA, Russia, China, India, Australia, and South Africa).[54] The US has 27% of the reserves (246,643 million tons), while Russia and China hold 17% and 13%, respectively. Latin America holds 2.2% of the world's reserves (19,893 million tons) with 1.1% and 0.7 % in Brazil and Colombia, respectively.

The US produced 1.54 billion tons of coal in 2006 (20% of the world's total) while China and India produced 2.38 billion and 447 million tons, respectively. China is currently the largest producer of coal (40% of the world's total).

World coal consumption is about 6.2 billion tons annually. In 2006, the U.S. consumed 931,349,000 metric tons of coal for electricity generation. About 68.7% of China's electricity comes from coal. Latin America produced 1.7%of the world's coal total production (Colombia and Brazil produced 0.1% and 1.4%, respectively) (British Petroleum, 2007).

Coal prices have significantly risen since the 1980s after decades of steady pricing. Figure 1 shows coal prices (US$/ton) for Northwest Europe, Central Appalachian US and Japan. US prices increased over US$150/ton in July of 2008 but later decreased to US$70/ton in mid January 2009. Coal is, compared to other energy sources, the least expensive commodity for power generation.

---

[54] Total world reserves: 909,064 million tons; total world production: 6,195 tons. All tons expressed in this paper refer to metric tons.

Figure 1. Price of coal in different regions of the world.

Source: British Petroleum, Statistical Review of World Energy 2007.

| US dollars per ton | Northwest Europe marker price | US Central Appalachian coal spot price index | Japan steam coal import cif price |
|---|---|---|---|
| 1987 | 31.30 | - | 41.28 |
| 1988 | 39.94 | - | 42.47 |
| 1989 | 42.08 | - | 48.86 |
| 1990 | 43.48 | 31.59 | 50.81 |
| 1991 | 42.80 | 29.01 | 50.30 |
| 1992 | 38.53 | 28.53 | 48.45 |
| 1993 | 33.68 | 29.85 | 45.71 |
| 1994 | 37.18 | 31.72 | 43.66 |
| 1995 | 44.50 | 27.01 | 47.58 |
| 1996 | 41.25 | 29.86 | 49.54 |
| 1997 | 38.92 | 29.76 | 45.53 |
| 1998 | 32.00 | 31.00 | 40.51 |
| 1999 | 28.79 | 31.29 | 35.74 |
| 2000 | 35.99 | 29.90 | 34.58 |
| 2001 | 39.29 | 49.74 | 37.96 |
| 2002 | 31.65 | 32.95 | 36.90 |
| 2003 | 42.52 | 38.48 | 34.74 |
| 2004 | 71.90 | 64.33 | 51.34 |
| 2005 | 61.07 | 70.14 | 62.91 |
| 2006 | 63.67 | 62.98 | 63.04 |

In 2006, there were 1,493 coal-powered units at electrical utilities across the US with a total nominal capacity of 335.8 GW.[55] The US average generated power from coal (in 2006) was 227.1 GW (1.991 trillion kilowatt-hours per year). In 2006, China produced 1.95 trillion kilowatt-hours but it is estimated that it has currently surpassed the US.

Without any global climate policies, it is expected that coal production (mainly driven by Australia, China, Russia, Ukraine, Kazakhstan and South Africa) and consumption may increase 30 to 50% by year 2025 (from 2007 data).

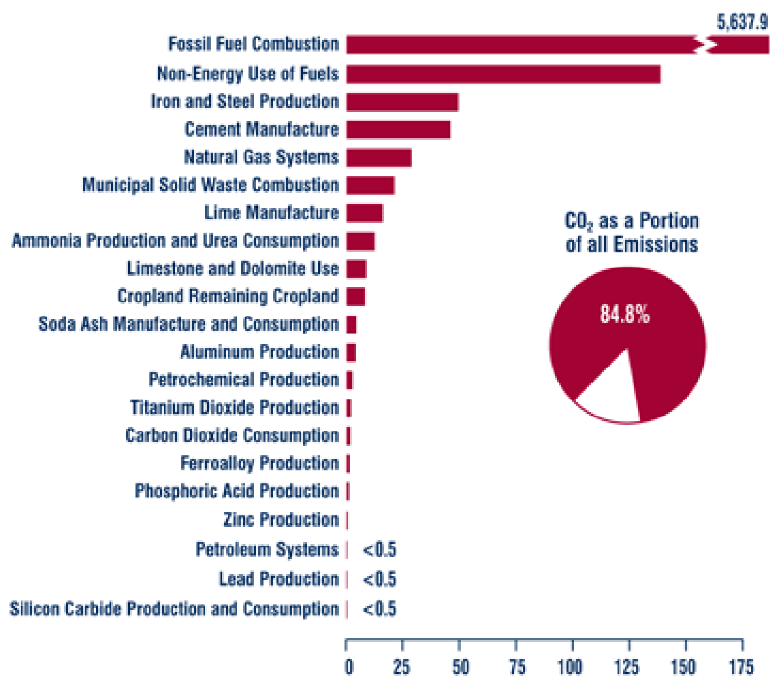
Coal power generation is the largest source of $CO_2$ production and the largest contributor of all gas emissions (85% of all emitted greenhouse gases in the

[55] There were 1,024 units at nominal 278 GW in year 2000.

US). Figure 2 shows that fossil fuel combustion (led by coal) is, by far, the largest source of US $CO_2$ emissions (data of Year 2006). The US produced about 1.5 billion tons of $CO_2$ from coal alone per year. Figure 3 depicts the world energy-related $CO_2$ emissions for the years 2005-2030 for OECD (Organization for Economic Co-operation and Development) and non-OECD nations. Figure 4 shows $CO_2$ emissions from coal for OECD and non-OECD countries. Both Figures 3 and 4 clearly show that OECD emissions marginally increase from the 2005-30 period while non-OECD nations (mainly China and India) almost double $CO_2$ emissions in the 25-year period.

Figure 2. 2006 US sources of $CO_2$ emissions.

Source: US EPA, **Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006**.




Teragrams of $CO_2$ Equivalents[56]

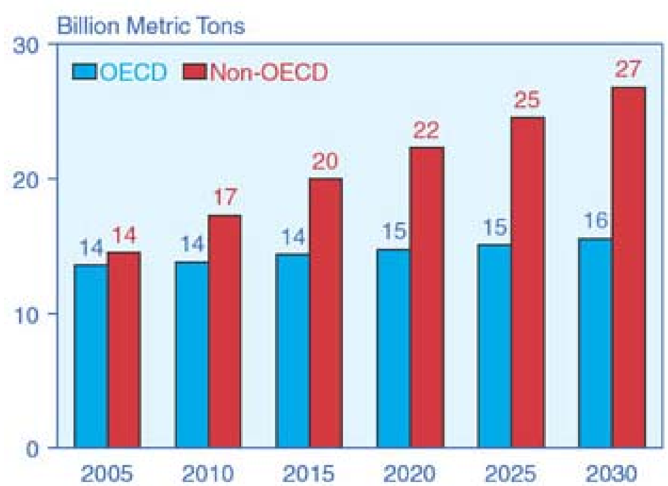
[56] One teragram is equal to $10^{12}$ grams or one million metric tons.

Present and Future of Coal Power Generation.

Traditional coal power generation starts with the pulverization of coal for later burning in a furnace. The furnace heat converts boiler water into steam which is used to spin turbines which turn generators to create electricity. The thermodynamic efficiency of the entire process reaches about 35% (65% waste heat released to the surrounding environment). Older power plants are significantly less efficient.

Figure 3. World energy-related $CO_2$ emissions, 2005-2030.

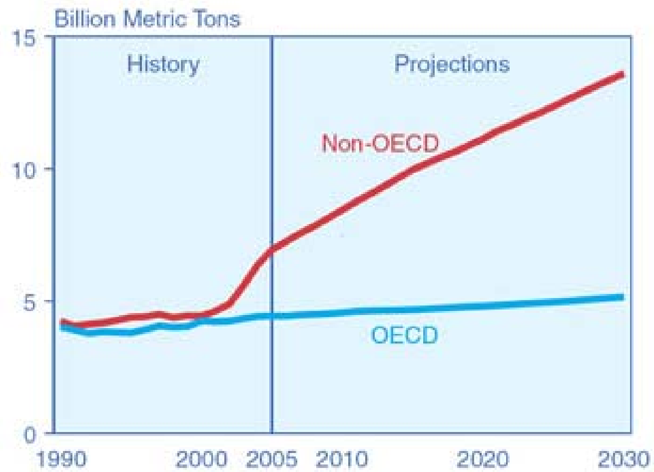
Source: US Energy Information Agency.




Year

Figure 4. World $CO_2$ emissions from coal, 1990-2030.

Source: US Energy Information Agency.




Year

A modification of the traditional system is related to the emergence of a supercritical turbine that runs the boilers at extremely high temperatures and pressures, with projected efficiencies of over 45%. The use of combined cycle units and combined heat and power cogeneration can even increase the efficiency of the entire system. Supercritical plants are capable of removing up to 96% of coal's sulfur dioxide ($SO_2$) content and 80% of its nitrogen oxide ($NO_x$) content. Supercritical plants also reduce carbon dioxide emissions by 27% and can, theoretically, be fitted with technology to capture and sequester the remaining $CO_2$. Ultra-super-critical plants are even cleaner, but while there are currently a few of them operating in Japan and Europe and one under construction in China, there are none in the U.S. presently.

Several technologies have been tried in order to increase efficiency and reduce $CO_2$ emissions. One that has been around for several decades (though only a handful have been built) is called Integrated Gasified Combined Cycle (IGCC). IGCC units do not directly burn pulverized coal but mixes it with oxygen and water in a high-pressure gasifier to make syngas (a combustible fluid -a mix of carbon monoxide and hydrogen gas, via the Fischer-Tropsch process- that produces extremely low emissions of sulfur, nitrous oxides, mercury and particulates). IGCC plants can also concentrate carbon-dioxide emissions, making CO2 easier to capture and store. IGCC plants are 10% more efficient than conventional coal plants, use 40 percent less water, and burn almost as cleanly as natural gas-fired plants. The cost to produce electricity could be 20-

50% higher than conventional coal-fired plants. These plants have been criticized as being inefficient, slow, risky (unreliable) and costly.

One method for properly disposing of $CO_2$ emissions is the so-called carbon dioxide capture and storage (CCS). It is a process consisting of the separation of $CO_2$ from industrial and energy-related sources, transportation to a storage location, and long-term isolation from the atmosphere. $CO_2$ could be stored or "sequestered" in deep (onshore or offshore), geological formations by using many of the same technologies that have been developed by the oil and gas industry. This has been proven to be an economically feasible option under specific conditions for oil and gas fields and saline formations. Figure 5 shows a schematic diagram of a CCS system with its $CO_2$ sources, transportation and sequestration components.

According to the National Academy of Sciences, as much as 40% of human-made $CO_2$ "could be removed from the atmosphere and tucked safely away." The oil industry has been injecting $CO_2$ into the ground for years in order to increase oil production, so the technology has a track record. Scientists are hopeful that $CO_2$ can be stored (or "sequestered") deep in the ocean or in underground coal seams and deep saline reservoirs. But the capture and storage of $CO_2$ from the world's coal-fired plants would be on a much larger scale. Moreover, there are concerns about $CO_2$ escaping to the surface; a sudden large release of $CO_2$ would pose immediate risks to life. Economics are potentially a bigger hurdle, as carbon capture and storage would be costly and add to the price of energy (The Sierra Club).

As shown in Figure 6, the cost of electricity for an IGCC power plant could be over 20% more than a conventional coal power plant. An increase of 20-80% more is expected if the plant has capture, transportation and storage or enhanced oil recovery mechanisms (IPCC, 2005).[57]Approximately, 80% of the costs are associated with capture and compression, and 20% with transportation and injection.

Figure 5. Schematic diagram of a potential CCS system.

Source: Intergovernmental Panel on Global Change.

---

[57] Pumping and other infrastructure is needed to complete the $CO_2$ capture, transportation, storage and oil-recovery activities.

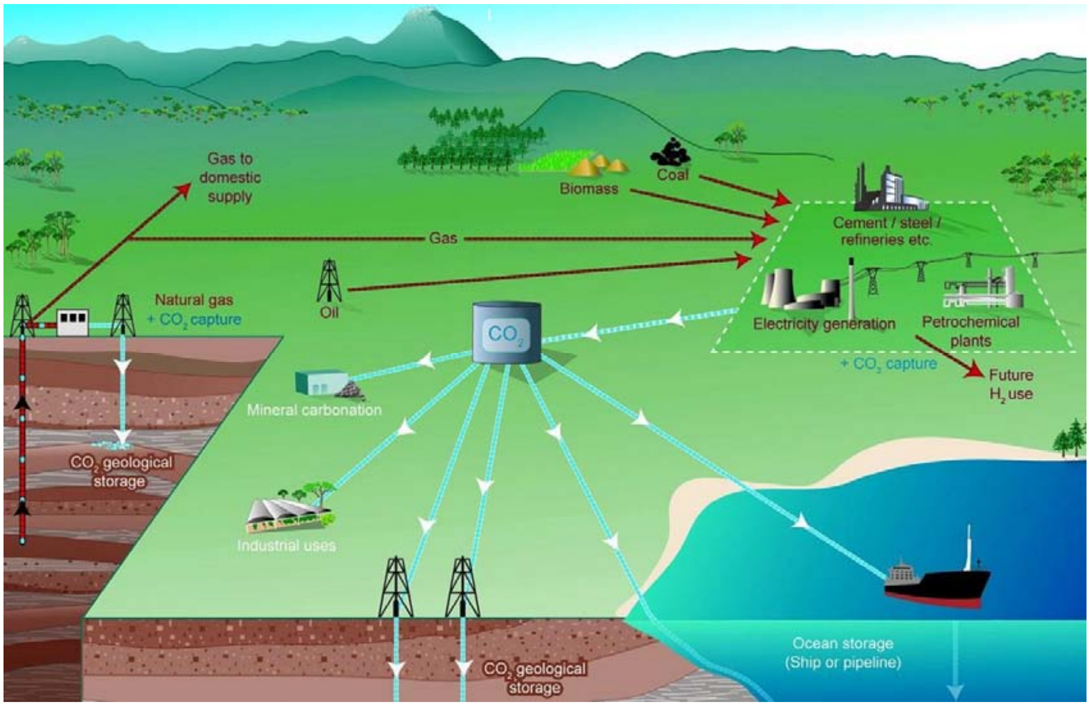



Figure 6. Range of total costs for $CO_2$ capture, transport and geological storage based on current technology for new power plants using bituminous coal or natural gas.

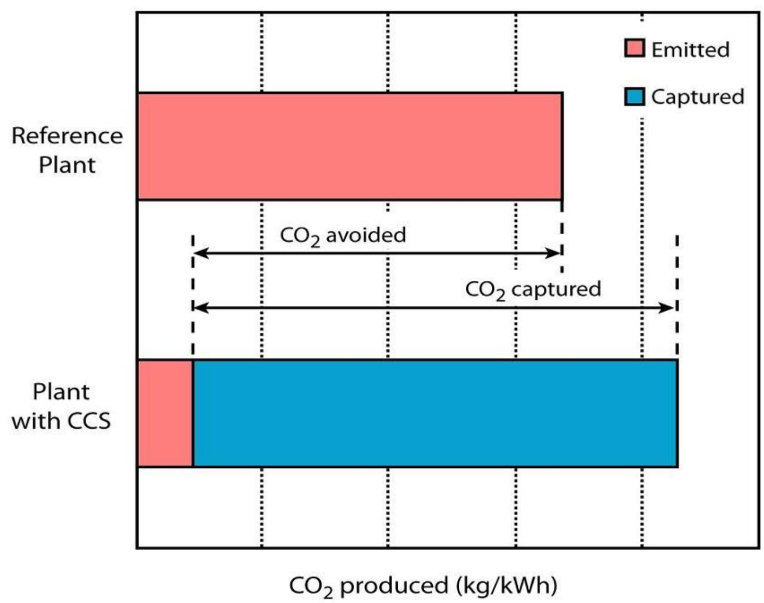
Source: Intergovernmental Panel on Global Change.

| | **Pulverized Coal Power Plant** | **Natural Gas Combined Cycle Power Plant** | **Integrated Coal Gasification Combined Cycle Power Plant** |
|---|---|---|---|
| Cost of electricity without CCS (US$/MWh) | 43-52 | 31-50 | 41-61 |
| **Power Plant with Capture** | | | |
| Increased Fuel Requirement (%) | 24-40 | 11-22 | 14-25 |
| $CO_2$ captured (kg/MWh) | 820-970 | 360-410 | 670-940 |
| $CO_2$ avoided (kg/MWh) | 620-700 | 300-320 | 590-730 |
| % $CO_2$ avoided | 81-88 | 83-88 | 81-91 |
| **Power plant with capture and geological storage** | | | |
| Cost of electricity (US$/MWh) | 63-99 | 43-77 | 55-91 |
| Electricity cost increase (US/MWh) | 19-47 | 12-29 | 10-32 |
| % increase | 43-91 | 37-85 | 21-78 |
| Mitigation cost (US$/tCO2 avoided) | 30-71 | 38-91 | 14-53 |
| Mitigation Cost (US$/tC avoided) | 110-260 | 140-330 | 51-200 |
| **Power plant with capture and enhanced oil recovery** | | | |
| Cost of electricity (US$/MWh) | 49-81 | 37-70 | 40-75 |
| Electricity cost increase (US/MWh) | 5-29 | 6-22 | (-5)-19 |
| % increase | 12-57 | 19-63 | (-10)-46 |
| Mitigation cost (US$/tCO2 avoided) | 9-44 | 19-68 | (-7)-31 |
| Mitigation Cost (US$/tC avoided) | 31-160 | 71-250 | (-25)-120 |

Although more energy is required to complete the CCS process, the $CO_2$ avoided and captured is substantial. If a $CO_2$ market is existent, the $CO_2$ avoided emissions could not only make up for the higher costs of electricity but even reduce the final cost of electricity. Figure 6 presents some estimates of the potential gains but still more precise estimates are dependent on the technologies used, the availability of pipelines and storage sites, etc. Figure 7 explains how the loss of overall efficiency is compensated as a consequence of $CO_2$ capture.

Figure 6. Loss of overall power plant efficiency as a consequence of $CO_2$ capture.

Source: Intergovernmental Panel on Global Change.




CCS technologies are still in development. It is believed that one more decade of intensive research is needed to attain a commercially cost efficient technology. The potential for this approach will depend not just on the technical performance and cost, but also on patterns of economic growth and their energy intensity, on the structure of international agreements to control greenhouse gases, and on the availability of low-carbon alternatives to fossil fuels.

Coal Combustion Products.

Solving the $CO_2$ problem from coal power generation has no easy and short-term solution. Even though a CCS technology is available, there are hundreds of power plants around the world that will continue generating power using the conventional power generation methods. The use of coal combustion products (CCP), specifically fly ash, is a proven cost-efficient process that could provide an important abatement to greenhouse gas emissions.

CCP are waste materials from the coal combustion process. Fly ash, one of the main CCP, is a fine powdery product that exhibits good pozzolanic properties (that is, it reacts with lime in presence of water to form hydraulic cement) therefore it may be used as a cement substitute. Depending of the quality of the coal and burning conditions, fly ash could be mixed with cement in percentages even higher than 50% to achieve maximum performance. Fly ash can be also used as raw feed in the production of Portland cement and other construction and agricultural applications.[58]

Cement factories release large amounts of $CO_2$. Depending of the kind of kiln (a large furnace subject to high temperatures that produces a chemical reaction that transforms limestone into lime for making cement) and the fuel used, these plants generate approximately one unit of $CO_2$ for each unit of cement produced. In 2007, the American Coal Ash Association (ACAA) reported that a survey of 161 US coal-fired power plants produced 64 million tons (71.7 million short tons) of fly ash of which only 12.2 tons (19% of the total) were used in concrete or as a concrete product. More than 40 million tons of fly ash are still being disposed of in US landfills annually. A portion of this does not comply with specification standards but the author believes that 35 to 40 million tons could be used as a cement substitute, rendering a savings of 35 to 40 million tons of $CO_2$ a year.

Fly ash and bottom ash (a coarser CCP) could be also used as an additive to Portland cement to produce a Portland pozzolan blended cement. In 2007, only

---

[58] A cement having the color of the Portland stone of England, made by calcining an artificial mixture of carbonate of lime and clay, or sometimes certain natural limestones or chalky clays. It is the most common commercial cement available.

3.25 million tons of fly ash and 595,000 tons of bottom ash (from 16.2 million tons) were used for this purpose. Figures 7 and 8 show production and use of US CCP, respectively.

Governments are beginning to see the benefits of using CCP for mitigating greenhouse emissions. For instance, the State of California through California Bill 32 (AB 32) is seeking reductions in greenhouse gas emissions from the production of cement, primarily carbon dioxide. The California Air Resources Board has already passed regulations requiring annual reporting of greenhouse gases-related emissions data from cement manufacturing plants. The program has these key elements:

A potential 1.1 million tons reduction in $CO_2$ emissions by 2020 from cement manufacturing with a 9% reduction from the base years (2009 – 2011).

A potential 0.6 to 1.8 million tons reduction in $CO_2$ emissions by 2020 from concrete manufacturing with a 9% to 27% replacement of Portland cement with CCP.

Quantifies true $CO_2$ factors for CCP.

Gives cement plants credit for CCP, electric power demand reductions, fuel efficiency improvements, and alternative fuels.

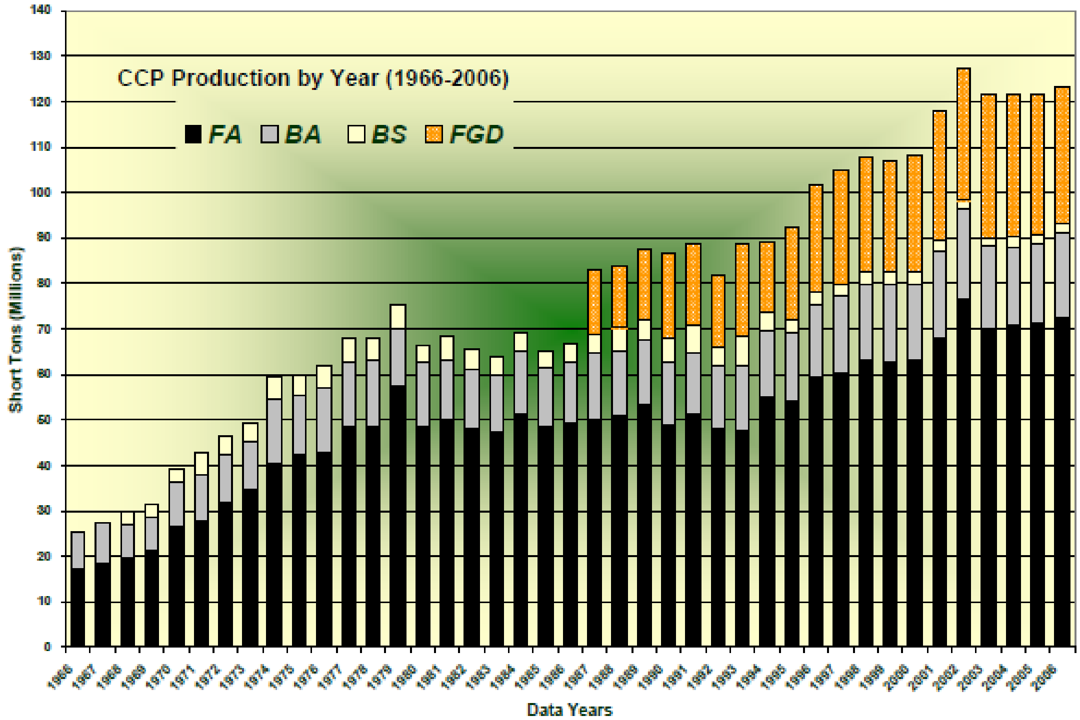
Generates marketable $CO_2$ credits for cement plants (minus power demand reductions).

Provides concrete producers a valuable $CO_2$ offset.

Provides $CO_2$ offsets from energy efficient structures using concrete.

Figure 7. United States CCP Production, 1996-2006

Source: (American Coal Ash Association.




Legend:

FA = Fly Ash; BA = Bottom Ash; BS = Boiler Slag; FGD = Flue Gas Desulfurization

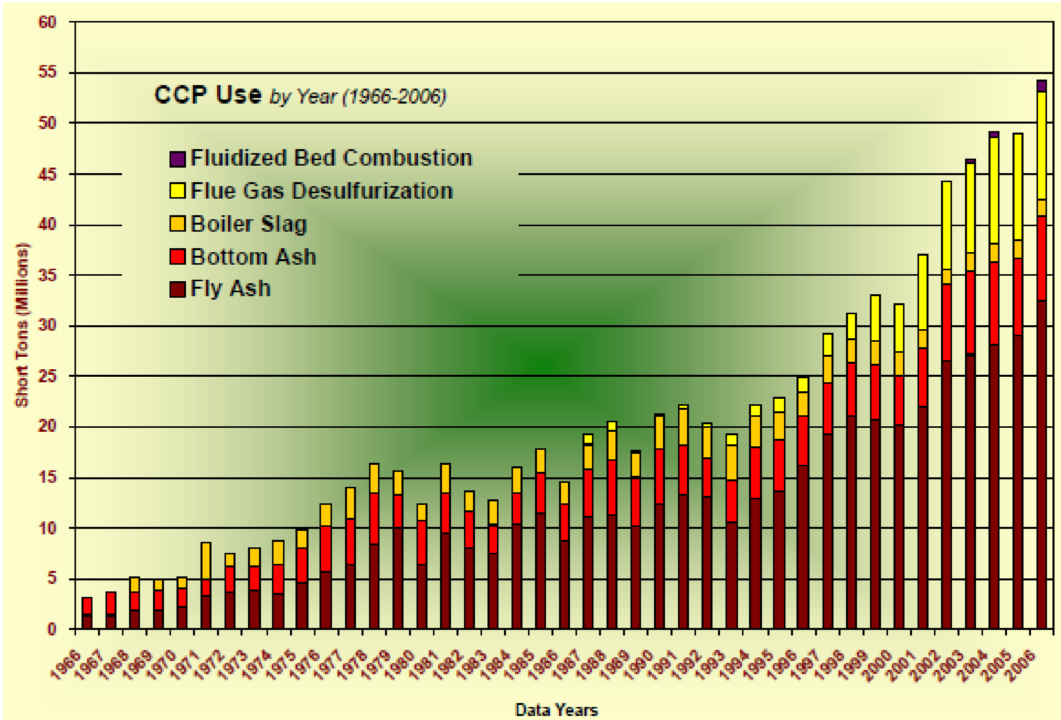
Conclusions.

Despite all global warming concerns and being in the midst of a financial crisis, an approximate growth of 30-50% of coal power generation is expected between 2007 to 2025. The installed capacity would jump to approximately 2.1 million MW. Initial estimates were even higher but the US and Europe are scaling back due to strong environmental pressures. China alone would add approximately 350,000 MW during this period while India would follow with more than 100,000 MW.

Latin America has traditionally relied on hydropower but has been looking for different ways to diversify its energy matrix. Many investments for power generation are allocated to gas turbines but coal is slowly becoming a more real option (several countries are challenged by gas supply restrictions). As stated previously, Latin America has approximately 2% of the proven coal reserves of the world, produces about 1.7% but consumed 22.4 million tons of oil equivalents in 2007, about 0.7% of the world total. It is, obviously, not a large player but has the potential to double its capacity in the next 20 years.

Figure 8. United States CCP use, 1996-2006.

Source: American Coal Ash Association.




The world of coal-based power generation has the potential to significantly increment coal use in a sustainable manner if lessons are drawn from the above discussion. For instance, an economically efficient technology for capturing, storing and using $CO_2$ from coal power generation is still in the drawing board. However, there is some consensus that the IGCC technology is the most likely blueprint for power generation. Still, few plants are in operation and new projects are being challenged by incremental investment and operational costs, and reliability issues.

The capture, storage and utilization of $CO_2$ also present many challenges. As previously stated, the oil and gas industry has several “sequestering” facilities around the world but none at the magnitude that it is being proposed.[59] According to the Future of Coal (MIT, 2007), if all of the $CO_2$ is transported for sequestration, the quantity is equivalent to three times the weight and, under typical operating conditions, one-third of the annual volume of natural gas transported by the US gas pipeline system. Also, if 60% of the $CO_2$ produced from US coal-based power generation were to be captured and compressed to a liquid for geologic sequestration, its volume would nearly equal the total US oil consumption of 20 million barrels per day.

There are still several demonstration projects that will soon yield valuable information with respect to site selection, monitoring techniques, risk evaluation and the economics of the projects. As of now, there is strong scientific evidence that it is feasible to store large quantities of $CO_2$ in saline aquifers. A comprehensive list with its characteristics is shown in Figure 9.

Figure 9. CCS commercial and demonstration projects.

Source: Shoichi Tanaka, 2008

| Project | Type | Country | Injection Start Date | Injection Depth from Surface (meters) | Approx. Annual Injection Rate (tons $CO_2$) | Source of CO2 | Storage Type |
|---|---|---|---|---|---|---|---|
| Sleipner | Commercial | Norway, offshore | 1996 | 1,000 | 1 Million | Produced gas, 9% CO2 | Saline Formation, sandstone |
| Weyburn | Commercial | Canada, onshore | 2000 | 1,450 | 1 Million | $CO_2$ from coal gasification plant | $CO_2$ Enhanced Oil Recovery (EOR) carbonate |
| In Salah | Commercial | Algeria, onshore | 2004 | 1,800 | 1 Million | Produced gas, about 10% $CO_2$ | Saline Formation, sandstone |
| Snohvit | Commercial | Norway, offshore | 2008 | 2,500 | 0.7 Million | Produced gas, about 15-8% $CO_2$ | Saline Formation, sandstone |
| West Pearl Queen | Demonstration | US, onshore | Feb 2001-Dec 2002 | 1,400 | 2,100 | Purchased commercial $CO_2$ | Depleted oil formation |
| Nagaoka | Demonstration | Japan, onshore | Jul 2003-Jan 2005 | 1,100 | 10,000 | Purchased commercial $CO_2$ | Saline Formation, sandstone |
| Frio | Demonstration | US, onshore | Oct 2004 | 1,500 | 1,600 | Purchased commercial $CO_2$ | Saline Formation, sandstone |
| Otway | Demonstration | Australia, onshore | April 2008 | 2,100 | 100,000 | Produced gas, 80% $CO_2$ | Depleted gas formation, sandstone |
| Ketzin | Demonstration | Germany, onshore | Planned 2009 | 700 | 60,000 | Purchased commercial $CO_2$ | Saline Formation, sandstone |

[59] In 2008, the US had 80 projects using CO2 for Enhanced Oil Recovery (EOR) producing 234,000 barrels per day (5% of domestic production).

There is no doubt that either IGCC units or advanced pulverization coal plants will largely exceed the unit cost per installed Kilowatt of a traditional power plant. This is magnified by the cost of adding the capture, transportation and sequestration of $CO_2$. Many believe that the costs would double but they could be somewhat mitigated by using the sequestered $CO_2$ for oil and gas recovery. Also, if comprehensive global policies for controlling greenhouse gasses is established, the industry could re-engineer itself and make use of market trading mechanisms (using some of the features used for the $SO_x$ and $NO_x$ now available) and even integrating it with the construction sector and making use of the benefits of coal combustion products.

It is essential to emphasize that the use of CCP could make key reductions in $CO_2$ emissions by using those byproducts to make cement, substituting Portland cement in concrete, and reducing energy given the energy-efficient nature of concrete structures. It is important to point out that the CCP option is only available for pulverized coal plants. IGCC units follow a different technique and do not produce any cementitious materials as by-products. The State of California is implementing the Integrated Greenhouse Gases Management Program for the California Cement and Concrete Industry Sector by linking emission reductions, credits, and offsets. These are important regulatory measures and would render very valuable information in order to disseminate the successful practices.

The non-OECD nations have mixed uses of coal for power generation. Asian countries and even African nations are much more intensive users of coal. Latin America is the least user of this commodity but has the potential to increase its use. It is extremely important to reach a global policy agreement that involves OECD nations as well as China and India. They all should adopt sustainable energy policies to avoid endangering energy security and control carbon emissions. Without any intervention, $CO_2$ could increase 42 Gigatons in 2030 from 27 in 2005.[60] This is a real and immense treat that has to be managed promptly.

---

[60] China has already surpassed the US as the largest carbon dioxide emitter. China emits 21% of the world's total, the US 19% and India is now in the third place.

References.


American Coal Ash Association. 2005. ACAA Fly Ash basics Quick Reference Card.

British Petroleum. 2007. BP Statistical Review of World Energy.

Blue Source.2008*. Opportunities for CCPs in the Carbon Markets*. American Coal Ash Association Meeting.

Energy Watch Group. 2007. *Coal: Resources and Future Production*, EWG-Paper No. 1/07, Updated version of July 2007.

Herzog, Howard. 2006. *The Future of Coal: Addressing Carbon and Other Environmental Concerns*, EIA Energy Outlook and Modeling Conference at the Massachusetts Institute of technology.

Intergovernmental Panel on Global Change. 2005. *Carbon Dioxide Capture and* Storage, Special Report, Cambridge University Press.

Massachusetts Institute of Technology. 2007. *The future of Coal*.

Samarin, Alex. 1999. Utilisation of Waste from Coal-Fired Power Plants- an Important factor in the Abatement of greenhouse Gas Emissions, Australian Academy of technological Sciences and Engineering Focus No. 106.

Tanaka, Soichi. 2008. *Current CCS Projects and Challenges*. Presentation to the International Meeting on Mid-Long Term Strategy .for Climate Change

The Sierra Club, Coal Glossary Web page.

US Energy Information Administration. 2007. *US Coal Supply and Demand, 2007 Review*.

**US Environmental Protection Agency. 2008. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006*, Report No. 430-R-08-005.**

## 13. Evaluación económica de la gasificación de carbón para generación eléctrica en Chile: un enfoque de valoración de opciones reales

**Alejandro Concha A., Oscar Farías F., Alejandro Andalaft Ch.**

Facultad de Ingeniería, Universidad de Concepción

E. Larenas 215 4º piso, 56-41-2203616, Fax 56-41-2207081, aconcha@udec.cl

Palabras claves: Gasificación – Carbón – Opciones Reales

Resumen:

Basado en la problemática que afecta al sector eléctrico chileno y sus posibles soluciones, se evalúa desde el punto de vista económico la utilización de la tecnología de gasificación de carbón en la generación eléctrica. Se utiliza información secundaria y el enfoque de valoración de opciones reales, con árboles binomiales de dos variables. En primer lugar, se analiza la adaptación de una central de gas natural de ciclo combinado para ser operada con syngas a partir de gasificación de carbón; un segundo caso consiste en encontrar las reglas de decisión de inversión óptimas, comparando una planta nueva de carbón pulverizado (PC) con una planta nueva de Gasificación de Carbón integrada a Ciclo Combinado (IGCC). En este último caso, se estudia la opción de "switching" de combustibles en la planta IGCC. Respecto a los precios de los combustibles, se utilizan modelos de Movimiento Browniano Geométrico No Homogéneo. En ambos casos, se consideran dos escenarios de precios y se realizan análisis de sensibilidad.

Los principales resultados para el primer caso son: es económicamente conveniente la adaptación a syngas de una planta de gas natural existente. El proyecto es altamente sensible a la eficiencia resultante. La sensibilidad respecto al monto de inversión no es significativa, como también respecto a los

gastos operacionales. Respecto al segundo caso, las ventajas económicas de una planta IGCC comparada con una planta PC no son claras en los escenarios de precios considerados. Sin embargo, analizando en diferentes contextos de precios de combustibles, la planta IGCC puede adquirir importante ventaja basada en la flexibilidad operacional por el "switching" de combustibles. Con relación a la sensibilidad, se repite las mismas conclusiones mencionadas para el caso primero. Finalmente, se sugieren varias líneas de estudio relacionadas con el tema de este trabajo, también se describen los esfuerzos que realiza un grupo de expertos de la Universidad de Concepción para lograr la implementación de una planta piloto de gasificación que permita generar conocimiento respecto a la operación óptima bajo diversos tipos de combustibles.

## 1.- Introducción

La industria eléctrica en Chile está compuesta por un total aproximado de 31 empresas generadoras, 5 empresas transmisoras y 34 empresas distribuidoras, que en conjunto suministran una demanda agregada nacional que en el año 2007 alcanzó los 60.138 gigawatts-hora (GWh) (Comisión Nacional de Energía, 2007a). Esta demanda se localiza territorialmente en cuatro sistemas eléctricos:

El Sistema Interconectado del Norte Grande (SING), que cubre el territorio comprendido entre las ciudades de Arica y Antofagasta con un 28,27% de la capacidad instalada en el país;

El Sistema Interconectado Central (SIC), que se extiende entre las localidades de Taltal y Chiloé con un 70,96% de la capacidad instalada en el país;

El Sistema de Aysén que atiende el consumo de la Región XI con un 0,26% de la capacidad;

El Sistema de Magallanes, que abastece la Región XII con un 0,51% de la capacidad instalada en el país (Comisión Nacional de Energía, 2007b).

Hasta el año 1996, la generación de energía eléctrica estuvo basada en forma importante en el recurso hidráulico. A partir del año 1997, comienza a utilizarse gas natural proveniente de Argentina, por lo que la generación de tipo térmica toma mayor participación en la matriz energética, en especial en el SING. Al año 2006, la situación en términos de capacidad instalada de generación se muestra en la tabla 1.

Tabla 1

Capacidad instalada de generación en Chile a Diciembre 2006, por tipo de energético y por sistema eléctrico

| Descripción | SING (MW) | SING (%) | SIC (MW) | SIC (%) |
|---|---|---|---|---|
| Por tipo de combustible: | | | | |
| Hidráulica | | | | |

| | | | | |
|---|---|---|---|---|
| Gas Natural | 13 | 0,4 | 4.745 | 55,7 |
| Carbón | 2.112 | 58,7 | 1.919 | 22,5 |
| Petróleo y derivados | 1.206 | 33,5 | 938 | 11,0 |
| Otros | | | | |
| | 266 | 7,4 | 731 | 8,6 |
| | 0 | 0 | 178,9 | 2,2 |
| Por clase: | | | | |
| Térmica | 3.583 | 99,6 | 3.767 | 44,3 |
| Hidráulica | 13 | 0,4 | 4.745 | 55,7 |
| Totales | 3.596 | 100 | 8.512 | 100 |

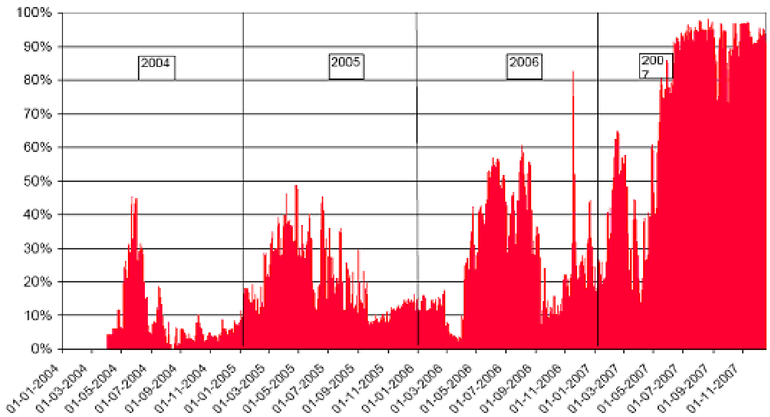
Fuente: Elaboración propia basada en (Comisión Nacional de Energía, 2007b)

A partir del año 2004 se inicia un proceso de cortes del suministro de gas natural argentino, derivados de problemas internos en la industria gasífera de ese país. Los cortes se fueron incrementando año a año, llegando a niveles cercanos al 100% en el 2007. La figura 1 ilustra la progresión en los cortes.

Figura 1

Restricciones de Gas desde Argentina

(en % respecto de requerimientos normales)




Fuente: Comisión Nacional de Energía, 2007c.

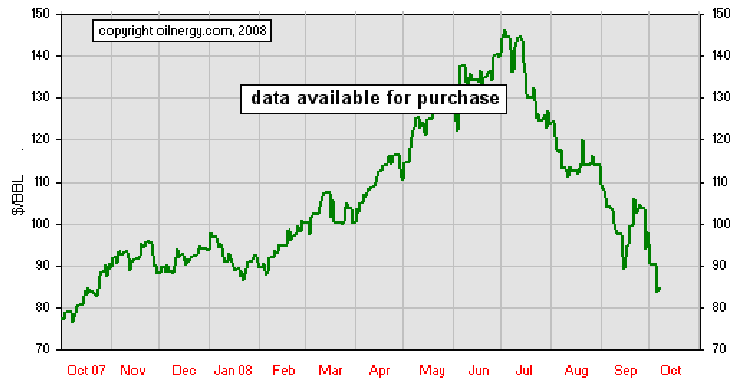
Las empresas generadoras en base a gas natural tuvieron que recurrir a sustitutos tal como el diesel. Esta restricción de suministro se vio agravada por el fuerte incremento de los precios en los combustibles fósiles en el mercado internacional, producto de la alta demanda de países con fuerte crecimiento como China e India. Esto ha significado en Chile un incremento en el costo de generación de energía eléctrica, lo que complica a en general a los sectores exportadores por la pérdida en sus competitividades.

El precio internacional del petróleo ha ido en aumento progresivo, sobrepasando los niveles de 90 US$ el barril como promedio en el año 2007, llegando a mediados de 2008 a 145 US$/barril como se muestra en Figura 2 (Oilnergy, 2008a).

Figura 2

Precios de Petróleo crudo

ICE Brent Crude

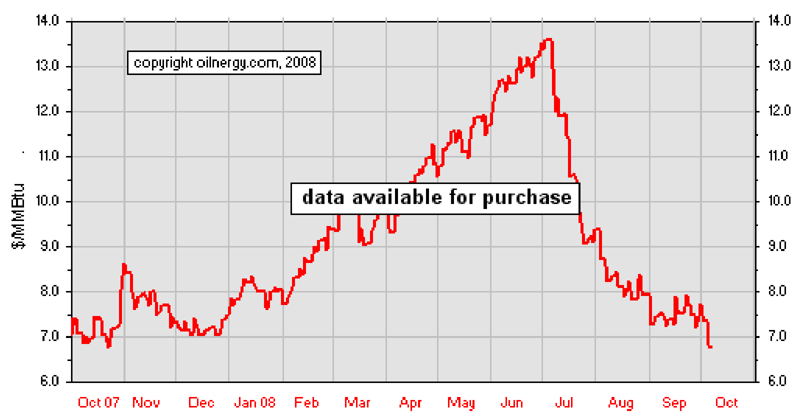



Fuente: Oilnergy 2008a

Comportamiento similar ha ocurrido con respecto a los precios de gas natural, donde se puede apreciar en Figura 3 el precio Henry Hub, cuyo promedio en diciembre de 2007 fue de de 7,2 US$/mmBTU y en enero de 2008 se ha elevado hasta niveles cercanos a 8,4 US$/mmBTU (Oilnergy, 2008b)

Figura 3

Precio Gas Natural Henry Hub

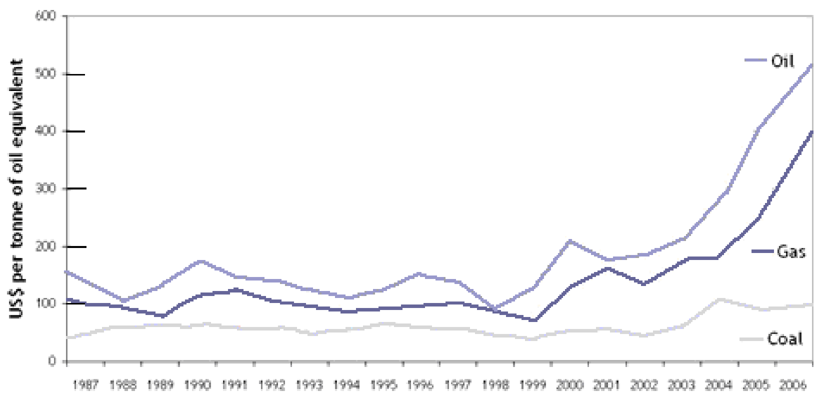



Fuente: Oilnergy, 2008b.

El precio de carbón, que tradicionalmente ha tenido un comportamiento más estable, también experimentó incrementos de precio, pero menores que el petróleo y el gas natural. La Figura 4 compara dichos precios, en toneladas de petróleo equivalentes (World Coal Institute).

Figura 4

Tendencias de precios de Petróleo, Gas natural y Carbón




Fuente: World Coal Institute.

La alta incertidumbre en el sector energético ha llevado a actores relevantes, tanto privados como del sector público, a plantear múltiples propuestas de solución. Algunas propuestas promueven el uso de recursos renovables no convencionales y otras promueven la diversificación en tecnologías y recursos energéticos definidos como convencionales pero no utilizadas plenamente en Chile. Es el caso de los incentivos y obligaciones para invertir en energías renovables no convencionales (ERNC), como también la discusión y análisis para el uso de la energía nuclear. En esta última materia, ya existe un primer informe a solicitud de la Presidencia de la República, elaborado por una comisión denominada “Grupo de trabajo en núcleo electricidad” que estudia dicha posibilidad con las conclusiones y recomendaciones pertinentes, y en lo cual no se descarta dicha opción (Grupo de Trabajo en Núcleo Electricidad, 2007).

Las alternativas de solución más recurridas en Chile para generar energía eléctrica son las centrales térmicas a carbón (ver tabla 2) (Comisión Nacional de Energía, 2007c). Si se compara las alternativas conocidas de generación de electricidad, en base a sus costos (ver tabla 3), las térmicas a petróleo y carbón se ubican en un tercer lugar después de las hidroeléctricas y la nuclear.

Tabla 2

Generadoras en construcción en SIC 2007-2010 y obras recomendadas para SING

| Fecha de entrada | Obras en Construcción | Potencia (MW) |
|---|---|---|
| Octubre 2007 | Ciclo combinado GNL San Isidro II (Oper. Ciclo abierto diesel) | 240 |
| Abril 2007 | Central Hidroeléctrica Quilleco | 70 |
| Junio 2007 | Central Hidroeléctrica Chiburgo | 19,4 |
| Septiembre 2007 | Central Eólica Canela | 18,15 |
| Agosto 2007 | Central Hidroeléctrica Hornitos | 55 |
| Octubre 2007 | Central Hidroeléctrica Palmucho | 32 |
| Marzo 2008 | Cierre Ciclo Combinado GNL San Isidro II (Ope. Diesel capacidad final) | 358 |
| Abril 2008 | Central Hidroeléctrica Ojos de Agua | 9 |
| Octubre 2008 | Central Hidroeléctrica La Higuera | 155 |
| Marzo 2009 | Cierre Ciclo Combinado GNL San Isidro II (Ope. GNL capacidad final) | 358 |
| Abril 2009 | Ciclo Combinado GNL San Isidro II Fuego Adicional (Capacidad final) | 377 |
| Octubre 2009 | Central Carbón Guacolda III | 135 |
| Enero 2010 | Central Carbón Nueva Ventanas | 242 |

| Central | Potencia Neta (MW) | Tipo | Fecha puesta en servicio | Costo Unitario de Inversión (US$/kW) |
|---|---|---|---|---|
| Mejillones I | 200 | Térmica-Carbón | Julio 2010 | 1.500 |
| Mejillones II | 200 | Térmica-Carbón | Julio 2010 | 1.500 |
| Tarapacá I | 200 | Térmica-Carbón | Julio 2013 | 1.500 |
| Diesel I | 50 | Térmica-Diesel | Julio 2014 | 499 |
| Tarapacá II | 200 | Térmica-Carbón | Abril 2015 | 1.500 |
| Mejillones III | 200 | Térmica-Carbón | Enero 2017 | 1.500 |

Fuente: Comisión Nacional de Energía, 2007c

Por otra parte, entre la tecnología de central térmica a carbón pulverizado (PC) y la tecnología de Gasificación de Carbón integrada a Ciclo Combinado (IGCC), puede afirmarse que esta última es económicamente competitiva con la primera, además de presentar ventajas desde el punto de vista medioambiental (Wong y Whittingham, 2006). La tabla 4 detalla los costos entre estas dos alternativas y la tabla 5 compara los impactos ambientales entre una planta de Gas Natural con Ciclo Combinado (NGCC) y una planta IGCC.

Tal como se indica en tabla 2, las principales obras en construcción y recomendadas en Chile para generación eléctrica son centrales termoeléctricas a carbón. Sin embargo, de lo observado en las tablas 4 y 5, la tecnología de Gasificación de Carbón integrada a Ciclo Combinado (IGCC) se ve como una alternativa viable económicamente y de bajo impacto ambiental, con la ventaja operar con diversos tipos de carbón. Por lo anterior, uno de los principales objetivos del trabajo es analizar desde el punto de vista económico la tecnología IGCC y su potencial de aplicación en Chile.

Tabla 3

Costos de generación eléctrica con recursos renovables y no renovables

| Tecnología de generación | Costo de generación eléctrica[1] | Costo de generación eléctrica[2] |
|---|---|---|
| | centUS$/kWh | centUS$/kWh |
| Hidráulica de embalse | 4,6 – 9 | 3,0 |
| Hidráulica de pasada | 2,5 – 8,3 | 3,1 |
| Nuclear | 4,6 – 6,6 | 4,3 |
| Térmica a Gas Natural | 5 – 6,6 | 4,5 – 8,0 |
| Térmica a Petróleo | 5,8 – 11 | |
| Térmica Diesel | 20 – 83 (motor) | 18 (turbina) |
| Térmica a Carbón (vapor) | 4,2 – 5,4 | 3,8 – 4,5 |
| Térmica a Biomasa | 4,6 – 15,6 | 4,0 - 20 |
| Geotérmica | 5,4 – 7,9 | 4,0 – 4,5 |
| Eólica | 5,1 – 11,6 | 4,0 – 20 |
| Fotovoltaico | 6,6 - 25 | 20 - 40 |

[61] Adaptado de Canadian Electricity Association, 2006

[61] GJ: Giga Joule

[2] Basado en Farías O.

Tabla 4

Costo de Generación Eléctrica con combustión de carbón e IGCC (centUS$/kWh)

| | 2006 | | 2010-2015 | |
|---|---|---|---|---|
| | PC | IGCC | PC | IGCC |
| COE(*) sin captura de $CO_2$ (centUS$/kWh) | 3,5-4,4 | 4,4-4,9 | 3,0-4,1 | 3,0-4,1 |
| COE con captura de $CO_2$ (centUS$/kWh) | 6,3-7,9 | 5,7-6,4 | 3,6-4,9 | 3,3-4,5 |

(*) COE: Costo de la energía en centUS$/kWh

Fuente: Wong y Whittingham, 2006.

Tabla 5

Parámetros medioambientales de plantas PC, IGCC y NGCC

| | PC | IGCC | NGCC |
|---|---|---|---|
| $CO_2$ Kg/MWh | 1000 | 735 | 400 |
| $SO_2$ Kg/MWh | 1,6 | ~0 | ~0 |
| $NO_x$ Kg/MWh | 2,1 | 0,25-0,45 | 0,12 |
| Partículas Kg/MWh | 0,5 | ~0 | ~0 |

Fuente: Wong y Whittingham, 2006.

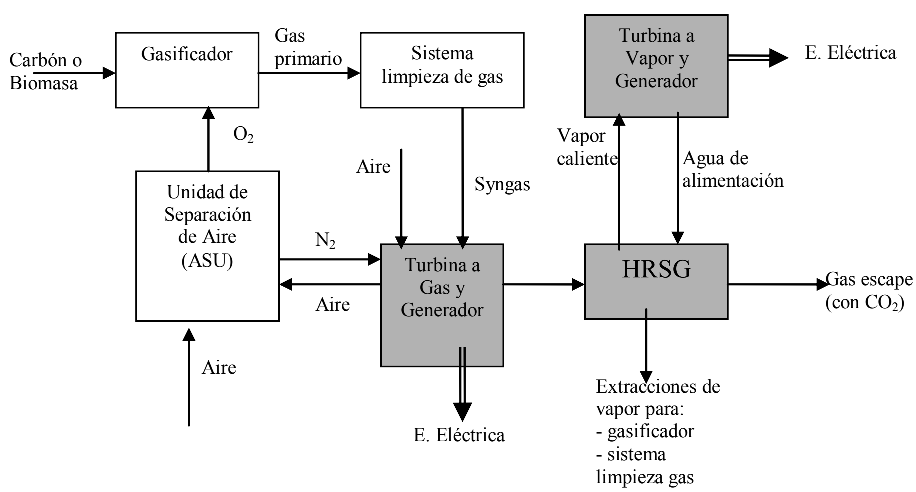
Los precios crecientes y con mayor volatilidad del petróleo y gas natural, ha llevado a diversos países a la utilización de la gasificación del carbón. En la actualidad, existen alrededor de 117 plantas de gasificación con 385 gasificadores operando alrededor del mundo, con 35 proyectos adicionales en varios estados de desarrollo. De las 117, alrededor 39% generan combustible, 19% generan electricidad y 42% generan productos químicos.

El 49% de las plantas usan carbón y un 36% usan petcoke. La capacidad total de plantas de generación con gasificación suman 24.000 MW de electricidad, con un crecimiento anual de alrededor 10%. Una vez que todas estas plantas inicien su operación, tendrán la capacidad de generar energía equivalente a 750.000 barriles por día de gas limpio para uso en generación, como también para producción de combustibles y químicos. La concentración mayor de recursos de gasificación en el mundo está centrada en las plantas de Sasol en Sud Africa, que contabilizaba el 31% del total de capacidad mundial a fines de 1999 (Research Reports Internacional, 2005).

Una planta IGCC se describe en la Figura 5, en donde se distinguen los principales componentes y flujos de materias y energías.

Figura 5

Planta IGCC y principales componentes



El carbón es gasificado a alta temperatura en el Gasificador, luego el gas producido es enfriado y limpiado para extraer las cenizas, impurezas y elementos contaminantes tales como azufre. La composición final del gas de síntesis (syngas) depende de las condiciones de presión y temperatura, que a su vez depende de los diferentes equilibrios que se establecen según el combustible y los agentes gasificantes (aire u oxígeno, vapor de agua) empleados.

El gas de síntesis, es llevado a la turbina a gas en una primera etapa. Los gases de combustión calientes son aprovechados en generar vapor en la unidad recuperadora de calor HRSG, vapor que es utilizado para accionar la turbina de vapor. De la unidad recuperadora se extrae vapor para el proceso de gasificación y para el sistema de limpieza de gas. Uno de los componentes importantes en la planta de gasificación es la Unidad de Separación de Aire (ASU), que provee de oxígeno para el proceso de gasificación, mejorando la eficiencia.

Una planta IGCC posee diversas ventajas, a mencionar:

Alta eficiencia (en comparación con otras tecnologías de generación que usan carbón)

Flexibilidad en la alimentación, ya que puede utilizar carbones de distintas calidades, combustibles alternativos tales como petcoke, biomasa.

Se puede utilizar un combustible secundario.

Además de la flexibilidad en la alimentación, posee flexibilidad en la producción, lo que permite minimizar riesgos comerciales:

Generar energía eléctrica

Producir hidrógeno

$CO_2$

Metanol

$NH_3$

Gasolinas

## 2.- Valoración de opciones reales en proyectos de energía

Evaluar proyectos tales como plantas de generación eléctrica es un desafío importante. Desde aspectos como la consideración de flexibilidad operacional hasta aspectos como el ajuste de un valor que refleje los riesgos no factibles de cubrir, la evaluación requiere de sofisticadas técnicas que vayan más allá que los métodos tradicionales de Flujos de Caja Descontados (FCD).

Para evaluar apropiadamente la flexibilidad operacional de una planta de generación eléctrica, se necesita una metodología que pueda evaluar el activo para todos los estados potenciales del mundo; se pueden ponderar así dichos estados en forma apropiada. Los métodos de valoración de opciones consideran estos problemas (St. Germain y Brett Humphreys, 2002).

Esta metodología surge de la aplicación de los enfoques de valoración de opciones financieras a problemas reales. En términos simples, una opción real es un derecho del administrador, pero no una obligación, de tomar una acción. La aplicación de la teoría de opciones al mundo real no siempre es fácil. El supuesto de retornos con distribución normal o, en forma equivalente, la distribución de precios de tipo log-normal es uno de los supuestos subyacentes de la valoración de opciones, sin embargo puede que no sea válido en la distribución de precios del mundo real. De hecho, en general, no se tiene idea clara acerca de la distribución potencial de valores futuros. Por estas limitaciones, algunos de los primeros trabajos en opciones reales se enfocaron en las opciones reales asociadas con commodities tales como minas, campos de petróleo y gas, y proyectos de exploración (St. Germain y Brett Humphreys, 2002).

En la medida que los mercados de energía eléctrica se fueron desregulando, el enfoque de opciones reales se fue aplicando a la producción o generación. Una excelente síntesis de la evolución del enfoque de opciones reales lo hace Fernández (Fernández, 1999). Revisión de los diversos métodos y técnicas de cálculo se detallan en (Leppard, 2002) y (Vásquez, 2006).

Existe una diversidad de aplicaciones del enfoque de valoración de opciones reales en proyectos energéticos. (Fleten y Näsäkkälä, 2003) analizan inversiones en plantas de turbinas a gas bajo condiciones estocásticas de precios de electricidad y gas natural. Aplican un modelo de 2 factores para el proceso de precio, permitiendo el análisis del valor de la flexibilidad operacional, la oportunidad de vender y abandonar los activos de capital, así como también encontrar umbrales de los precios de energía para los cuales las inversiones sean convenientes.

(Abadie y Chamorro, 2006) analizan la valoración de opciones al incorporar flexibilidad de una planta de energía IGCC. Primero utilizan como caso base la oportunidad de invertir en una planta de gas natural de ciclo combinado, derivando la regla óptima de inversión como una función del precio de combustible y de la vida remanente del derecho de invertir. En segundo lugar, estudian la valoración de una planta IGCC, con costos de cambio entre estados y la elección del mejor modo de operación. La valoración de esta planta sirve de base para obtener el valor de la opción de postergar la inversión de este tipo. Finalmente derivan el valor de la oportunidad de invertir tanto en una planta NGCC o IGCC, esto es, elegir entre una tecnología inflexible y una flexible, respectivamente. (Laurikka, 2006) realiza un modelo de simulación, en el cual la inversión es considerada como un problema de una única empresa en un ambiente de trabajo con precios múltiples y estocásticos. El modelo de simulación se utiliza para explorar el impacto de las transacciones de emisiones, en particular el esquema de intercambio de emisiones de la Unión Europea (EUETS) en inversiones de plantas IGCC. Presenta 2 casos reales estudiados: modificaciones a una planta térmica existente con condensado de vapor y una nueva planta combinada de calor y electricidad.

(Chandra, 2005) estudia tres tecnologías de combustión de carbón en un ambiente de precio de $CO_2$ incierto: carbón pulverizado (PC), IGCC de línea base y IGCC con pre-inversiones que la hacen menos costosa cuando se le adapta un sistema de captura de $CO_2$. Todas estas plantas pueden ser modernizadas para capturar $CO_2$ y pueden ser consideradas “listas para captura”, aun cuando el costo y las dificultades técnicas para reacondicionar pueden variar en forma importante. Los modelos de flujos de caja para casos específicos de estas tres tecnologías fueron desarrollados de estudios de literatura.

(Patiño-Echeverri et al., 2004) examinan las decisiones a nivel de empresa para adquirir concesiones para una planta existente, modernizar la planta con controles de emisión o construir una nueva planta con tecnología de control de emisiones. Modelan la evolución de los precios de concesiones para $SO_2$, NOx, $H_g$ y $CO_2$ usando movimiento browniano geométrico con flujos (drift), volatilidad y saltos y utilizan un análisis basado en opciones para encontrar el valor de diferentes alternativas de inversión.

(Sekar et al., 2007) analizan cómo las inciertas regulaciones de carbón en USA determinan la elección actual del tipo de planta a construir. El foco está en carbón pulverizado (PC) y planta IGCC. La tecnología PC es más barata, asumiendo que no hay necesidad de control de emisiones. La tecnología IGCC puede ser más barata si el carbón pudiera ser capturado. Dado que las plantas de generación duran varios años y las futuras regulaciones son inciertas, una empresa eléctrica norteamericana enfrenta decisiones estándares bajo incertidumbre. Si se asigna suficiente probabilidad a escenarios con regulaciones más estrictas, entonces la tecnología IGCC es más conveniente.

(Reedman, Graham y Coombes, 2006) realizan un estudio para el caso australiano, basados en que el clima presente para inversiones en activos de generación de electricidad es incierto. Los principios conductores del trabajo son: la naturaleza en gran parte irreversible y duradera de los activos para generación de electricidad y por otra parte la posibilidad que los inversionistas de tales activos tengan que pagar impuestos de carbón por las emisiones, producto de la generación en alguna fecha futura desconocida.

(Oda J., Matsuhashi y Yoshida, 2004) explican cómo los inciertos costos sociales pueden influir en la decisión de una empresa para invertir en tecnología de reducción de emisiones. Para el caso de estudio, suponen una empresa que es propietaria de una planta térmica a carbón antigua en los Estados Unidos. Calculan numéricamente el comportamiento óptimo de la inversión sujeto a subvenciones de precios estocásticos de las emisiones de $CO_2$, precio de gas natural y costos sociales, usando la ecuación de Bellman y modelos de mallas con pocas variables.

## 3.- Aplicaciones

En este trabajo se realiza la evaluación de dos casos que tienen relación con la generación de energía eléctrica:

<u>Caso 1:</u> Adaptación planta NGCC existente para la utilización de syngas de carbón o biomasa

<u>Caso 2:</u> Decisión de Inversión en planta con tecnología IGCC o en planta con tecnología de carbón pulverizado (PC)

Para ello, se considera a los precios de combustibles como variables aleatorias que siguen un proceso IGBM (Inhomogeneous Geometric Brownian Movement), también conocidos como GBM integrado o proceso geométrico de Ornstein-Uhlenbeck, de acuerdo a lo descrito en (Abadie y Chamorro, 2006). Se opta por este tipo de modelo dado que los precios de subyacentes no siempre siguen un proceso estocástico tal como el GBM (Geometric Brownian Movement), especialmente el caso de activos de reversión a la media como precios de commodities no financieros. Por tal razón, los precios de gas natural y carbón serán considerados como estocásticos, obedeciendo al proceso IGBM.

El modelo Integrado o No homogéneo de Movimiento Browniano Geométrico (IGBM) se representa por la expresión

$$dS_t = k(S_m - S_t)dt + \sigma S_t dZ_t \qquad (1)$$

donde:

$S_t$ precio del combustible en el tiempo $t$.

$S_m$ nivel del precio de combustible al cual tiende en el largo plazo.

$k$ velocidad de reversión hacia el nivel "normal". Puede ser calculado como $k$ = log2/$t_{1/2}$, donde $t_{1/2}$ es la media-vida esperada, esto es el tiempo para que el gap entre $S_t$ y $S_m$ se reduzca a la mitad.

$\sigma$ volatilidad instantánea del precio del combustible, que determina la varianza de $S_t$ en $t$.

$dZ_t$ incremento de un proceso Wiener standard. Es distribuido en forma normal con media cero y varianza $dt$.

Para el cálculo se emplea la metodología de árbol binomial desarrollada por (Cox, Ross y Rubinstein, 1979), que ha sido ampliamente utilizada en aplicaciones diversas, ya que generaliza el modelo de Black-Scholes-Merton y considera las principales restricciones de este modelo.

Es simple de usar, flexible y depende de un número limitado de parámetros. A medida que el intervalo de tiempo $\Delta t$ disminuye, converge a un proceso GBM. Para el caso del proceso IGBM, se trabaja en base al desarrollo que se presenta a continuación. El horizonte de tiempo $T$ se subdivide en $n$ pasos, cada uno de largo $\Delta T = T/n$. Comenzando desde un valor inicial $S_o$ en el tiempo $i$, después de $j$ incrementos positivos de tamaño $u$, el valor del combustible está dado por $S_o u^j d^{i-j}$, donde $d = 1/u$. Si se considera un activo cuyo precio de riesgo neutro sigue la diferencial estocástica:

$$d\hat{S} = [k(Sm-\hat{S}) -\rho\sigma\varphi\, \hat{S}]dt + \sigma\hat{S}dZ \qquad (2)$$

Adoptando la transformación $X=ln\hat{S}$ y siguiendo procedimientos estándares, se puede mostrar que los movimientos hacia arriba deben ser de tamaño $\Delta X = \sigma\sqrt{\Delta t}$. Por lo tanto $u = e^{\sigma\sqrt{\Delta t}}$ y $d = e^{-\sigma\sqrt{\Delta t}}$.

La probabilidad de un movimiento hacia arriba en el nodo $(i,j)$ está dada por:

$$p_u(i,j) = p\left(\frac{1}{2} + \frac{\hat{\mu}(i,j)\sqrt{\Delta t}}{2\sigma}\right) \qquad (3)$$

$$\left\{ \right.$$

*0, si x<0*

donde p(x) = x, si $0 \leq x \leq 1$

1, si x>1

siendo,

$$\hat{\mu}(i,j) \equiv \frac{k\left(S_m - \hat{S}(i,j)\right)}{\hat{S}(i,j)} - \rho\sigma\phi - \frac{1}{2}\sigma^2 \qquad (4)$$

Si se considera ahora dos activos cuyos precios obedecen a los siguientes procesos de riesgo neutro:

$$d\hat{S}_1 = \left[k_1\left(S_{m1} - \hat{S}_1\right) - \rho_1\sigma_1\phi\hat{S}_1\right]dt + \sigma_1\hat{S}dZ_1 \qquad (5)$$

$$d\hat{S}_2 = \left[k_2\left(S_{m2} - \hat{S}_2\right) - \rho_2\sigma_2\phi\hat{S}_2\right]dt + \sigma_2\hat{S}dZ_2 \qquad (6)$$

donde $dZ_1 dZ_2 = \rho_{12} dt$

Además, definiendo $\Delta X_1 = \sigma_1\sqrt{\Delta t}$ y $\Delta X_2 = \sigma_2\sqrt{\Delta t}$, las probabilidades conjuntas son las siguientes:

$$p_{uu} = \frac{\Delta X_1 \Delta X_2 + \Delta X_2 \hat{\mu}_1 \Delta t + \Delta X_1 \hat{\mu}_2 \Delta t + \rho\sigma_1\sigma_2\Delta t}{4\Delta X_1 \Delta X_2} \qquad (7)$$

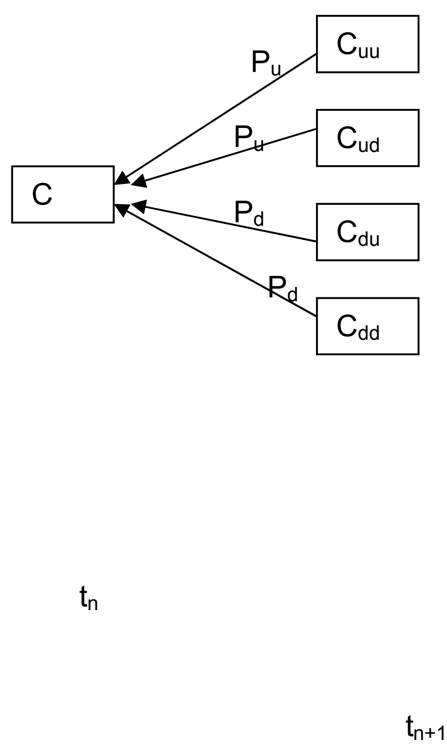
$$p_{ud} = \frac{\Delta X_1 \Delta X_2 + \Delta X_2 \hat{\mu}_1 \Delta t - \Delta X_1 \hat{\mu}_2 \Delta t - \rho\sigma_1\sigma_2\Delta t}{4\Delta X_1 \Delta X_2} \qquad (8)$$

$$p_{du} = \frac{\Delta X_1 \Delta X_2 - \Delta X_2 \hat{\mu}_1 \Delta t + \Delta X_1 \hat{\mu}_2 \Delta t - \rho \sigma_1 \sigma_2 \Delta t}{4 \Delta X_1 \Delta X_2} \quad (9)$$

$$p_{dd} = \frac{\Delta X_1 \Delta X_2 - \Delta X_2 \hat{\mu}_1 \Delta t - \Delta X_1 \hat{\mu}_2 \Delta t + \rho \sigma_1 \sigma_2 \Delta t}{4 \Delta X_1 \Delta X_2} \quad (10)$$

Figura 6

Nodos de un árbol binomial de 2 variables




En el caso de un árbol binomial con dos variables estocásticas, el valor de una opción C en el momento $t_n$ depende de los 4 nodos subsecuentes en $t_{n+1}$ multiplicados por sus respectivas probabilidades, como se muestra en la figura 6.

Estas probabilidades se deben censurar para que sus valores queden en el rango entre 0 y 1, lo que en el caso de árboles con dos variables estocásticas existen diversos criterios y metodologías. En este caso, se emplea el método aplicado por (Hahn y Dyer, 2008) y en (Bastián et al., 2005), que consiste en emplear la regla de Bayes $p(Xt \cap Yt)=p(Yt|Xt)\ p(Xt)$. Calculando las probabilidades $p_u$ y $p_d$, según la expresión (3), se calcula las probabilidades condicionales $p_{u/u}$, $p_{u/d}$, $p_{d/u}$ y $p_{d/d}$ según las siguientes expresiones:

$$p_{u/u} = \frac{\Delta X_1 \Delta X_2 + \Delta X_2 \hat{\mu}_1 \Delta t + \Delta X_1 \hat{\mu}_2 \Delta t + \rho \sigma_1 \sigma_2 \Delta t}{2 \Delta X_2 \left( \Delta X_1 + \hat{\mu}_1 \Delta t \right)} \quad (11)$$

$$p_{d/u} = \frac{\Delta X_1 \Delta X_2 + \Delta X_2 \hat{\mu}_1 \Delta t - \Delta X_1 \hat{\mu}_2 \Delta t - \rho \sigma_1 \sigma_2 \Delta t}{2 \Delta X_2 \left( \Delta X_1 + \hat{\mu}_1 \Delta t \right)} \quad (12)$$

$$p_{u/d} = \frac{\Delta X_1 \Delta X_2 - \Delta X_2 \hat{\mu}_1 \Delta t + \Delta X_1 \hat{\mu}_2 \Delta t - \rho \sigma_1 \sigma_2 \Delta t}{2 \Delta X_2 \left( \Delta X_1 - \hat{\mu}_1 \Delta t \right)} \quad (13)$$

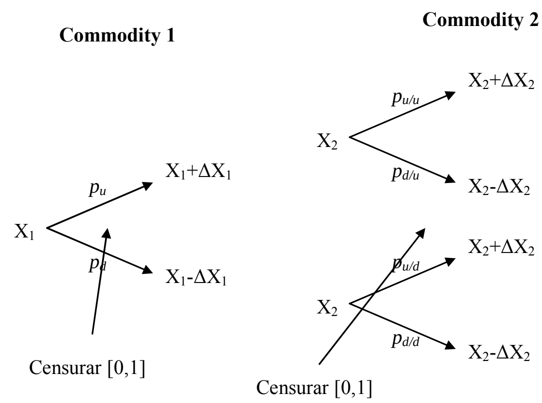
$$p_{d/d} = \frac{\Delta X_1 \Delta X_2 - \Delta X_2 \hat{\mu}_1 \Delta t - \Delta X_1 \hat{\mu}_2 \Delta t + \rho \sigma_1 \sigma_2 \Delta t}{2 \Delta X_2 \left( \Delta X_1 - \hat{\mu}_1 \Delta t \right)} \quad (14)$$

Se debe cumplir que $p_{u/u} + p_{d/u} = 1$ y $p_{u/d} + p_{d/d} = 1$. El cálculo de las probabilidades conjuntas se realiza multiplicando la probabilidad condicional por la respectiva probabilidad $p_u$ o $p_d$ , debiéndose cumplir además que $p_{uu} + p_{ud} + p_{du} + p_{dd} = 1$ y las probabilidades deben estar todas entre 0 y 1.

En la notación de las probabilidades conjuntas $p_{uu}$, $p_{ud}$, $p_{du}$ y $p_{dd}$ , el primer subíndice se refiere al movimiento del activo 1 y el segundo al movimiento del activo 2. Los 4 nodos en el árbol binomial de la figura 7 se pueden dividir en sus nodos marginales y condicionales de la forma indicada en figura 8.

Figura 7

División de los nodos en árbol binomial con dos variables




3.1.- Caso 1: Adaptación planta NGCC existente

Se evalúa la decisión de adaptar una planta NGCC existente de generación eléctrica con un sistema de gasificación para producir syngas a partir de carbón o biomasa. En algunos casos se han adaptado centrales existentes para utilizar syngas proveniente de un gasificador, requiriendo una inversión de aproximada de 5 millones de dólares para la adaptación de una turbina de 350 MW (Research Reports Internacional, 2005), además de adicionar las unidades señaladas más adelante. En Chile, existen 18 unidades NGCC y actualmente sus posibilidades de operación son:

Operar con gas natural

Operar con Diesel, en caso de falta de gas natural

No operar

En este caso, se evalúa la inversión para modificar la planta NGCC y operarla con carbón, teniendo como base la operación de la central no modificada con GNL. La ventaja que tendría una planta modificada es que podría operar utilizando carbón, teniendo gas natural como combustible secundario, dependiendo de los precios de estos combustibles. Como referencia, se considera los parámetros de Central Atacama, localizada en Mejillones perteneciente a la empresa Gas Atacama. Los datos de operación y especificaciones técnicas son obtenidos de Anuario 2007 (CDEC-SING, 2006) y del Informe Técnico Definitivo "Fijación De Precios De Nudo Sistema Interconectado del Norte Grande (SING)" (Comisión Nacional de Energía, 2007c). La figura 6 muestra las unidades (sombreadas) que se requiere agregar a la planta NGCC: Gasificador, Sistema de limpieza de gas y Unidad de Separación de Aire (ASU).

Para el cálculo del Valor Presente del costo de combustible ($VP_{Comb}$) durante la vida útil de la planta $\tau$, cuyo precio sigue un proceso IGBM, se utiliza la expresión desarrollada por (Abadie y Chamorro, 2006).

$$VP_{Comb} = B\left[\frac{kS_m\left(1-e^{-r\tau}\right)}{r\left(k+\rho\sigma\phi\right)} + \frac{S-\frac{kS_m}{k+\rho\sigma\phi}}{r+k+\rho\sigma\phi}\left(1-e^{-(r+k+\rho\sigma\phi)\tau}\right)\right] \quad (15)$$

Además, el Valor Presente de ingresos por venta de energía eléctrica ($VP_{Ing}$) y el Valor Presente de costos variables ($VP_{Cvar}$), durante la vida útil de una planta, se pueden calcular con las expresiones siguientes:

$$VP_{Ing} = A * P_e \frac{\left(1-e^{-\tau(r-r_a)}\right)}{r-r_a} \quad (16)$$

$$VP_{C\,\mathrm{var}} = A * C_{\mathrm{var}} \frac{\left(1-e^{-\tau(r-r_a)}\right)}{r-r_a} \quad (17)$$

Donde,

| | |
|---|---|
| $B$ | Energía de combustible requerida, en GJ/año |
| $A$ | Producción anual de energía eléctrica, en millones de KWh |
| $C_{var}$ | Costos variables unitarios de operación (no combustible), en US$/kwh |
| $k$ | velocidad de reversión a la media |
| $S_m$ | Nivel de precio del combustible al cual tiende en el largo plazo US$/GJ |
| $S$ | Precio del combustible en US$/GJ |
| $r$ | Tasa libre de riesgo |

$r_a$ Tasa de crecimiento de precio de energía y costos variables

$\tau$ Vida útil de la planta en años

$\sigma$ Volatilidad instantánea del precio de combustible, que determina la varianza de $S_t$ en $t$

$\rho$ coeficiente de correlación entre los retornos en el portafolio del mercado y el activo combustible.

$\phi$ Precio de mercado del riesgo, lo que es definido como $\phi \equiv \frac{r_m - r}{\sigma_m}$, siendo $r_m$ el retorno esperado del portafolio de mercado y $\sigma_m$ es su volatilidad.

La evaluación se realiza en la vida restante de la central NGCC existente, que es de 22 años. Se utiliza una tasa libre de riesgo $r$ = 5% anual.

3.2.- Caso 2: Decisión de Inversión en una planta con tecnología IGCC o en una planta PC

Se evalúa la decisión de instalar una planta nueva de tecnología IGCC. Como alternativa, se considera la instalación de una planta PC (carbón pulverizado). Como referencia, se considera una planta que en Chile cumple con las normas mínimas de tipo ambientales y que tiene precios relativamente bajos dentro de las alternativas tecnológicas de plantas a carbón, con las siguientes características y componentes (Codelco, 2007).

Caldera con carbón pulverizado o lecho fluidizado circulante

Precipitador electrostático

Desulfurizador de flue gas

Quemadores de bajo $NO_x$

Vida útil de 30 años

La comparación se realiza básicamente considerando los costos de inversión, los costos variables de operación (no combustible) y los costos variables de combustible. Para ello, se considera el precio de carbón y de GNL como variables estocásticas siguiendo un proceso IGBM, y se utilizan las ecuaciones (15), (16) y (17).

La evaluación de flexibilidad al cambiar el modo o tipo de combustible dependiendo de sus precios, se realiza mediante la construcción de 2 árboles binomiales que incorporan dos variables aleatorias (precios de 2 combustibles) en sus cálculos. Si se comienza del tiempo *t=0*, para un período de tiempo *Δt*, los beneficios del modo de operación obtenidos de la diferencia de los ingresos por venta de energía menos los costos variables de operación y el costo de combustible del período, se calculan según las ecuaciones (18) y (19).

$$\pi_c = A \times P_e \times e^{r_a t} \frac{\left(1 - e^{\Delta t (r - r_a)}\right)}{r - r_a} - B_c \Delta t S_c - A \times C_{\text{var}\,c} \times e^{r_a t} \frac{\left(1 - e^{\Delta t (r - r_a)}\right)}{r - r_a} \tag{18}$$

$$\pi_g = A \times P_e \times e^{r_g t} \frac{\left(1 - e^{\Delta t (r - r_a)}\right)}{r - r_a} - B_g \Delta t S_g - A \times C_{\text{var}\,g} \times e^{r_a t} \frac{\left(1 - e^{\Delta t (r - r_a)}\right)}{r - r_a} \tag{19}$$

Donde:

$\pi_c$ Beneficios netos de la operación con carbón, en millones de US$ (M US$)

$\pi_g$ Beneficios netos de la operación con gas natural, (M US$)

$S_c$ Precio actual de carbón (US$/GJ)

$S_g$ Precio actual de gas natural (US$/GJ)

$B_c$ Requerimientos de energía en modalidad carbón (GJ/año)

$B_g$ Requerimientos de energía en modalidad gas natural (GJ/año)

$C_{c(c,g)}$ Costo de cambio desde carbón a gas natural (US$)

$C_{c(g,c)}$ Costo de cambio desde gas natural a carbón (US$)

Si inicialmente la planta IGCC consume carbón, entonces debe elegirse entre las dos opciones siguientes:

Continuar: Se obtiene el valor presente del árbol de carbón, más las ganancias esperadas de operar en el modo carbón en ese instante.

Cambiar: Se obtiene el valor presente del árbol de gas natural, más las ganancias esperadas de operar en el modo gas natural en ese instante y menos los costos de cambiar desde carbón a gas natural, $C_{c(c,g)}$

Los árboles binomiales tomarán entonces los valores según las expresiones (20) y (21).

$$V_c = Max\left(\pi_c + e^{-r\Delta t}\left(p_{uu}V_c^{++} + p_{ud}V_c^{+-} + p_{du}V_c^{-+} + p_{dd}V_c^{--}\right), \pi_g - C_{c(c,g)} + e^{-r\Delta t}\left(p_{uu}V_g^{++} + p_{ud}V_g^{+-} + p_{du}V_g^{-+} + p_{dd}V_g^{--}\right)\right) \quad (20)$$

$$V_g = Max\left(\pi_g + e^{-r\Delta t}\left(p_{uu}V_g^{++} + p_{ud}V_g^{+-} + p_{du}V_g^{-+} + p_{dd}V_g^{--}\right), \pi_c - C_{c(g,c)} + e^{-r\Delta t}\left(p_{uu}V_c^{++} + p_{ud}V_c^{+-} + p_{du}V_c^{-+} + p_{dd}V_c^{--}\right)\right) \quad (21)$$

Finalmente, en el tiempo $t=0$, el modo de operación óptimo queda determinado por $Max(V_c, V_g)$, lo que permite encontrar el valor de una planta IGCC con cambio de combustibles o flexible.

Cabe señalar que en la determinación de la planta flexible no se ha incorporado el costo de Inversión Inicial, ya que es irrelevante en esta parte. Sin embargo, cuando se compara los resultados de la planta IGCC flexible con la planta PC, se considera los valores de inversión, lo que determina finalmente el VAN o el Costo total de cada planta, según corresponda.

## 4.- Resultados

Para los dos casos descritos anteriormente, se ha considerado un escenario 1 que considera precios tanto de carbón como de gas natural equivalentes al promedio del año 2006 y un escenario 2 con estimaciones de precios mayores de acuerdo a proyecciones que a inicios del año 2008 se podía realizar basado en las tendencias al alza que experimentaron ambos combustibles.

En cuanto a la energía eléctrica, se ha estimado de acuerdo a los valores de precio nudo (Antofagasta) que regían en el año 2006 (escenario 1) como promedio de los meses de abril y octubre y en el año 2008 (escenario 2), considerando el promedio con los meses de octubre 2007 y abril 2008. La tabla 6 detalla los valores de las variables de precio y otros parámetros utilizados. Por otra parte, la tabla 7 indica los parámetros técnicos de las centrales que son utilizados en las evaluaciones.

Tabla 6

Precios de combustibles y energía, parámetros asociados en dos escenarios

| Item | Valores<br>Escenario 1 | Valores<br>Escenario 2 |
|---|---|---|
| Precio de Gas Natural: | | |
| Precio actual, $S_0$ US$/Mbtu | 6,7 | 19 |
| Precio de largo plazo, $S_m$ US$/Mbtu | 12,5 | 23 |
| Volatilidad anual, $\sigma$ | 0,25 | 0,3 |
| Velocidad de reversión a la media, *k* | 0,25 | 0,25 |
| Factor correlación con mercado, $\rho$ | 0 | 0 |
| Precio del riesgo, $\Phi$ | 0,4 | 0,4 |
| | 9.000 | 9.000 |

| | | |
|---|---|---|
| Poder calorífico, kcal/$m^3$ | | |
| Precio de Carbón: | | |
| Precio actual, $S_0$ US$/ton | 56 | 121 |
| Precio de largo plazo, $S_m$ US$/ton | 150 | 190 |
| Volatilidad anual, $\sigma$ | 0,2 | 0,12 |
| Velocidad de reversión a la media, *k* | 0,3 | 0,3 |
| Factor correlación con mercado, $\rho$ | 0 | 0 |
| Precio del riesgo, $\Phi$ | 0,4 | 0,4 |
| Poder calorífico, kcal/kg | 5.400 | 5.400 |
| Precio de biomasa: | | |
| Precio actual, $S_0$ US$/ton | 130 | 150 |
| Precio de largo plazo, $S_m$ US$/ton | 180 | 190 |
| Volatilidad anual, $\sigma$ | 0,3 | 0,3 |
| Velocidad de reversión a la media, *k* | 0,1 | 0,1 |
| Factor correlación con mercado, $\rho$ | 0 | 0 |
| Precio del riesgo, $\Phi$ | 0,4 | 0,4 |
| Poder calorífico, kcal/kg | 4.200 | 4.200 |
| Precio energía eléctrica, US$/kWh[1] | 0,0451 | 0,0946 |

[1] Datos basado en precio nudo publicado en Comisión Nacional de Energía, equivalente en dólares.

Para el caso 1, la adaptación de la planta NGCC con tecnología de gasificación de carbón obtiene un VAN diferencial negativo de – 58,72 millones de US$. La misma planta para biomasa obtiene un VAN diferencial negativo de – 764,96 millones de US$. Por lo anterior, se profundiza el análisis de la adaptación hacia gasificación de carbón, por ser la alternativa más atractiva.

En el escenario 1, la planta NGCC resulta con un VAN negativo de – 813,95 millones de US$ en su vida útil restante considerando su inversión total. Si se excluye la inversión, el costo total de generación de energía eléctrica en esta planta (combustible y costos variables) es de 0,06772 US$/kWh. La planta NGCC adaptada resulta con un costo de generación de energía de 0,05922 US$/kWh. Si se incluye la inversión incremental, se llega a 0,06983 US$/kWh. Este último valor es un 3,12% mayor que lo que tiene la planta NGCC. El máximo precio de carbón que el proyecto NGCC adaptada soporta es de 28,54 US$/ton, con un precio de reversión de 150 US$/ton.

Tabla 7

Parámetros técnicos utilizados en caso 1

| Item | Planta NGCC sin adaptar | Operación con carbón o biomasa |
|---|---|---|
| Potencia eléctrica, MW | 298 | 298 |
| Inversión específica central, US$/kW[1] | 616 | 1.518 |
| Costo operación, en Cent euros /kWh [2] | 0,32 | 1,05 |
| Costo operación en US$/MWh[3] | 3,84 | 12,6 |
| Eficiencia neta % [4] | 59% | 49,3% |
| Factor de utilización % | 80 | 80 |
| Vida útil, años | 22 | 22 |

[1] Basado en datos de (Rubin et al., 2007), ajustado por variación USA GDP deflactor al 2007.

[2] En centavos de Euros, valor promedio de datos obtenidos de (Schumacher y Sands, 2005)

[3] Considera 1 euro = 1,2 US$

[4] Basado en (Schumacher y Sands, 2005), valores promedios.

En el escenario 2, el VAN de la planta NGCC adaptada a carbón resulta en 1.251,03 millones de dólares y la adaptación con gasificación de biomasa resulta en 807,9 millones de dólares. En este escenario, el VAN de la planta NGCC sería de -1.198 MUS$.

El máximo precio de carbón que soporta el proyecto es de 705,39 US$/ton. Sin embargo, si se evalúa como planta IGCC completa, con toda la inversión, no es rentable y en tal caso el precio máximo de carbón sería de 145,78 US$/ton.

Por lo anterior, la alta rentabilidad del proyecto de NGCC adaptada se debe exclusivamente al ahorro de costos que se logra con una inversión incremental de 295,68 MUS$. En este sentido, el costo de generación de energía eléctrica pasa de 0,1376 US$/KWh en la central NGCC actual a un costo de 0,0927 US$/KWh, es decir una reducción de 32,63% con la NGCC adaptada. La tabla 8 detalla el análisis de sensibilidad y su efecto en el precio de carbón y en el VAN diferencial del proyecto.

Tabla 8

Análisis de sensibilidad Caso 1, Escenario 2

| VARIACIONES | VAN Diferencial (5%) M US$ | Variación % | Precio máximo de carbón US$/ton | Variación % |
|---|---|---|---|---|
| Resultados Escenario 2 | 1.251,03 | -- | 705,39 | -- |
| Inversión incremental +20% | 1.191,90 | -4,73 | 677,76 | -3,92 |
| Eficiencia planta IGCC -20% | 812,88 | -35,02 | 424,77 | -39,78 |

| | | | | |
|---|---|---|---|---|
| Precio de reversión a la media +20% | 952,32 | -23,88 | 565,85 | -19,78 |
| Velocidad de reversión -20% | 1.281,37 | +2,43 | 617,56 | -12,45 |

La tabla 9 indica los parámetros técnicos utilizados para los cálculos y evaluaciones del caso 2. Se evalúa el VAN de una planta IGCC flexible, con opción de switching de combustible, la planta IGCC a carbón y se comparan con el VAN de una planta PC.

Tabla 9

Parámetros de planta PC y planta IGCC

| Item | Planta Termo-eléctrica PC | Planta IGCC | |
|---|---|---|---|
| | | Operación con carbón | Operación con Gas Natural |
| Potencia eléctrica, MW | 298 | 298 | 298 |
| Inv. específica, US$/kW | 1.430[(1)] | 1.518 | 1.518 |
| Costos var. (no comb) | 7,68 | 12,6 | 12,6 |
| US$/MWh | 45,3[(2)] | 49,3 | 59 |
| Eficiencia neta % | 80 | 80 | 80 |
| Factor de utilización % | 30 | 30 | 30 |
| Vida útil, años | | | |

[1] Según (Comisión Nacional de Energía, 2007c), la inversión específica para PC es de 1.300 US$/kW para centrales de 400 MW y de 1.500 US$/kW para centrales 200 MW. Interpolando para 298 MW, da un valor de 1.400 US$/kW

[2] Basado en (Schumacher y Sands, 2005)

Para una vida útil de 30 años, los resultados obtenidos son indicados en la tabla 10. Se puede que todas las plantas resultan con VAN negativo a los precios estimados. Esto se debe a que el precio de energía considerado es bajo en relación a los precios de combustible, aunque en la práctica los ingresos de una planta pueden ser mayores por los contratos que pueden pactar con clientes libres (no regulados), lo que aquí no se considera.

Por tal razón, se incluye en la tabla 10 la comparación solamente respecto al costo anual equivalente (CAE) y el Costo de la Energía (COE). La planta PC es la más conveniente, siguiendo la planta IGCC flexible y en último lugar la planta IGCC carbón.

Tabla 10

Comparación de alternativas escenario 1

| | VAN | CAE[1] | COE[2] |
|---|---|---|---|
| | MUS$ | MUS$/año | US$/KWh |
| Planta PC | -725,91 | 140,91 | 0,0675 |
| Planta IGCC flexible | -784,50 | 144,68 | 0,0693 |
| Planta IGCC carbón | -788,94 | 144,96 | 0,0694 |

(1) Costo Anual Equivalente, considerando todos los costos de la planta

(2) Costo de la Energía

Existe una leve ventaja de la planta flexible frente a la misma planta IGCC operada sólo con carbón, debido a que el precio del gas es caro frente al precio del carbón. En unidades equivalentes, los precios son $S_0$ = 2,48 US$/GJ y $S_m$

= 6,64 US$/GJ para el carbón; $S_0$ = 6,35 US$/GJ y $S_m$ = 11,84 US$/GJ[62] para el gas natural.

Para el escenario 2, las plantas resultan con VAN positivo. La planta PC obtiene 371,51 millones de dólares, en tanto que la planta IGCC a carbón obtiene 349,76 millones de dólares.

Para tener una visión más amplia de las condiciones de precio de combustible que hacen más ventajosa a la planta IGCC flexible, se muestra en la tabla 13 los resultados del VAN de planta PC y planta IGCC flexible, además del cálculo del VAN diferencial $VAN_{IGCC}$-$VAN_{PC}$ .La figura 12 muestra los gráficos correspondientes, a la izaquierda el VAN de la planta IGCC flexible y a la derecha el VAN diferencial. La trama horizontal está ubicada al nivel 0.

Finalmente, la tabla 12 muestra el análisis de sensibilidad realizado para el caso 2.

Tabla 11

VAN de IGCC y PC según precio de combustibles, 30 años

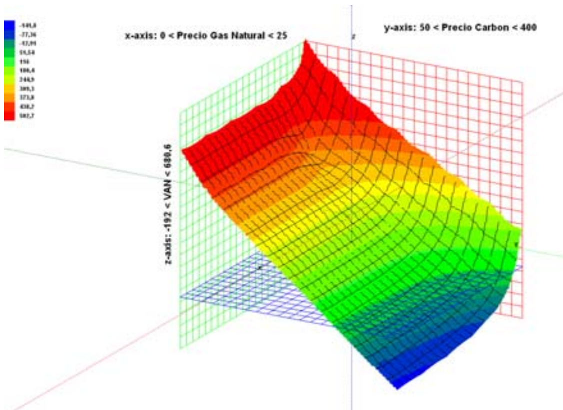
| Precio Gas US$/Mbtu | Precio Carbón US$/ton | VAN IGCC MUS$ | VAN PC MUS$ | $VAN_{IGCC}$ - $VAN_{PC}$ MUS$ | Precio Gas US$/Mbtu | Precio Carbón US$/ton | VAN IGCC MUS$ | $VAN_{IGCC}$ - $VAN_{PC}$ MUS$ |
|---|---|---|---|---|---|---|---|---|
| 0,5 | 50 | 680,55 | 520,45 | 160,10 | 10 | 50 | 546,39 | 25,94 |
| | 100 | | | 137,30 | | 100 | | -30,76 |
| | 150 | 552,86 | 415,56 | 153,33 | | 150 | 384,80 | -22,97 |
| | 200 | | | 187,95 | | 200 | | -13,72 |
| | 250 | 464,01 | 310,68 | 227,17 | | 250 | 287,71 | 2,03 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 300 | 393,75 | 205,80 | 264,27 | | 300 | 192,08 | 20,98 |
| | 350 | 328,08 | 100,91 | 298,51 | | 350 | 102,94 | 41,17 |
| | 400 | 260,26 | -3,97 | 330,66 | | 400 | 17,01 | 61,38 |
| | | 189,65 | -108,86 | | | | -67,73 | |
| | | 116,92 | -213,74 | | | | -152,36 | |
| 1 | 50 | 613,55 | 520,45 | 93,10 | 15 | 50 | 546,39 | 25,94 |
| | 100 | 483,92 | 415,56 | 68,36 | | 100 | 384,80 | -30,76 |
| | 150 | 398,42 | 310,68 | 87,74 | | 150 | 287,71 | -22,97 |
| | 200 | 329,01 | 205,80 | 123,21 | | 200 | 190,62 | -15,18 |
| | 250 | 261,03 | 100,91 | 160,12 | | 250 | 94,62 | -6,28 |
| | 300 | 189,79 | -3,97 | 193,77 | | 300 | 3,0 | 6,97 |
| | 350 | 116,08 | -108,86 | 224,94 | | 350 | -86,09 | 22,81 |
| | 400 | 40,42 | -213,74 | 254,16 | | 400 | -174,00 | 39,74 |
| 3 | 50 | 570,51 | 520,45 | 50,06 | 20 | 50 | 546,39 | 25,94 |
| | 100 | 398,46 | 415,56 | -17,10 | | 100 | 384,80 | -30,76 |
| | 150 | 312,76 | 310,68 | 2,08 | | 150 | 287,71 | -22,97 |
| | 200 | | | 35,56 | | 200 | | -15,18 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 241,36 | 205,80 | | | | 190,62 | |
| | 250 | 168,96 | 100,91 | 68,05 | | 250 | 93,54 | -7,36 |
| | 300 | 93,97 | -3,97 | 97,94 | | 300 | -2,31 | 1,66 |
| | 350 | 16,45 | -108,86 | 125,35 | | 350 | -94,86 | 14,04 |
| | 400 | -62,68 | -213,74 | 151,02 | | 400 | -185,52 | 28,22 |
| 5 | 50 | 568,27 | 520,45 | 47,82 | 25 | 50 | 546,39 | 25,94 |
| | 100 | 385,59 | 415,56 | -29,97 | | 100 | 384,80 | -30,76 |
| | 150 | 293,08 | 310,68 | -17,60 | | 150 | 287,71 | -22,97 |
| | 200 | 212,42 | 205,80 | 6,62 | | 200 | 190,62 | -15,18 |
| | 250 | 134,50 | 100,91 | 33,59 | | 250 | 93,53 | -7,37 |
| | 300 | 56,26 | -3,97 | 60,23 | | 300 | -3,5 | 0,47 |
| | 350 | -23,37 | -108,86 | 85,53 | | 350 | -99,0 | 9,86 |
| | 400 | -104,21 | -213,74 | 109,53 | | 400 | -191,97 | 21,77 |

Figura 8

VAN de planta IGCC flexible (izquierda) y VAN diferencial IGCC-PC (derecha)



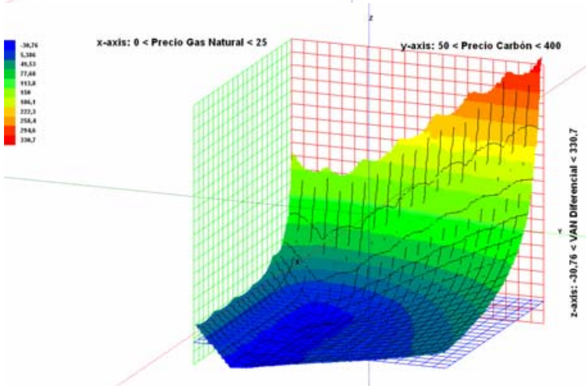




Tabla 12

Resultados análisis de sensibilidad caso 2

| VARIACIONES | IGCC | IGCC flexible | PC |
|---|---|---|---|
| Inversión inicial (+20%) | -25,9% | +26,3% | -22,9% |
| Eficiencia planta (-20%) | -132,8% | -135,9% | -136,1% |
| Precio de reversión a la media de carbón (+20%) | -92,9% | -95,1% | -95,2% |
| Precio de reversión a la media de carbón (-20%) | +92,9% | +95,1% | +95,2% |
| Precio de reversión a la media de gas natural (+20%) | 0% | 0% | 0% |

| | | | |
|---|---|---|---|
| Precio de reversión a la media de gas natural (-20%) | 0% | 0% | 0% |
| Velocidad de reversión de carbón (-20%) | +7,9% | +8,0% | +8,1% |
| Velocidad de reversión de gas natural (-20%) | 0% | 0% | 0% |

## 5.- Conclusiones del estudio

Respecto a los resultados del caso 1, la evaluación en el escenario 1 no resulta rentable, obteniéndose un VAN negativo de -58,72 MUS$ (millones de dólares). El máximo precio de carbón que podría soportar este proyecto sería de 28,54 US$/ton. En el escenario 2, la situación es más favorable, dada la relación precio de energía a precio de combustible, resultando el proyecto de adaptación a syngas de carbón con un VAN positivo de 1.251,03 MUS$ y el precio máximo de carbón que soporta es de 705,39 US$/ton. Por lo anterior, se puede concluir que para una mejor decisión, es clave definir escenarios de precios de la manera más realista posible.

Además, los análisis de sensibilidad indican que la rentabilidad del proyecto es crítica a las variaciones de eficiencia de la planta y con sensibilidad algo menor respecto al precio de reversión a la media ($S_m$) del combustible. La sensibilidad respecto al monto de inversión incremental es poco significativa.

Una ventaja que adquiere la planta NGCC adaptada es la capacidad de utilizar gas natural como combustible de respaldo, lo que valoriza su operación.

Respecto al caso 2, en el escenario 1, para una vida útil de 30 años, la planta PC obtiene un VAN más negativo que la planta IGCC. Sin embargo, si se realiza un análisis más exhaustivo, sometiendo a ambas plantas a distintas combinaciones de precios de gas natural y de carbón, las ventajas son relativas. En este escenario, la planta IGCC tiene menor costo de generación de la energía en relación a la planta PC para precios de gas natural inferiores a 0,5 US$/Mbtu. En el escenario 2, las dos plantas obtienen VAN positivo, obteniendo la planta PC un VAN mayor que la planta IGCC funcionando en modalidad flexible.

Sin embargo, los resultados para distintos precios de gas natural y carbón muestran que la planta IGCC flexible adquiere ventajas frente a la planta PC cuando el precio de carbón es menor que 59,7 US$/ton. Si el precio de gas natural desciende de los 10 US$/Mbtu, la conveniencia de la planta IGCC se mantiene para precios de carbón de hasta aproximadamente 85 US$/ton. Asimismo, la planta IGCC tiene ventaja económica frente a la planta PC cuando el precio de carbón es alto. A modo de ejemplo, si el precio de gas natural es 5 US$/Mbtu, para un precio de carbón superior a 190,56 US$/ton la planta IGCC tiene mayor VAN que la planta PC. Si el precio de gas natural es mayor, por ejemplo 15 US$/Mbtu, sobre un precio de carbón de 255,55 US$/ton la planta IGCC es más conveniente.

La principal conclusión que se puede obtener de estos cálculos para el caso 2 es que, utilizando la metodología de valoración de opciones reales y considerando además los precios de gas natural y carbón como procesos IGBM, la ventaja de una planta frente a otra queda en función de los precios de ambos combustibles. Por lo tanto, nuevamente es necesario señalar que la estimación de los precios y sus expectativas son aspectos críticos para la decisión de qué planta elegir.

Este análisis no sería posible realizarlo con la metodología tradicional de Flujo de Caja descontado, ya que ésta no contempla la toma de decisiones a lo largo del proyecto de acuerdo a cómo evolucionen los precios.

Respecto a los escenarios de precios, se debió recurrir a estadísticas de precios internacionales para el caso de gas natural ya que los precios que rigieron durante la entrega desde Argentina no reflejaban el valor del combustible a nivel internacional. Con la perspectiva de adquirir gas natural a otros países, se trabaja entonces con índices internacionales, tal como el Henry Hub de Estados Unidos. Para el caso de carbón, se utiliza la estadística que se publica en los anuarios de CDEC, y por lo tanto existe una buena base de que dichos precios reflejan el costo real para una central termoeléctrica. Además, dado que el carbón es 100% importado, las variaciones de precio corresponden a las fluctuaciones del mercado internacional. No obstante, dada la alta incerteza que existe en los precios de combustibles actualmente, se sensibiliza para diversos escenarios de precios, lo que permite un análisis enriquecido.

La tecnología de gasificación tiene ventajas tanto operacionales como ambientales. La principal ventaja de una planta IGCC es la variedad de combustibles que puede utilizar, aspecto que en otras plantas como la planta PC no la poseen. Además, permite tener flexibilidad en los productos, ya que el syngas no solamente se puede destinar para la generación de energía eléctrica, sino también puede destinarse en la producción de otros productos tales como hidrógeno y combustibles líquidos. Esta es una ventaja importante cuando la utilización de la planta es sólo por períodos.

En cuanto al aspecto medioambiental, la planta IGCC tiene grandes ventajas frente a la planta PC, tal como se detalla en la tabla 5. En general, la planta IGCC emite menos contaminantes que la planta PC, por lo que si se valoriza este aspecto de la planta IGCC, las ventajas económicas se inclinarían más fuertemente hacia esta última planta. Si se analiza desde el punto de vista de los costos, en un escenario de mayor estrictez en la normativa ambiental nacional, las plantas PC deberán invertir en filtros y dispositivos de tratamiento para ajustarse a las normas, aspecto que encarecerá su costo.

Como líneas de trabajo que pueden derivarse de esta tesis, se puede mencionar lo siguiente:

Estudio de la aplicación de la tecnología de gasificación de carbón en usos diferentes a la generación de energía eléctrica, como por ejemplo en la generación de syngas para ser utilizado en la generación de calor en las empresas medianas y grandes del país, que actualmente deben utilizar petróleo, petróleo diesel o carbón.

Así también, es necesario estudiar, tanto desde el punto de vista técnico, logístico, económico y ambiental la utilización de diferentes materias sólidas que puedan constituirse en combustibles, tales como los desechos domiciliarios e industriales y la biomasa.

Para dilucidar las verdaderas ventajas de las tecnologías de gasificación frente a las de combustión, debe realizarse las evaluaciones incorporando los efectos medioambientales.

Es importante señalar, finalmente, que para introducir la tecnología en Chile minimizando los riesgos, es necesario comenzar por una experiencia piloto.

Esto permitiría generar conocimiento respecto a la operación óptima de una planta de gasificación, evaluar el efecto de diversos combustibles, de diversas configuraciones o diseños de gasificadores y evaluar la potencialidad de subproductos derivados del syngas. Esta es una estrategia que los países donde se utiliza la tecnología IGCC a mayores escalas han adoptado en general.

6.- Avances de la Universidad de Concepción en el tema

La Universidad de Concepción (UdeC) ha realizado diversos esfuerzos de investigación sobre la tecnología de gasificación de carbón, como también para llegar a generar una experiencia piloto que permita lograr una investigación más aplicada y con fines demostrativos. Uno de los esfuerzos se centró en la ejecución de un proyecto de la línea "Estudios de preinversión de consorcios" de Innova Bío-Bío, denominado "Consorcio para el desarrollo e integración de tecnologías de gasificación de carbón sub-bituminosos en la matriz energética chilena". Dentro de las actividades que se realizaron en dicho proyecto, se pueden mencionar:

Se firma un acuerdo con empresa Ecogestión, representante en Chile de la empresa canadiense Energy Quest Inc. para la inclusión en el Consorcio de la tecnología basada en Lecho Fluidizado. Se estudian aplicaciones con soluciones de cogeneración para potencia inferiores a 20 MW.

Se realiza un estudio de la tecnología de lecho fijo WES™ de la empresa norteamericana American Eco Energy, y la propuesta de Ben Gurión University (BGU) para combinar dicho reactor con uno de lecho arrastrado para su aplicación con carbones sub-bituminosos como los presentes en Chile. Se aplicó FLUENT a la simulación de reactores de lecho fluidizado y fijo. En el primer caso, los resultados fueron lo suficientemente aceptables como para tener confianza en disponer, en el mediano plazo, de una herramienta de análisis, optimización y diseño para uso del Consorcio.

Además, se evalúan tecnologías de empresas y centros contactados, tales como la tecnología Bioswirl de la empresa TPS, que combina principios de gasificación y combustión para biomasa (pellets). Se realizan visitas a instalaciones en Suecia en colaboración con la empresa nacional Andes BioPellets y se estudia una propuesta de implementación para reemplazo de gas natural en calderas de UdeC.

Se realizan visitas para conocer la planta demostrativa de 18 MWth que incorpora un ciclo IGCC del Växjö Värnamo Biommass Gaification Centre AB (VVBGC), en Suecia y la planta de IGCC a carbón para generación de 350 MWe en Puertollano, España.

Se elabora un plan conjunto entre la BGU y UdeC para modelación y desarrollo tecnológico. Este plan se inicia con la modelación de un reactor de combustión de lecho arrastrado implementado en la BGU, mediante el código FLUENT.

Se realizan reuniones de trabajo avanzadas con diversas empresas nacionales para realizar diagnósticos preliminares de necesidades de syngas para hornos y calderas, evaluaando la implementación de tecnología americana y canadiense. Además, dada la disponibilidad de pellets de madera en el mercado nacional, se busca una asociación para introducir las tecnologías de gasificación y combustión de este combustible. También, se estudia la instalación de una planta de gasificación en base a desechos sólidos domiciliarios para generación de electricidad.

Se define el marco general para un Consorcio Tecnológico, para lo cual se considera la participación de una empresa proveedora de tecnología de gasificación, un Centro Tecnológico para desarrollo de actividades de I+D, Proveedores de combustible tales como pellets, carbón o desechos sólidos domiciliarios y Clientes que requieran gas para aplicaciones térmicas, generación de energía eléctrica o cogeneración. Se propone el desarrollo de tres etapas para el Consorcio y se evalúa desde el punto de vista económico el impacto de la creación del Consorcio para dos escenarios. Las etapas son:

Experiencia demostrativa con tecnología canadiense de 10 MWth, operando con pellets y un cliente que permita realizar modificaciones para estudiar la tecnología bajo diferentes condiciones operacionales.

Escalamiento de la tecnología para potencias entre 10 y 50 MWth.

Construcción en Chile de parte de la tecnología y expansión del mercado.

## 7.- Referencias


Abadie L. y Chamorro J., “Valuing flexibility: the case of an integrated gasification combined power plant”, *Energy Economics*, 2006 http://dx.doi.org/10.1016/j.eneco.2006.10.004

Bastian C., Brandao L. y Hahn W., “Modeling Switching Options using Mean Reverting Commodity Price Models”, *Escuela de Negocios Universidad Católica de Rio de Janeiro*, 2005 consultada el 26/2/2008, http://www.iag.puc-rio.br/~brandao/Pesquisa/Modeling%20Switch%20Options%20with%20Mean%20Reverting%20Prices%20-%205-23-07.pdf (visitada el 26/2/2008)

Canadian Electricity Association, Power *generation in Canada, a guide*, 2006, consultada el 22/1/2008, http://www.canelect.ca/en/Pdfs/HandBook.pdf

CDEC-SING, *Anuario 2006*, consultada el 26/2/2008, http://suse-sing.cdec-sing.cl/pls/portal/cdec.pck_inf_sing.anuario

Chandra R., *Carbon Dioxide Capture from Coal-Fired Power Plants: A Real Options Analysis*, Thesis para Master of Science in Technology and Policy and Master of Science in Mechanical Engineering at the Massachusetts Institute of Technology, June 2005, ©2005 Massachusetts Institute of Technology.

Codelco, “Suministro Energía Eléctrica de Largo Plazo”, *seminario Cámara Chileno-Australiana de Comercio (Auscham)*, 2 de Octubre de 2007, consultada el 18/2/2008, www.auscham.cl/ppt/CODELCO.ppt (visitado el 18/2/2008).

Comisión Nacional de Energía, 2007a, *Balance de Energía 2007*, Chile, consultada el 19/1/2008, http://www.cne.cl/estadisticas/nacionales/electricidad/f_precio.html

Comisión Nacional de Energía, 2007b, *Capacidad instalada de generación*, Julio 2007, Chile, consultada el 19/1/2008, http://www.cne.cl/archivos_bajar/capacidad_instalada_de_generacion.xls

Comisión Nacional de Energía, 2007c, *Fijación De Precios De Nudo Sistema Interconectado del Norte Grande (SING), Informe Técnico Definitivo*, Abril 2007, consultada el 21/1/2008, http://www.cne.cl/electricidad/destacados/precio_octubre2007.php

Comisión Nacional de Energía, 2008, consultada el 15/1/2008, http://www.cne.cl/archivos_bajar/restricciones_gas/grafico_restricciones_2004-2008.pdf

Cox J., Ross S., and Rubinstein M., “Option pricing: A simplified approach”, *Journal of Financial Economics*, Volume 7, Issue 3, September 1979, Pages 229-263.

Farías, O., “Gasificación de carbón, una alternativa energética para Chile”, *Revista Colegio de Ingenieros de Chile*, Consejo Zonal Bio-Bio, artículo en prensa.

Fernández V., “Teoría de Opciones: una síntesis”, *Revista de Análisis Económico*, Vol.14 Nº 2, pp. 87-116, Noviembre 1999.

Fleten S.-E. y Näsäkkälä E., “Gas Fired Power Plants: Investment Timing, Operating Flexibility and Abandonment”, *Arne Ryde symposium*, The Nordic Electricity Market, Lund, Sweden October 3-4 2003, consultada el 22/1/2008, http://www.sal.hut.fi/Publications/c-index.html

Grupo de Trabajo en Núcleo Electricidad, 2007, *La opción núcleo-eléctrica en Chile*, Informe Septiembre 2007, consultada el 21/1/2008, http://www.cne.cl/noticias/otros/Informe.pdf

Hahn W.J. y Dyer J.S., “Discrete time modeling of mean-reverting stochastic processes for real option valuation”, *European Journal of Operational Research*, Volume 184, Issue 2, 16 January 2008, Pages 534-548.

Laurikka H., 2006, “Option value of gasification technology within an emissions trading scheme”, *Energy Policy* 34 (2006) 3916-3928.

Leppard S., “Options and Options Valuation Techniques”, publicado en Ronn E. (ed) *Real Options and Energy Management*, Risk Books, pp 61-113, 2002

Oda J., Matsuhashi R.y Yoshida Y., “The decision to invest in emissions reduction technologies based on the real options approach”, *Proceedings of the 7th International Conference on Greenhouse Gas Control Technologies*, 2004.

Oilnergy, 2008a, *ICE Brent Crude Oil Price*, consultada el 14/10/2008, http://www.oilnergy.com/hpix/1obrenty.gif

Oilnergy, 2008b, *Henry Hub Natural Gas Price*, consultada el 14/10/2008, http://www.oilnergy.com/1gnymex.htm#year

Patiño-Echeverri D., Morel B., Apt J. and Chen C., “Retrofitting or Replacing: The Decision of Installing Equipment to reduce emissions from a coal-fired power plant”, *Resources for the future*, 2004, disponible en http://www.rff.org/rff/Events/loader.cfm?url=/commonspot/security/getfile.cfm&PageID=27484.

Reedman L., Graham P. y Coombes P., “Using a Real-Options Approach to Model Technology Adoption Under Carbon Price Uncertainty: An Application to the Australian Electricity Generation Sector”. *Economic Record*, Vol. 82, No. S1, pp. S64-S73, September 2006 disponible en SSRN: http://ssrn.com/abstract=922166 or DOI: 10.1111/j.1475-4932.2006.00333.x

Research Reports Internacional, *Coal Gasification for Power Generation*,1st edition, September 2005.

Rubin E., Chen C. y Rao B., “Cost and Performance of Fossil Fuel Power Plants with CO2 Capture and Storage”, *Energy Policy* 35, pp. 4444-4454, 2007.

Schumacher K. y Sands R., “Innovative energy Technologies and climate policy in Germany”, *German Institute of Economics Research*, Discussion Papers 509, Agosto 2005.

Sekar R., Parsons J., Herzog H. y Jacoby H., “Future carbon regulations and current investments in alternative coal-fired power plant technologies”, *Energy Policy* Vol. 35, pp. 1064–1074, 2007.

St. Germain J.P. and Brett Humphreys H., “Peaking Plant Valuation: a discounted cashflow/real option comparison”, publicado en Ronn E. (ed.) *Real Options and Energy Management*, Risk Books, pp. 305-322, 2002.

Vásquez E., Evaluación de alternativas de inversión a través de valoración por simulación de opciones reales americanas, Tesis de Magíster en Ingeniería Industrial, Universidad de Concepción, 2006.

Wong R. and Whittingham E., “A Comparison of Combustion Technologies for Electricity Generation”, *The Pembina Institute*, 2nd Edition, Canada, Published November 2006.

World Coal Institute, *Coal Price*, consultada el 23/1/2008, http://www.worldcoal.org/pages/content/index.asp?PageID=438

Building Chile’s National Energy Efficiency Program: An innovative experience in participatory public policy

Alfredo Del Valle, Ph.D. and Nicola Borregaard, Ph.D. Faculty of Economics and Business, Universidad Alberto Hurtado Erasmo Escala 1835, Santiago, Chile. Phone: 56-2-8897458, Fax: 56-2-6920303 E-mail: adelval@uahurtado.cl; nicola.borregaard@gmail.com

Key words: Energy efficiency; public policy; innovation; participation

**Abstract:** The public-policy experience of designing and implementing the National Energy Efficiency Program (NEEP) in Chile through a participatory process, between 2005 and 2007, is presented systematically. The principles and concepts on which it was based, the specific actions that brought it into practice, and the impacts achieved in the first three years, are all made explicit.

The crisis of Argentina-supplied gas that started in 2004 created conditions for actively developing an Energy Efficiency (EE) policy in Chile; this 20-year-old claim from several quarters was finally listened to by the political system. The strategy adopted by the government involved three key elements: (a) making visible the significant *potential* of EE for long-term energy sustainability; (b) promoting the initiative by means of an *enabling leadership* style, which would bring together into a common endeavor actors from government agencies, the private sector and civil society; and (c) designing the policy and its key projects through *strong participation* methods, i.e., the interactive co-creation of visions, objectives and action instruments through a specialized set of concepts and tools.

Following a description of the initial conditions and the strategy, the paper presents the theoretical grounds, managerial principles and practical steps upon which the strategy was built. This should provide a deeper understanding of the process, for making it replicable. Such elements correspond to social systems thinking, or complex thinking, and are integrated into a methodological model called *Participatory Innovation*.

The paper continues with a detailed description of the practical elements that were applied to implement the strategy: (1) the political mandate of NEEP and the character of its organization and operations; (2) the generation of its multi-actor political base; and (3) the participatory design of its strategic agenda and some key specific projects. Subsequently, a summary of achievements in the first three years of application of this strategy is provided; it includes impacts on the political, operational, financial and cultural spheres, with innovations under way in housing, transport, public administration, mining, manufacturing, household devices and health.

The paper concludes with the authors' view about the need for Chile to keep applying a participatory and complex (i.e., non-simplifying) vision in its EE policy. The initial co

creation process should continue to expand and to deepen in Chile, and should become a comprehensive co-operation system, to make Energy Efficiency a permanent component of the culture of every public service, every business company and every family.

## 1.-Introduction: A high-impact, methodical experience

The purpose of this paper is to provide a comprehensive and systematic account of the public-policy experience that took place in Chile for the design and initial implementation of the National Energy Efficiency Program (NEEP), by means of a participatory process. This experience took place between 2005 and 2007, within the appropriate context of a crisis in natural gas supply from Argentina, and had three key characteristics that need to be highlighted, which are inter-dependent:

An *enabling leadership* style, through which all relevant actors, in government, the private sector and civil society, were convened to become active and creative partners of the initiative.[1]

A *systemic understanding* of Energy Efficiency (EE) as a continuous process of improving patterns of energy use, which should take place in all sectors and should be made sustainable by incorporating relevant contents into society's culture.

A *participatory method,* which made it possible to deal practically and effectively with the whole complexity of this challenge, and to mobilize the creative capacities of the actors convened.[2]

The body of the paper deals with the initial context given by the natural gas crisis and other elements, the strategy that was defined to promote energy efficiency, the principles and concepts on which it was based, the specific actions that brought the strategy into practice and the impacts achieved in the three years covered by this paper.

Since it is too early for any impacts on energy intensities or consumption to be measurable, the ones to be shown are process impacts, geared to the mobilization of energy-related actors and resources that started in Chile. Four types of impacts will be described in the paper: political, operational, financial and cultural. In each of these it is shown that the participatory strategy applied in the NEEP has led to a mobilization of resources and a large range of concrete products and impacts. Existing mandates and previous work in different public and private sector institutions were taken advantage of and strengthened through this participatory approach.

[1] Dr. Nicola Borregaard, co-author of this paper, was appointed by Minister of Economy and Energy Jorge Rodríguez Grossi to lead this program.

[2] Dr. Alfredo Del Valle, co-author of this paper, was hired by the Ministry of Economy to provide methodological support to this program. He is the author of the *Participatory Innovation* model.

## 2.- The context: the Argentinean gas crisis and other conditions favorable to energy efficiency

The crisis of Argentina-supplied natural gas that started in 2004, created conditions for actively intervening the demand side of the energy markets in Chile.[3] The question at that moment was whether this intervention would, once more, as in previous situations of scarcity of supply, consist in an energy savings campaign of short duration, usually successfully applied in events of water scarcity due to droughts, or whether a longer term view should be taken and an Energy Efficiency (EE) strategy should be developed and implemented, under considerable time pressure.

In the political decision that was made in favor of the latter, the following factors were critical:

The crisis regarding the supply of natural gas was regarded to last possibly for a longer period of time.

The crisis was not as acute and severe as in the cases of droughts.

Previous work on energy efficiency, either unpublished or not fully taken advantage of, carried out by the National Energy Commission and some other public agencies could be built upon.

In parts of the Chilean academic sector as well as on behalf of international cooperation agencies, such as the German Technical Cooperation, energy efficiency had been a topic for decades and substantial resources had been invested in previous years in search for raising awareness of the importance of the topic in the political system.

The lack of decoupling of the growth in energy consumption to economic growth was striking in the case of Chile, a country with an emerging economy that enjoyed significant growth over the past two decades and was a candidate for membership in the OECD.

First rough estimates of what might be saved through energy efficiency measures and of the cost-benefit ratios, primarily based on the international experience, were very convincing.

[3] In early 2004 Argentina started to apply strong restrictions to natural gas exports to Chile, leaving available only the volumes corresponding to residential consumption. Such restrictions reflected supply shortages which also affected Argentina's consumers; they originated in low domestic prices for natural gas set by the government, which provided no incentives for developing new supply capacities. Over the previous years, Chile had made a significant process of

fuel conversion to natural gas in industry, power generation and residential consumption, along with investments to bring over the gas across the Andes, under the shelter of a Protocol on Gas Integration and Natural Gas Supply signed by both governments in 1995. Such Protocol had been understood by Chilean government and private investors to offer sufficient guarantees of supply continuity.

## 3.- The proposal: A participatory strategy

Making an energy efficiency program effective and sustainable, however, was not trivial for a country that had not made the deep economic and cultural learning from the energy shocks of the 1970's and 1980's that Europe, North America and some Asian countries had already made. An appropriate strategy was required, and the one adopted by the government involved three key elements:

Making visible the significant *potential* of EE for long-term energy sustainability, and showing that such a potential could only be tapped with the active participation of new actors. Such actors would come from: (a) the energy-using sectors, such as industry, mining, appliances, transport, housing and public administration; (b) many government agencies that have significant contributions to make; and (c) several organizations relevant to the subject that represent civil society and the private sector.

Promoting the initiative by means of an *enabling leadership style*, by calling upon such actors to become partners in the new endeavor, and by providing them with effective capacity to contribute to the design and implementation of the program.

Designing and implementing the program and its key projects with the support of a *methodology* that could provide appropriate guidance under the existing conditions.

The methodology that was applied is called Participatory Innovation and is described in the following section. The specific activities carried out in the first three years, along with the impacts achieved, are presented in the rest of the paper.

## 4.- Conceptual grounds for the strategy: The *Participatory Innovation* model

### 4.1 A social-systems view of energy

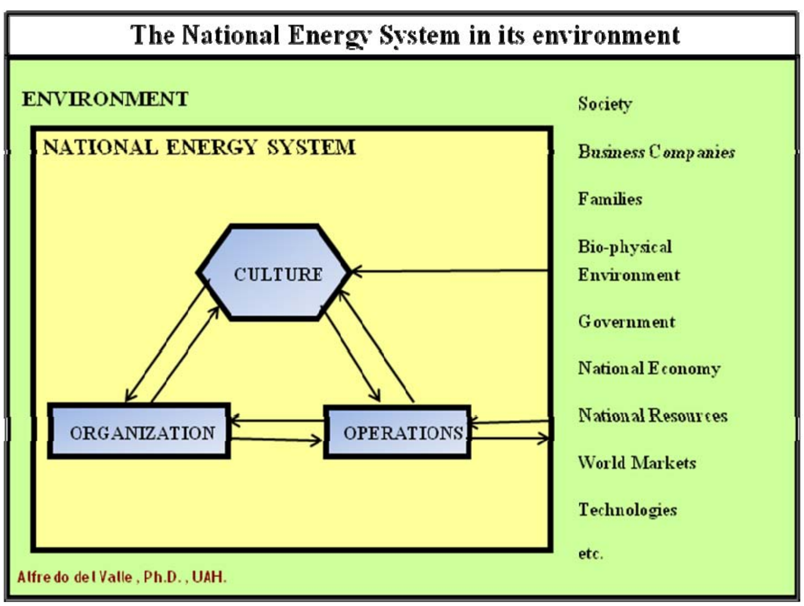
Any public policy is intended to promote some process of change in society. Understanding such a process in the EE case is facilitated by a social-systems view (Del Valle, 2002) of the National Energy System, as presented on Figure

1. This system performs its duties within an environment that has a wide variety of components, from society and families to world markets and technologies. The system has *operations*, such as drilling oil wells, supplying electric power to homes and factories or changing light bulbs at home. It has an *organization* for carrying out the operational responsibilities; in Chile it involves roles for both private and state-owned companies, along with regulatory roles for the state. And it has a *culture*[4] that provides meaning and coherence to the whole; all members of the system

[4] Following Schein (1984), the culture of a group is understood as a pattern of shared basic assumptions about the correct way of perceiving, thinking and feeling about the group's problems of external adaptation and internal integration. Such assumptions are unconscious and are considered valid because they have worked well enough over a long-term learning process, in which concrete problems of both types have been faced.

unconsciously abide by the basic assumptions of its culture. The operations are directly connected to the environment, in both directions, while the system's culture receives influence from other cultures in the environment. All three aspects are interdependent and change together when they do.

Figure 1




Notice two, highly relevant points for the energy efficiency policy:

Some basic, unconscious assumptions in the energy culture of countries like Chile are: (a) the word 'energy' refers only to energy supply activities, not to energy use activities; (b) energy-related matters are highly technical and only experts should deal with them; and (c) individuals, families and most business companies have nothing to do with energy-related activities.

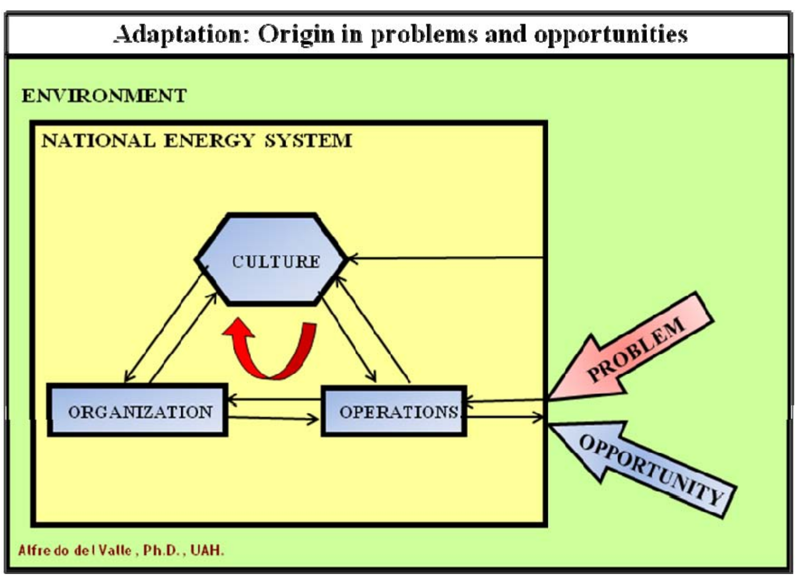
The most effective way of inducing a permanent change in a culture is by producing sustainable changes in the operations and the organization of the corresponding social system. For instance, a family might get permanent energy awareness once it has substituted efficient light bulbs for incandescent ones.

4.2 Adaptation and innovation: Contrasting types of change

How does any change take place in a social system? Figure 2 shows the case of *adaptation*. An event takes place in the environment, such as a rise in oil prices or the announcement of a new technology. It is labeled *problem* or *opportunity* by the system actors, according to its potential impact upon them; the same event may be a problem for a consumer and an opportunity for a company. The event is perceived initially by the operations, is evaluated as significant and some *reaction* is defined to face the problem or to take advantage of the opportunity: an additional operation of the same kind of the existing ones is established (or

some old operation may be closed). The reactive wave moves on to the organization, in which the existing actors provide a place to the new operation. And finally reaches the culture and may change some of its assumptions. A *cycle of adaptation* is set in, which moves clockwise until a new balance is achieved between all three aspects of the system.

Figure 2




An example of adaptation in Chile's energy system was the introduction of natural gas from Argentina in the 1990's, to take advantage of favorable price conditions and also to face the severe atmospheric pollution of Santiago.

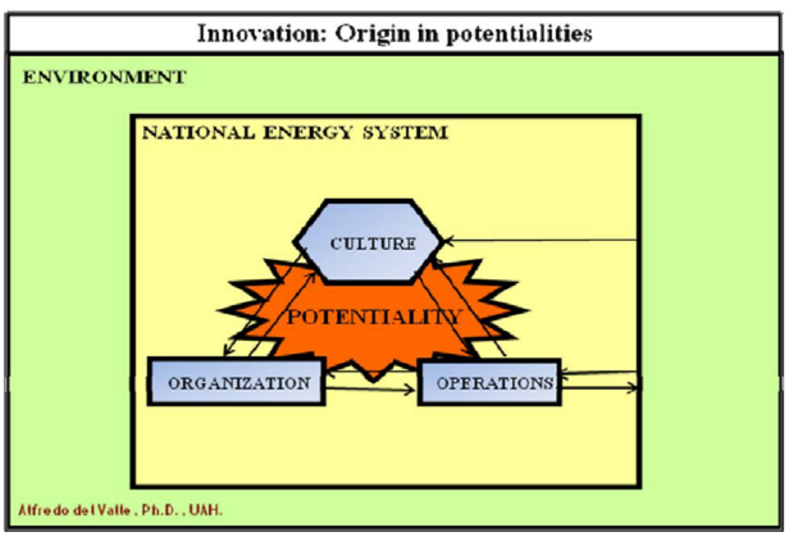
Another, short-term, example is the restrictions to energy consumption that are sometimes used to face supply shortages.[5]

*Innovation* is a different type of change and is outlined in figures 3 and 4. It originates in a new vision of the system's future that is not dependent on, or reactive to, specific events in the environment, although it is indeed related to the environment as anything in the system.[6] It is *proactive* rather than reactive. Its starting point is the discovery and the awareness of a *potentiality*, i.e., of a potential action that is feasible and valuable enough to be undertaken. It also involves changes in operations, organization and culture, but the new operations that become established are qualitatively different from the prior ones and usually involve different actors. In an energy efficiency policy the new operations will be related to energy use and will involve actors that are new to the energy system, such as the suppliers of electric motors, transport services or light bulbs.

[5] Developing countries are mostly adaptive social systems. Their histories may be seen as long series of adaptations to events occurring in their environments. Their cultures value and promote adaptive behavior; they are cultures of adaptation. This is significant, since the lack of adaptive capacity may imply severe losses or damage under adverse conditions.

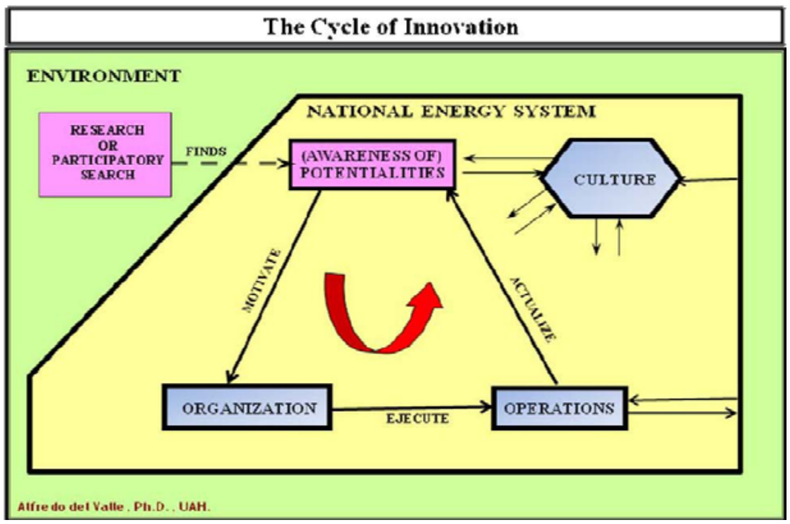
[6] The EE policy initiative was more than an adaptive reaction to the natural gas crisis, as discussed above. Its promotion did take advantage of the energy awareness raised by the crisis, but the motivation of its promoters and supporters was deeper and oriented to the long term.

Figure 3




How does the innovation process work? As shown in Figure 4, its starting point is the need to raise *awareness of the potential* and to promote that it be tapped. Such awareness should create *motivation* at the organizational level and lead to establishing a new actor, to *execute* new operations geared to the potentiality. If the operations are well designed and implemented they will show *results* that will *actualize* the potentiality and demonstrate that it indeed exists and is valuable. This should reinforce the awareness and strengthen the whole process. This is a positive feedback cycle, the *cycle of innovation*, and it runs counter-clockwise. It goes beyond saying that this is not at all an automatic process, but one that requires management and leadership.

Figure 4




4.3 Overcoming common sense: The complexity-participation nexus

Consider a minister of energy interested in setting up a comprehensive and high-impact energy efficiency policy in a developing country with limited experience in this field and no agency in charge. He faces a condition we characterize as *high complexity*, which typically involves: (a) a large number of inter-connected issues; (b) a large number of interrelated actors, with or without conflicts among them; (c) a large number of inter-dependent actions to be undertaken; (d) a large number of relevant disciplines and professions, with their peculiar languages and methods; and (e) several non-communicated cultures at play, such as the political, the academic, the business and the public service ones.

How could the public policy be started? *Common sense* normally advises: (a) use experts, consultants, surveys and analyses of varied sorts as sources of knowledge, and (b) take one or two highly-visible measures like introducing efficient street lamps or subsidizing lowfuel-consumption cars, with the support of a strong media campaign. This approach deals with the complexity of the situation by *simplifying* it, in order to make it manageable. The minister would not cover the whole situation, but just what he believes he can handle. Will this approach work for the long run? Hardly so, since the next minister, who needs to differentiate in order to survive politically, may not support the same measures and launch his own ones, but only if he feels that energy efficiency is still attractive at all. Such experience may leave a strong frustration among those involved, and may postpone any attention to the subject for another decade. Only as an exception might permanent capacities become established, with autonomous funding, but this is certainly not the rule.

Going beyond common sense, the key to an alternative approach –which turns out to be highly effective– is not to simplify but rather *to deal with the whole complexity of the situation and to consider it as a significant source of wealth*. In this case the minister would convene all actors to become his allies, would consider aspects of energy efficiency that could make other aspects feasible, would present energy inefficiency as the deep cultural lack it in fact is, and would not miss the details, nuances and cultural insights that make things work in practice. The minister would now be able to *describe* the real world as it actually is. He will have acquired the relevant descriptive capacity, or, in the technical terms of the systems sciences, *requisite variety* (Ashby, 1956).

The alternative way is based on a theoretical principle that was originally proposed by Del Valle (1992), which states that high complexity can be effectively matched through methodical participation. It is based on the fact that no one can better describe the real world as it is than the people who experience it day after day and know it from practice. In this approach the minister would: (a) use the real-world actors as the key source of knowledge, along with experts for technical issues, and (b) take a large number of measures at the same time, so as to cover the energy efficiency field as widely as possible. His policy-making process would apply effective methods to elicit the actors' knowledge, to systematize it and to convert it into effective action. Del Valle (1992, 1999, 2002 and 2007) has developed such *high-variety* methods and tools and has applied them in a large number of fields. They do have a high descriptive capacity because of their built-in logic, and because they use methodically the appropriate instrument for dealing with nuances, details and insights, which is human language.

A word must be said about the notion of participation in this approach, which is labeled *strong participation* (Del Valle, 2009). Notice first that a common usage of the term participation refers to situations such as attending some event, being consulted about a specific subject, voting among a few alternatives, being present at an assembly or being a member of a focus group. In such instances the ground has been defined in advance by the conveners, so that the individual has no chance of making any significant difference; such are instances of *weak* participation. *Strong participation*, on the contrary, is what happens when people are convened to create a future relevant to them, in a context of free and effective interaction with other people similarly convened. It is the *interactive co-creation of reality by its relevant actors*. It is a process that multiplies capabilities, enriches ideas, humanizes people and dignifies them. With appropriate methods and tools it can be highly effective and yield realistic outputs, and can be very attractive and fun for those convened.

4.4 Ten managerial principles: Building innovation systems and cultures

The discussions of the preceding sections are now brought together. The challenge is not just to carry out one or two innovations but a large number of them, and to carry them out synergically. This leads to a central question: *How to build up an effective and sustainable innovation system for energy efficiency as a whole, which may generate a permanent stream of diversified and effective innovations?* The focus is now the whole energy efficiency system rather than individual measures. It is not even possible to separate individual impacts, since the number of projects and initiatives is normally large[7] and strong and permanent interactions take place among them and among the actors in charge. It is the joint effect of these interacting projects which brings about the overall impact of the policy, rather than the separate effects of specific projects.

The answer to the above question is practical, and is found by applying a set of ten managerial principles that make it possible to *match* the real-world complexity –rather than ignoring, missing or simplifying it– by building up a capability for effective action that is equally complex. Such principles are:

**Understand energy efficiency as a social system – not a physical or technical one:** The physical effects of energy efficiency actions, in any particular situation, take place in the context of broader interactions in the political, social, economic and cultural spheres of society. The action capability to be built should be able to impact upon such broader spheres and should be understood as a system of social actors rather than a physical or technical system.

**Declare the political intention to build a wide action system:** This is a key act of leadership. It was accomplished in this case by coining the name National Energy

[7] Around 100 projects and initiatives were actually designed and implemented by the NEEP, at different degrees of completion, in the period under consideration. Some details are provided in section 8.

Efficiency Program[8] and by stating that the central objective was to build such a wide-ranging system. This idea proved motivating and provided a concrete and practical focus for generating political will and for mobilizing action capabilities from many areas of Chilean society.

**Aim at knowing and actualizing the whole potential involved:** There is always a huge development potential behind any complex social system, which is latent and in principle can be materialized. According to the nature of the field, it is often visualized via idealized goal-setting (e.g., zero accident, scientific limits), benchmarking studies or other procedures[9]. Visualizing the whole system potential provides strong motivation for the actors to participate.

**Mobilize a large and diverse number of people around this future-building task:** This is the most effective way to make sure that the whole complexity of energy efficiency will be considered and no aspect of it will be missed. The people's stock of knowledge, experience and valuable insights is huge. Moreover, people are normally willing to contribute, provided they will be respected and acknowledged, and not exploited.

**Apply an enabling leadership style – not a domineering one:** A truly effective leader in the complex world is the enabler of people to contribute proposals and actions, not the controller of people. By facilitating the rise of new actors, such a leader will have wide coverage of the field and faithful allies. A usual excuse for the domineering style, i.e., the supposed ineffectiveness of participation, is based on a confusion of participation with assembly-like activities.

**Let the real-world actors create – not just the technicians:** All interested ones should be allowed to make proposals and contribute to implementation. Experts usually know more about means, but real-world actors –managers, operations engineers, architects, teachers, road designers, health officers– know better the ends to be pursued and know the practical details.

**Use specialized tools to externalize people's knowledge:** Non-expert knowledge, though huge, is rarely tapped because it is not formalized and readily-available, or *explicit*. In knowledge-management terms it is *tacit*, and needs to be externalized. This difficulty is solved through the special methods and tools of *Participatory Innovation*, the outputs of which will be presented further on. In systems terms, they are high-variety methods and tools.

**Generate via participation a clear blueprint for the system to be built:** The blueprint is provided by a strategic agenda which is prepared through the *action map* tool (see section 7). It facilitates the leadership and coherence of the process by providing a clear vision of future for the system to be built. This map provides a

[8] In Spanish the name is "Programa País de Eficiencia Energética"; in literal terms it means Country Energy Efficiency Program. It carries the added connotation of a program belonging to all citizens.

[9] Benchmarking studies are common in energy efficiency.

content-rich structure for achieving a common understanding of the system to be built and for managing in practice the process of building it up, i.e., the design and implementation of the policy and its specific projects.

**9. Implement a large number of inter-related and realistic projects:** The high complexity of energy efficiency, –which is a multi-dimensional challenge– can only be matched with a large number of projects that cover all dimensions. No “star” project can match such complexity by itself. Projects are identified via participation to secure their realism, are designed in mutual interaction to secure their overall impact, and are normally implemented as joint-ventures with participating actors.

**10. Set up a multi-actor management system:** An integrated management system for the whole process is essential, but should not be built until the blueprint of the system and the first significant group of projects are well defined. Otherwise it may become just another instance of power struggles. It should have a management team with systemic vision and social and technical strengths, deal with both strategy and operations, and evaluate and re-design periodically the system through participation.

It may be clear that a consistent application of the above principles over an extended period of time should produce not only a permanent stream of innovations, but also a coherent system of innovations that are mutually reinforcing. At a deeper level it should produce qualitative changes of great significance in the National Energy System:

The performance of *new operations*, such energy labeling of appliances, energy efficiency audits or large-scale co-generation projects.

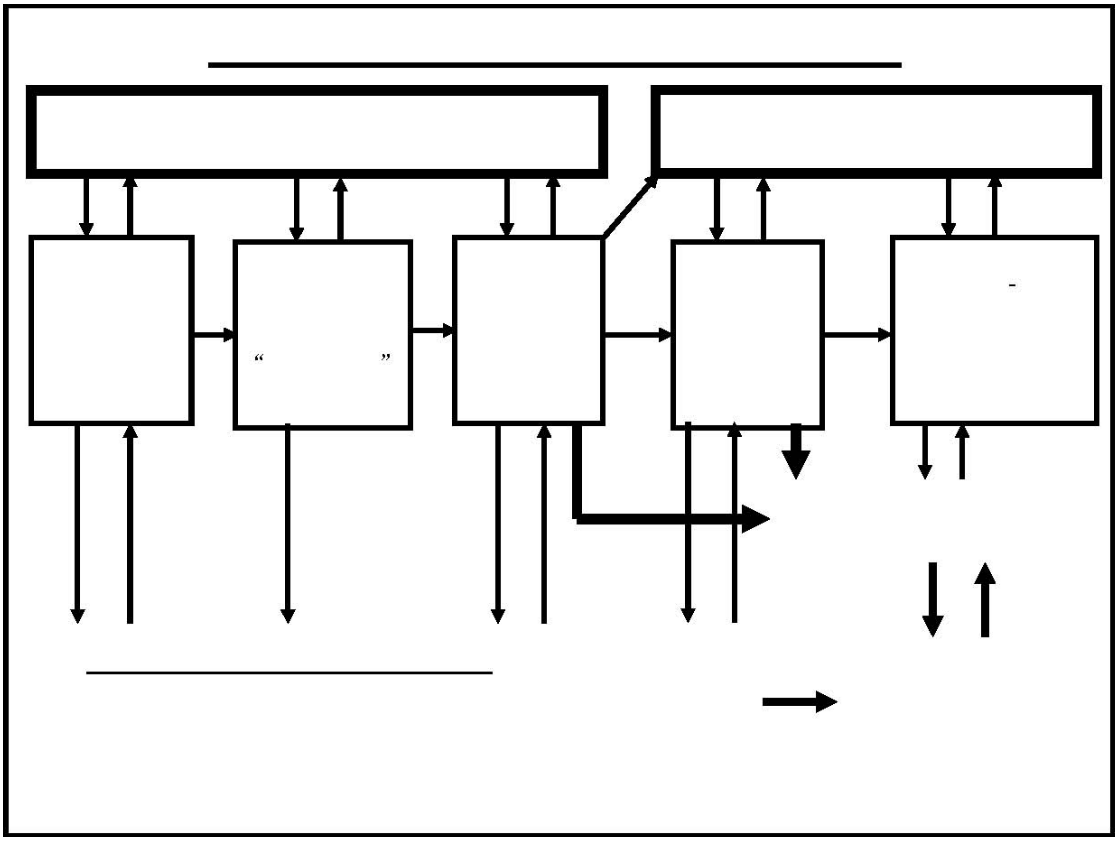
The entry of *new actors* into the system, such as energy efficiency consultants, ESCOs or government programs that subsidize energy efficiency investments.

The incorporation of *new contents into the culture* of the system, such as the new assumption that every family and every business company is responsible for the efficiency of its energy use, and can actually do something about it.

### 4.5 The methodological steps of *Participatory Innovation*

The Participatory Innovation model involves four key methodological steps, which bring to practice the principles of the preceding section. They are shown on Figure 5 and will now be described in general terms. The specific situations occurred in the design and the initial implementation of the NEEP are described in the respective sections of the paper.

Figure 5



**1. Constitution of a Convening Capacity:** The participatory process to build up the public policy must be *convened* by a high-level group of actors. Such actors should jointly cover *all key themes* of the field of action *and all key types of actors* in order to provide legitimacy to the process. In this first step a systemic conception of the process is proposed, the actors who could convene it are identified, a Group of Conveners is formally established and this group takes over the strategic management of the process. The key practical tasks of the conveners are to select the actors that will participate in the process, to define implementation priorities and to contribute to the design of the management system.

**2. Creation of the Vision of Development:** In this step an attractive and viable vision of the future of energy efficiency in the country is created. It arises from the knowledge, experience and visions of the participating actors. It is practical, actionoriented and content-rich. It fully respects the complexity energy efficiency, and makes it understandable and manageable. By doing so, it facilitates the motivation and commitment of the actors to build up such a future. It also provides a diagnosis the current level of development. It is carried out through a workshop of 25-30 participants, by using the *Action Map* tool and its building techniques.

3. **Generation of the Project Portfolio:** The set of projects that could be undertaken, in order to achieve the future envisaged in the Vision of Development, is identified and defined conceptually in this step via participation. Implementation priorities are also proposed. Participants apply the already-mentioned concept of potentiality, which refers to the sustainable action capacity that lies behind any successful innovation, by means of a tool of the model called *Potentiality Profile*. They do so in a series of methodical workshops that may involve hundreds of participants and may identify hundreds of potentialities. Each priority project is defined conceptually in a methodical session with people who know its subject in depth, in which a Potentiality Profile is prepared.

4. **Design of the Management System:** Projects are given priorities and a design is prepared for the system that will provide long-term management to the process. It should make sure that the priority projects be effectively implemented and that innovation will continue taking place in the future. Its contents come from the preceding steps and its outputs involve policies and management criteria, structure of responsibilities and mechanisms for follow-up, evaluation and re-programming. Once implementation starts, this management system takes over the duties of the Group of Conveners.

The above steps yield not only the tangible outputs that were just described. As a central consequence of *strong participation* they also produce a key set of *intangible outputs* that belong to the cultural sphere and are essential for the success and sustainability of any highcomplexity process. Such outputs are also shown on Figure 5: awareness of the potential, motivation, trust, consensus, a common language, leaderships, alliances, networks and permanent innovation capacities. As a practical way for strengthening such outputs and facilitating the whole process, all participants are often linked together on line, through an inter-personal network supported by another tool of the model, called the Participatory Workspace (PWS).

5.-The strategy in practice 1: Mandate and organization

The strategy for the National Energy Efficiency Program (NEEP) was defined and started to be implemented at late 2004 and early 2005 under particularly favorable conditions in the government structure, since the Minister of Economy, under whose aegis the NEEP was established, was at the same time chairman of the National Energy Commission (NEC). This fact was significant since:

- The institutional mandate of the Ministry of Economy involves the key energysupply-policy role of setting prices for electricity and hydrocarbons. It is also in charge of several agencies whose active role was essential for this policy, such as the Economic Development Agency (CORFO) that promotes innovation, the Superintendence of Electricity and Fuels (SEC), the National Consumer's Service (SERNAC) and the National Standardization Institute (INN). It has a transversal mandate and had no difficulty in establishing links with sectoral ministries and agencies.

- The mandate of the National Energy Commission NEC was sectoral, focused on the energy sources and the energy supply system. It was also in charge of the studies required for price setting. Nevertheless, it did carry out some activities related to energy efficiency in the context of its environment unit; it had dealt with efficient public lighting in the past, with German cooperation support, and had recently carried out studies of the energy efficiency potential.

Following the considerations that were presented in section 3, a political mandate and an organizational structure were established for the NEEP, with the following characteristics:

The Minister of Economy and Energy was given, by the President of the Republic, the responsibility for developing and implementing an energy efficiency program, and for coordinating all relevant government agencies in this task.

The management unit of this initiative, under the NEEP name, was established at the Minister's cabinet.

A group of key actors of government agencies, the private sector and civil society was invited to become conveners of the NEEP by appointing the members of the Operational Committee, which would provide guidance and actively participate in the NEEP activities on a permanent basis.

Shortly after the above group started working and the first technical activities took place, the NEEP was officially launched at the Presidential Palace. The ceremony was chaired the by Vice-President because the President was travelling abroad.

## 6.- The strategy in practice 2: Building a multi-actor political base

The *enabling leadership* style that characterized the NEEP was established from the outset and was kept consistently in force throughout the period covered by this paper. Key aspects were the broad membership in the

Operational Committee of the NEEP and the open management style. Table 1

| Conveners of the NEEP, who appointed the initial members of its Operational Committee |
|---|
| *Ministries* Ministry of Economy and Energy (chair) Ministry of the Presidency Ministry of Finance Ministry of Public Works, Transport and Telecommunications Ministry of Housing and Urban Development Ministry of Education Ministry of Health *Business associations* National Confederation of Production and Commerce National Industry Association SOFOFA Chilean Chamber of Construction *Civil society organization* "Sustainable Chile" Program *Other government agencies* National Energy Commission National Environment Commission Economic Development Agency (CORFO) |
| Source: National Energy Efficiency Program, Ministry of Economy, 2005. |

presents the actors that were invited by the Minister of Economy and Energy to become conveners of the NEEP by appointing their representatives to the first meeting of the Operational Committee.

The membership in the Operational Committee remained basically stable over the period, with some new actors becoming members along the way. Typical sessions of the Committee took place on a monthly basis, involved some 20 to 25 participants, provided wide information about what was going on in the field, openly discussed issues and proposals in all areas in which the NEEP was getting involved, and included one or two technical presentations about projects under way or other matters.

Table 1

A very significant responsibility of the Operational Committee was to broaden the reach of the NEEP by proposing who should be invited to its activities. This involved both building up mailing lists for mass invitation to seminars and open events, and carefully selecting participants to be invited to methodical workshops. The output of such workshops is the subject of the next section.

7.- The strategy in practice 3: Participatory design of the strategic agenda and specific projects

The formulation of the strategic agenda was the first technical activity to be undertaken by the NEEP, by means of a *Vision of Development Workshop*. The *Action Map* tool of Participatory Innovation was used for this purpose and the agenda is presented on Table 2. The resulting map is a blueprint of a real-world system the participants propose to build up in Chile, which is called National Energy Efficiency System.

The map was formulated by a workshop of 30 participants, who had been selected by the Operational Committee. Basic selection criteria were to have the widest possible representation of all relevant actors of energy efficiency in Chile, along with a few experts. Diversity in areas, regions, professions and other criteria was also sought. Designing the map took one, very intensive working day; all work was done in plenary session and the output reflects the consensus of the participants.

Table 2

*Action Map:* **National Energy Efficiency System** ***UPPER CASE:*** Established line of action (with a
Non-established line of action

**A. Generation of energy efficiency culture**

A-1 Public information on EE
A-2 Awareness-raising campaign in mass communication media
A-3 Dissemination of individual advantages of EE for the consumer

A-4 Advisory mechanisms to consumers for assessing their energy saving potentials A-5 Education program on efficient household energy use A-6 Positioning of EE in public opinion as required behavior A-7 Instruments for public recognition A-8 Energy education A-9 Dissemination of emblematic cases for education A-10 INCORPORATION OF EE INTO CURRICULAR GRIDS OF KEY UNIVERSITY PROGRAMS A-11 Incorporation of EE into curricular grids of technical education A-12 Incorporation of EE into the school curriculum A-13 Emphasis on EE in the national system for environmental certification of schools

**B. Formulation of a national EE Policy**
B-1 Promotion of and integrated vision of EE which considers quality, reliability and security B-2 EVALUATION OF THE COUNTRY'S EE POTENTIAL B-3 Identification and removal of public policy obstacles to EE B-4 System of national EE goals B-5 National indicative program of EE goals and actions B-6 Policy of minimal EE standards B-7 Incorporation of EE as a source in energy supply plans B-8 Policy of support to distributed generation B-9 Policies for cogeneration and use of residual energy B-10 Incentives to the diversification in exploration and exploitation of hydrocarbons and other national primary energy sources B-11 Consideration of EE in the evaluation of public investment projects B-12 Policy for urban development with EE

B-13 Promotion of RRR (reducing, recycling and re-using)
B-14 Institutional structure for EE
B-15 Mechanisms for public-private cooperation for EE

**C. National system for EE monitoring and control**
C-1 Making transparent the contributions of EE to the reduction of externalities
C-2 System of indicators
C-3 EE auditing system
C-4 Enforcement of regulations
C-5 Dissemination of results and impacts of EE programs

**D. Economic policy framework**

D-1 Policy of free and transparent prices and Exchange rates
D-2 Freedom of energy trade
D-3 FLAT TARIFFS POLICY
D-4 Non-discriminatory tax policy
D-5 Policy for imported fuel prices reflecting importation parity

**E. Regulatory framework for energy efficiency** E-1 Establishment of minimal EE standards E-2 Establishment of national EE standards E-3 Coordination and complementation in regulations and legislation E-4 Adjustment of the regulatory framework of energy supply to EE E-5 Removal of entry barriers to distribution of electricity and hydrocarbons E-6 Incorporation of EE, quality and safety to regulations for medium and high tension E-7 Cogeneration and other energy integration systems E-8 Regulation of the use of minimal standards in motors and transformers E-9 Minimal standards and promotion of EE in public lighting E-10 Regulation of imports of second-hand equipment

E-11 Energy consumption standards for stand-by equipment

**F. EE certification system** F-1 EE labeling and seals F-2 Energy information on the life cycle of final products F-3 Information about energy content in inputs and raw materials **G. Instruments and economic, tax and financial incentives for EE** G-1 Consideration of EE in public financing of private investment projects G-2 Development of financing instruments G-3 Development of incentives G-4 EE investment fund

G-5 Incentive to energy service companies (ESCOs) **H. Promotion of EE in business companies** H-1 Incorporation of EE in Corporate Social Responsibility
H-2 Voluntary EE programs
H-3 Incorporation of EE criteria into Clean Production Agreements
H-4 Voluntary diffusion on energy performance of companies

**I. Incorporation into international EE mechanisms**

I-1 MAKING USE OF KYOTO PROTOCOL AND SIMILAR MECHANISMS
I-2 Preparation for the incorporation of EE as an international competitiveness requirement
I-3 Incorporation and dissemination of international experiences

**J. Sectoral EE po
buildings
and construction**
J-1 EE STANDARDS I
J-2 EE STANDARDS (
INTERNAL HOUSING
J-3 Program for retrofi
buildings
and installations J-4 P
5 Promotion of decons
**Sectoral EE polic**
Revision of specific ta
OF PUBLIC TRANSP
transport K-4 EE in te
IN TRAFFIC MANAGE
fleets K-7 Efficient veh
**program on indu
commerce)**

L-1 Cogeneration of el
L-2 Use of residual th
synergies among com
waste **M. Sectoral
conversion** M-1 E
Verification by load di
associated operationa
standards for the use
**policy and progr**
of obstacles to public
public procurement po

N-3 Energy efficiency
policy and program in
**innovation for E**
O-1 RESEARCH INTO
O-2 Technological de
O-3 Technology trans
O-4 DEVELOPMENT
Training in companies

O-6 Training in other c
O-7 Systems for EE b
O-8 District heating an
O-9 PARTICIPATION
NETWORKS

Action map generated in a Vision of Development Workshop, on 7 January 2005, by 30 actors of energy efficiency and specialists in the field. Participants were
National Energy Efficiency Program, whose members are public, private and civil society actors. The *vision of development workshop* and the *action map* are
methodology, which facilitates the understanding of high-complexity innovation processes and makes possible their effective management.

Source: National Energy Efficiency Program, Ministry of Economy, 2005.

The structure of the map shows a large number of components that are called *lines of action*. They correspond to areas in which there are, or there should be, permanent actors carrying out activities in search for objectives implicit in the lines' names. For instance, a clear objective is implicit in the name of line H, "Promotion of EE in business companies". Lines of action are *parallel* and should be understood as *inter-dependent actions*; for instance, the EE certification system (line F) and the sectoral policy on industrial use (line L) would provide important support to the objectives of line H.

There are two kinds of lines of action, *basic and specific.* The basic lines, like those already mentioned, are on boldface and should be understood as the *dimensions* of the system to be built. The specific lines provide content, precision and detail to the basic; for instance, 13 specific lines provide content to line A, "Generation of energy efficiency culture". All names are expected to be self-explanatory. This particular map has 15 basic lines of action and 96 specific ones. Some of the lines are printed on upper-case letters and most are on lower case. The first ones are the *established* lines of action, i.e., those having actors, activities and impact at the time the map is built. The other ones are *non-established* or potential and correspond to areas that should be developed in the country.

What does this action map offer? This may be synthesized as follows:

A conceptualization of the whole task ahead for building Chile's National Energy Efficiency System, in its full wealth and complexity, and without simplification. There are 15 basic areas to be developed in parallel, which are presented in significant detail. This is, in other words, a *vision of future* for the system.

A *diagnostic assessment* of the progress made in this task. The map shows only 11 established lines of action at the specific level, out of 96, and not a single one at the basic level. Some lines of action such as J "Sectoral EE policy and program on housing, buildings and construction", do show some progress, but according to the participants it did not qualify as established. This is a measure of progress to the envisaged future, and it clearly shows that Chile was just at the starting level.

A systematic basis for identifying the projects and initiatives to be undertaken in order to build up the envisaged future. Every line of action is an area where concrete potentialities exist; they should be identified and should be tapped by means of specific projects. Thus, the map provides a practical basis for project identification, which is done line by line.

On the basis of this map, a large number of specific projects were identified and prioritized in subsequent, methodical workshops, for several basic lines of the map. Such workshops typically involved 20 participants and took half a day. Table 3 shows, as an example, the project portfolio for line F, "Sectoral EE policy and program on transport", which also includes initiatives on urban management.

Table 3

| Project portfolio for line F, “Sectoral EE policy and program on transport” |
|---|
| *Basic knowledge* 1. Development of an information and statistical system on EE for decision-making in transport and territorial development, including base lines and follow-up indicators. 2. Follow-up of the state of the art in vehicle and fuel technologies. *Specific debates and proposals* 3. Debates and proposals about EE urban models and priority to public transport. 4. Generation, evaluation and discussion of alternative scenarios for specific cities with high EE potential. 5. Evaluation and discussion of EE impacts of policies related to fuel prices, taxes and subsidies. 6. Evaluation and proposals about EE in the inter-urban freight transport system (truck, rail, ship, airplane, ducts) considering externalities, with international benchmarking. 7. Generation, dissemination and application of EE management models in urban transport systems, considering externalities (congestion, environmental impacts, safety) with international benchmarking: congestion pricing, differed time schedules, timing, regulation of trip generation, parking management, traffic management, and other. 8. Generation, dissemination and application of EE management models in urban freight transport and logistics: fleet management, loading terminals, vehicle technologies, training of operators. etc. 9. Generation dissemination and application of EE management models in passenger transport: differed school time schedules, trip harmonization, incentives to multi-modality, tele-work, shared cars, etc. 10. Evaluation of impact on EE of motorcycle dissemination in several cities, including benchmarking. 11. Promotion of EE initiatives by government, private and citizen organizations, based on international experiences: incentives to public transport, incentives to bicycle, shared cars, etc. 12. Evaluation and continuous improvement of EE in transport systems of the armed forces. *Certification* 13. EE certification, labeling (seal) and dissemination for all types of motorized vehicles. *Incorporation of EE into other policies* 14. Incorporation of EE criteria in territorial planning instruments, down to the pedestrian scale. 15. Incorporation of EE criteria in the renewal of vehicle fleets of the public sector. 16. Incorporation of EE criteria in the Environmental Impact Assessment System. 17. Incorporation of EE criteria and life-cycle assessment in road infrastructure investment and its maintenance. *Incentives* 18. Incentive to energy management in business companies with transport fleets, including public transport fleets. 19. Evaluation of, and incentives to, the incorporation of district energy systems (hot water, heating, electricity, refrigeration, cogeneration, etc.) in urban, housing and industrial developments. 20. Policy to promote the use of bicycle including: segregated cycle ways, continuity and network building, safe parking, obligation in concessions, obligation in urban developments. 21. Policy to promote walking, including: space, networks and circuits for pedestrians, obligation in concessions, obligation in urban developments. *Awareness raising* 22. Awareness raising and public education on efficient vehicle driving, starting at the educational system. *Transparency* 23. Promotion of transparency in traffic information on concessional roads and infrastructure, for purposes of traffic management, planning and consumer protection 24. Development of on-line mechanisms for dissemination of transport-related information to users. |
| Source: National Energy Efficiency Program, Ministry of Economy, 2005. |

Participatory design work was also carried out for the conceptual design of a large number of specific projects and initiatives. To this end the *Potentiality Profile* tool of Participatory Innovation was used in methodical workshops, which typically involved 10 to 15 participants and took 3 to 4 hours. As an example, Table 4 presents the profile for a project on energy efficiency in public buildings, which involves several government agencies.

| An illustrative conceptual project design: "Energy efficiency in existing public buildings, Phase 1. Pilot case in Public Works Ministry" | | |
|---|---|---|
| Requirement | Resources | Instrument |
| To incorporate the management of energy requirements into the administration of existing public buildings | • Potential energy savings in the public buildings<br>• Knowledge at the National Energy Commission about energy saving potentials in public buildings<br>• Managerial capacities of public building administrators<br>• Capacity of the Budget Directorate (DIPRES) to decide the use of savings in public services • Managerial and technical capacities at Ministry of Public Works (MOPTT) • Managerial and technical capacities at Superintendence of Electricity and Fuels (SEC) • Managerial and technical capacities at Ministry of Housing and Urban Development (MINVU) • Potential of the ESCO model (energy service companies) for energy management of public buildings | Pilot Project at MOPTT, with the support from SEC, DIPRES and MINVU, for definition and testing of a model for managing energy efficiency in public buildings, which should involve:<br>• Inventorying of MOPTT buildings and estimation of their economic energy saving potential<br>• Review of international experiences in the field • Preliminary definition of management models, such as: ◷ Call ESCOs for competitive bidding for high-potential buildings ◷ Own energy management for buildings of medium and low potential ◷ Budgetary mechanisms which may incentive energy savings • Selection of pilot buildings and testing of the models • Evaluation and dissemination of results |
| Source: National Energy Efficiency Program, Ministry of Economy, 2005. | | |

Table 4

## 8.-Impacts: The achievements of the first three years

Four types of impacts will be shown: political, operational, financial and cultural.

### 8.1. Main political impacts

The following actors become active members of the Operational Committee of the NEEP: 8 ministries, 4 public agencies, 6 business associations, and 3 civil society organizations.

The NEEP was launched by the Presidency of the Republic.

• The NEEP´s “Advisory Council”, with two regular meetings per year, brought together six Ministers, as well as the Presidents of two of the most relevant business

associations (the National Industry Association SOFOFA, and the Chilean Chamber of Construction), and four outstanding academic experts, national and international, and non-governmental representatives, appointed by the President of the Republic. The NEEP maintained collaboration and performance agreements with ten different ministries and public services, including, amongst others, key political ministries such as the Ministry of Finance

8.2. Main operational impacts

Table 5 presents the areas of work of the NEEP with the different public agencies and ministries. In each case concrete products have been generated already in the years between 2005 and 2008. An example is listed in Table 6 for the case of Industry and Mining.

Table 5

Table 6

| Example of products generated by NEEP in Industry and Mining, 2005-2007 | | |
|---|---|---|
| Sector | Products | Actor in charge* |
| Industry and Mining | Subsidy to co-finance the implementation of energy audits in SMEs (small and medium sized enterprises) | Economic Development Agency (CORFO) |
| | Establishment of a Register for Consultants in Energy Efficiency | National Standardization Institute (INN) |
| | Incorporation of energy efficiency in eight Clean Production Agreements | National Council for Clean Production |
| | Study to characterize energy consumption at the level of SMEs | National Energy Commission (CNE) |
| | Creation of a Round Table on Energy Efficiency in Large Mining Operations | Ministry of Mining |
| | Voluntary Agreements to reduce energy consumption in the commercial sector | NEEP with different Malls |
| | Annual Energy Efficiency Award | National Confederation of Industry and Commerce |
| | Study for the design of a preferential credit system for energy efficiency projects | NEEP, with CORFO and German Technical Cooperation |
| | Implementation of promotion and discount for energy efficient motors | NEEP with ABB, WEG, Siemens |
| | Study and design of subsidy for energy efficient motors | NEEP |
| | Industry survey (forestry, metal and metal-finishing industry, wine industry) | NEEP |
| Source: Own elaboration based on presentations by directors of the NEEP *NEEP participates in the respective initiatives | | |

8.3 Main financial impacts

Table 7 shows the funds that were mobilized by the NEEP from the national public budget and the German bilateral cooperation. The table shows that there has been a substantial and continuous increase of resources obtained by this Program.[10] Also, public national funds have clearly been the principal source of funding during these years, with a percentage participation of about 90% in the period 2005-2008. The commitment by the German Technical Cooperation at the beginning of the Program, however small it might sound at first sight, was a decisive factor for leveraging the first national budget and starting up the

| Areas of work of NEEP with different public agencies and ministries, 2005-2007 | | |
|---|---|---|
| Sector or Area | Line of work | Actor in charge |
| Housing and buildings | Insulation of houses | Housing Ministry |
| | Certification of energy consumption in houses | |
| | Energy efficiency in social housing | |
| Transport | Management of transport | Ministry of Transport |
| | Certification of energy consumption in vehicles | |
| | Policy instruments for increasing energy efficiency in passenger and freight transport | |
| Public administration | Energy efficiency in public works and infrastructure | Ministry of Public Works |
| | Energy efficiency in public buildings | Ministry of Finance |
| | Energy efficiency in government procurement | Ministry of Finance (National Procurement Service) |
| | Energy efficiency in public lighting, especially street lighting | Superintendence of Electricity and Fuels |
| Mining | Energy Efficiency in large mining companies and energy efficiency in small and medium sized mining operations | Ministry of Mining |
| Industry | Energy efficiency in large companies | NEEP, with Industry Associations |
| | Energy efficiency in SMEs | NEEP, with National Industry Association as well as Economic Development Agency (CORFO), and National Council for Clean Production |
| | Promotion of an energy efficiency service industry (concept of Energy Service Companies, ESCOs) | NEEP |
| Household devices | Energy efficiency labeling of household appliances (starting with refrigerators and light bulbs) | Superintendence of Electricity and Fuels; National Consumer's Service |
| General public | Awareness campaigns, integration of energy efficiency into education at primary, secondary and tertiary level | National Environment Commission and Ministry of Education |
| Source: Own elaboration based on presentations by directors of the NEEP | | |

Program.

10

| Funds mobilized by the National Energy Efficiency Program, 2005-2008 (in million US$) | | | | | |
|---|---|---|---|---|---|
| Source of funds | 2005 | 2006 | 2007 | 2008 | Total |
| Chilean public funds (National Budget) | 0 | 1 | 3 | 13 | 17 |
| German Technical Cooperation (GTZ) | 0.2 | 0.3 | 0.4 | 0.4 | 1.3 (total commitment of US$2 million over six years) |
| Inter-American Development Bank | | | | 0.35 | 0.35 (total commitment of 0.6 over 18 months) |
| Global Environment Facility | | | | | A total of US$ 2.6 million approved in Project Identification Form, for 2009-2012 |
| German Financial Cooperation | | | | | A total of 80 million Euros is committed for credits in energy efficiency and renewable energy projects |
| International and national private funds (Renewable Energy and Energy Efficiency Program, together with the Energy Agency of Berlin, Procobre, numerous private Chilean companies) | 0.1 | 0.1 | 0.2 | 0.2 | 0.6 |
| Source: National Budget Law, years 2005, 2006, 2007, 2008. Numbers are approximate, with a fixed Exchange rate of 500 pesos to the dollar. | | | | | |

This trend is continued in 2009, with a total approved budget of about US$30 million (exchange rate of 650 pesos to the dollar).

Table 7

Additional funds were committed by several public agencies in charge of different areas related to energy efficiency. For example, the Economic Development Agency (CORFO) financed directly the subsidy for co-financing energy audits in industry, and the National Council for Clean Production financed directly the design, implementation and monitoring of the Clean Production Agreements, which integrated energy efficiency as one of their main elements. Certainly, most of the public funds leveraged considerable additional financing on behalf of private companies and institutions. Estimates for these leveraged funds are not available. However, the case of Spain indicates that the ratio between public and private funds can vary considerable between the different sectors that are intervened, at 1 to 3.4 in the case of industry in general, up to 1 to 155 in the case of the energy sector (IDAE, 2005).

8.4 Main cultural impacts

At the point of initiation of the NEEP, the concept of "energy efficiency" was hardly known to the general public, and in the media it was too often confused with and taken to be identical to the notion of energy saving.[11] Over the course of the first two years of

[11] See press releases at the time of launching the Program in early 2005.

operation of the Program the media changed its perspective and understanding, emphasizing the technological changes implied by energy efficiency initiatives. This is reflected in the 220 articles and television reports published in specialized and mass media about the Program and its activities during 2007.[12] At the same time the Program established a virtual community based on the *Participatory Workspace (PWS)* tool of Participatory Innovation, which brought together more than 300 professionals during the first year of operation, as well as a webpage with around 50.000 visits per year.

A first public campaign was launched in 2007, under the slogan "Follow the current – use your energy efficiently"[13], and an energy efficiency fair was held, with over 40 companies and institutions exposing their products and services for one week on the central square in front of the Presidential Palace, containing, amongst others, an installation of two houses for visitors to understand basic concepts of energy efficiency in practice.

The International Energy Efficiency Day as well as the World Water Day were taken advantage of to launch different educational initiatives. To deepen the impact at the educational level, a program for capacity building of teachers was implemented together with the National Environment Commission, CONAMA, specifically aiming at the more than 500 schools that form part of the National System for Environmentally Certified Schools.

9.- Why is it necessary to keep the original principles? Towards an Energy Efficiency culture in Chile

We conclude by stating our view that the basic principles through which the NEEP was established and started its work should be kept under application in the coming years. They have been described in this paper in detail and need not be repeated. A participatory and complex (i.e., non-simplifying) vision of the Energy Efficiency action is necessary because the field is wide and interconnected, and the only way to be effective is to work at the same time and synergically in the whole action space. As demonstrated elsewhere and now in Chile, EE is necessarily a multi-actor endeavor, involving government, business and civil society, and any reductionism in this regard could be expensive for the country in the long run.

The above statement applies with particular strength to the need for a sustainable culture of EE in Chile. As discussed above, culture has to do with unconscious assumptions and it takes long time, sustained and consistent messages, and especially action-oriented efforts, to transform the existing assumptions into new ones. Under certain conditions such a cultural change might take place following a deep shock, as occurred in the developed

[12] 2007 is the first year with a quantitative monitoring regarding this aspect. Internal memo, National Energy Efficiency Program..

[13] According to the evaluation of the campaign, carried out three months after the campaign finished, 62% of the respondents still remembered specific energy efficiency measures promoted in the campaign.

countries after the international oil crises of the 1970's and 1980's, which prompted them to set up wide-ranging innovation efforts in EE. But developing countries including Chile did not learn from the same crises and did not innovate, for reasons beyond the scope of this paper. There is now a chance to bring this incipient cultural change process to maturity, by keeping in force the EE process, to which a large number of people and organizations contributed. The co-creation effort should continue and should give rise to a fully co-operational system, in order to bring EE into the culture of every public service, every business company and every family in Chile.

10.- References

• Ashby, W. Ross (1956), "Variety, constraint and the law of requisite variety" (From

W.R. Ashby, An introduction to cybernetics, London: Chapman and Hall, Chapter 7, pp. 123-124 and Chapter 11, pp. 202-209). Reprinted in W. Buckley (ed.), *Modern systems research for the behavioral scientist. A sourcebook.* Chicago: Aldine Publishing Company, 1968. Second printing 1969, pp. 129-136.

Del Valle, Alfredo (1992), *Innovative planning for development: An action-oriented approach.* A dissertation in social systems sciences submitted to the University of Pennsylvania. Ann Arbor: University Microfilms International, xi + 291 p.

Del Valle, Alfredo (1999), "Managing complexity through methodical participation: The case of air quality in Santiago de Chile", *Systemic Practice and Action Research,* Vol. 12, Nº 4 pp. 367-380.

Del Valle, Alfredo (2002), “Development: Innovation with participation. Towards a systemic theory and practice of development”. *Revista Chilena de Administración Pública,* August, pp. 29-56. [In Spanish.]

Del Valle, Alfredo (2007), “Initiating road safety policy through participation: A successful experience with a Chilean methodology”. Proceedings 14th International Conference “Road Safety in Four Continents”, Bangkok, Thailand, 14 – 16 November 2007.

Del Valle, Alfredo (2009), “The time for strong participation”. *Mensaje,* Santiago, Chile, forthcoming. [In Spanish.]

IDAE (2005), *Strategy for Energy Savings and Efficiency in Spain 2004-2012,* Institute for Energy Diversification and Savings IDAE, Ministry of Industry, Tourism and Commerce, Spain, 2005. [In Spanish.]

Schein, Edgar H. (1984), “Coming to a new awareness of organizational culture”, *Sloan Management Review*, Winter, pp. 3-16.

# 14. Building Chile's National Energy Efficiency Program: An innovative experience in participatory public policy

Alfredo Del Valle, Ph.D. and Nicola Borregaard,

**Ph.D. Faculty of Economics and Business, Universidad Alberto Hurtado Erasmo Escala 1835, Santiago, Chile, Phone: 56-2-8897458, Fax: 56-2-6920303 E-mail: adelval@uahurtado.cl; nicola.borregaard@gmail.com**

**Key words: Energy efficiency; public policy; innovation; participation**

**Abstract:** The public-policy experience of designing and implementing the National Energy Efficiency Program (NEEP) in Chile through a participatory process, between 2005 and 2007, is presented systematically. The principles and concepts on which it was based, the specific actions that brought it into practice, and the impacts achieved in the first three years, are all made explicit.

The crisis of Argentina-supplied gas that started in 2004 created conditions for actively developing an Energy Efficiency (EE) policy in Chile; this 20-year-old claim from several quarters was finally listened to by the political system. The strategy adopted by the government involved three key elements: (a) making visible the significant *potential* of EE for long-term energy sustainability; (b) promoting the initiative by means of an *enabling leadership* style, which would bring together into a common endeavor actors from government agencies, the private sector and civil society; and (c) designing the policy and its key projects through *strong participation* methods, i.e., the interactive co-creation of visions, objectives and action instruments through a specialized set of concepts and tools.
Following a description of the initial conditions and the strategy, the paper presents the theoretical grounds, managerial principles and practical steps upon which the strategy was built. This should provide a deeper understanding of the process, for making it replicable. Such elements correspond to social systems thinking, or complex thinking, and are integrated into a methodological model called *Participatory Innovation*.

The paper continues with a detailed description of the practical elements that were applied to implement the strategy: (1) the political mandate of NEEP and the character of its organization and operations; (2) the generation of its multi-actor political base; and (3) the participatory design of its strategic agenda and some key specific projects. Subsequently, a summary of achievements in the first three years of application of this strategy is provided; it includes impacts on the political, operational, financial and cultural spheres, with innovations under way in housing, transport, public administration, mining, manufacturing, household devices and health.

The paper concludes with the authors' view about the need for Chile to keep applying a participatory and complex (i.e., non-simplifying) vision in its EE policy. The initial co

creation process should continue to expand and to deepen in Chile, and should become a comprehensive co-operation system, to make Energy Efficiency a permanent component of the culture of every public service, every business company and every family.

## 1.-Introduction: A high-impact, methodical experience

The purpose of this paper is to provide a comprehensive and systematic account of the public-policy experience that took place in Chile for the design and initial implementation of the National Energy Efficiency Program (NEEP), by means of a participatory process. This experience took place between 2005 and 2007, within the appropriate context of a crisis in natural gas supply from Argentina, and had three key characteristics that need to be highlighted, which are inter-dependent:

- An *enabling leadership* style, through which all relevant actors, in government, the private sector and civil society, were convened to become active and creative partners of the initiative.[1]
- A *systemic understanding* of Energy Efficiency (EE) as a continuous process of improving patterns of energy use, which should take place in all sectors and should be made sustainable by incorporating relevant contents into society's culture.
- A *participatory method,* which made it possible to deal practically and effectively with the whole complexity of this challenge, and to mobilize the creative capacities of the actors convened.[2]

The body of the paper deals with the initial context given by the natural gas crisis and other elements, the strategy that was defined to promote energy efficiency, the principles and concepts on which it was based, the specific actions that brought the strategy into practice and the impacts achieved in the three years covered by this paper.

Since it is too early for any impacts on energy intensities or consumption to be measurable, the ones to be shown are process impacts, geared to the mobilization of energy-related actors and resources that started in Chile. Four types of impacts will be described in the paper: political, operational, financial and cultural. In each of these it is shown that the participatory strategy applied in the NEEP has led to a mobilization of resources and a large range of concrete products and impacts. Existing mandates and previous work in different public and private sector institutions were taken advantage of and strengthened through this participatory approach.

[1] Dr. Nicola Borregaard, co-author of this paper, was appointed by Minister of Economy and Energy Jorge Rodríguez Grossi to lead this program.

[2] Dr. Alfredo Del Valle, co-author of this paper, was hired by the Ministry of Economy to provide methodological support to this program. He is the author of the *Participatory Innovation* model.

## 2.- The context: the Argentinean gas crisis and other conditions favorable to energy efficiency

The crisis of Argentina-supplied natural gas that started in 2004, created conditions for actively intervening the demand side of the energy markets in Chile.[3] The question at that moment was whether this intervention would, once more, as in previous situations of scarcity of supply, consist in an energy savings campaign of short duration, usually successfully applied in events of water scarcity due to droughts, or whether a longer term view should be taken and an Energy Efficiency (EE) strategy should be developed and implemented, under considerable time pressure.

In the political decision that was made in favor of the latter, the following factors were critical:

- The crisis regarding the supply of natural gas was regarded to last possibly for a longer period of time.
- The crisis was not as acute and severe as in the cases of droughts.
- Previous work on energy efficiency, either unpublished or not fully taken advantage of, carried out by the National Energy Commission and some other public agencies could be built upon.
- In parts of the Chilean academic sector as well as on behalf of international cooperation agencies, such as the German Technical Cooperation, energy efficiency had been a topic for decades and substantial resources had been invested in previous years in search for raising awareness of the importance of the topic in the political system.
- The lack of decoupling of the growth in energy consumption to economic growth was striking in the case of Chile, a country with an emerging economy that enjoyed significant growth over the past two decades and was a candidate for membership in the OECD.
- First rough estimates of what might be saved through energy efficiency measures and of the cost-benefit ratios, primarily based on the international experience, were very convincing.

[3] In early 2004 Argentina started to apply strong restrictions to natural gas exports to Chile, leaving available only the volumes corresponding to residential consumption. Such restrictions reflected supply shortages which also affected Argentina's consumers; they originated in low domestic prices for natural gas set by the government, which provided no incentives for developing new supply capacities. Over the previous years, Chile had made a significant process of fuel conversion to natural gas in industry, power generation and residential consumption, along with investments to bring over the gas across the Andes, under the shelter of a Protocol on Gas Integration and Natural Gas Supply signed by both governments in 1995. Such Protocol had been understood by Chilean government and private investors to offer sufficient guarantees of supply continuity.

## 3.- The proposal: A participatory strategy

Making an energy efficiency program effective and sustainable, however, was not trivial for a country that had not made the deep economic and cultural learning from the energy shocks of the 1970's and 1980's that Europe, North America and some Asian countries had already made. An appropriate strategy was required, and the one adopted by the government involved three key elements:

- Making visible the significant *potential* of EE for long-term energy sustainability, and showing that such a potential could only be tapped with the active participation of new actors. Such actors would come from: (a) the energy-using sectors, such as industry, mining, appliances, transport, housing and public administration; (b) many government agencies that have significant contributions to make; and (c) several organizations relevant to the subject that represent civil society and the private sector.
- Promoting the initiative by means of an *enabling leadership style*, by calling upon such actors to become partners in the new endeavor, and by providing them with effective capacity to contribute to the design and implementation of the program.
- Designing and implementing the program and its key projects with the support of a *methodology* that could provide appropriate guidance under the existing conditions.

The methodology that was applied is called Participatory Innovation and is described in the following section. The specific activities carried out in the first three years, along with the impacts achieved, are presented in the rest of the paper.

## 4.- Conceptual grounds for the strategy: The *Participatory Innovation* model

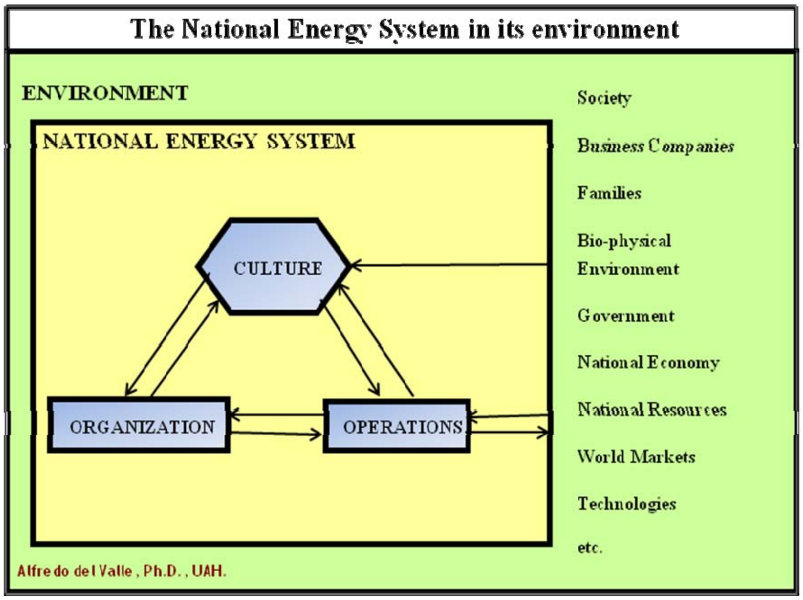
### 4.1 A social-systems view of energy

Any public policy is intended to promote some process of change in society. Understanding such a process in the EE case is facilitated by a social-systems view (Del Valle, 2002) of the National Energy System, as presented on Figure 1. This system performs its duties within an environment that has a wide variety of components, from society and families to world markets and technologies. The system has *operations*, such as drilling oil wells, supplying electric power to homes and factories or changing light bulbs at home. It has an *organization* for carrying out the operational responsibilities; in Chile it involves roles for both private and state-owned companies, along with regulatory roles for the state. And it has a *culture*[4] that provides meaning and coherence to the whole; all members of the system

[4] Following Schein (1984), the culture of a group is understood as a pattern of shared basic assumptions about the correct way of perceiving, thinking and feeling about the group's problems of external adaptation and internal integration. Such assumptions are unconscious and are considered valid because they have worked well enough over a long-term learning process, in which concrete problems of both types have been faced.

unconsciously abide by the basic assumptions of its culture. The operations are directly connected to the environment, in both directions, while the system's culture receives influence from other cultures in the environment. All three aspects are interdependent and change together when they do.

Figure 1



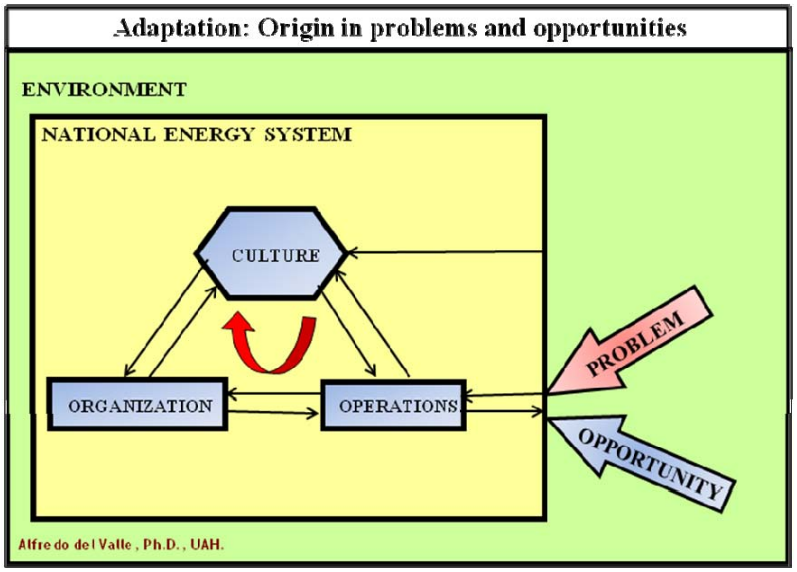

Notice two, highly relevant points for the energy efficiency policy:

- Some basic, unconscious assumptions in the energy culture of countries like Chile are: (a) the word 'energy' refers only to energy supply activities, not to energy use activities; (b) energy-related matters are highly technical and only experts should deal with them; and (c) individuals, families and most business companies have nothing to do with energy-related activities.
- The most effective way of inducing a permanent change in a culture is by producing sustainable changes in the operations and the organization of the corresponding social system. For instance, a family might get permanent energy awareness once it has substituted efficient light bulbs for incandescent ones.

### 4.2 Adaptation and innovation: Contrasting types of change

How does any change take place in a social system? Figure 2 shows the case of *adaptation*. An event takes place in the environment, such as a rise in oil prices or the announcement of a new technology. It is labeled *problem* or *opportunity* by the system actors, according to its potential impact upon them; the same event may be a problem for a consumer and an opportunity for a company. The event is perceived initially by the operations, is evaluated as significant and some *reaction* is defined to face the problem or to take advantage of the opportunity: an additional operation of the same kind of the existing ones is established (or some old operation may be closed). The reactive wave moves on to the organization, in which the existing actors provide a place to the new operation. And finally reaches the culture and may change some of its assumptions. A *cycle of adaptation* is set in, which moves clockwise until a new balance is achieved between all three aspects of the system.

Figure 2



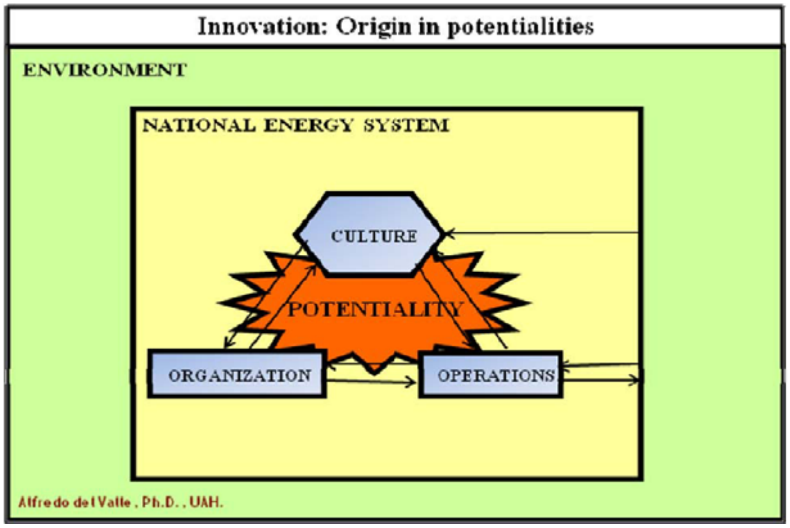

An example of adaptation in Chile's energy system was the introduction of natural gas from Argentina in the 1990's, to take advantage of favorable price conditions and also to face the severe atmospheric pollution of Santiago. Another, short-term, example is the restrictions to energy consumption that are sometimes used to face supply shortages.[5]

*Innovation* is a different type of change and is outlined in figures 3 and 4. It originates in a new vision of the system's future that is not dependent on, or reactive to, specific events in the environment, although it is indeed related to the environment as anything in the system.[6] It is *proactive* rather than reactive. Its starting point is the discovery and the awareness of a *potentiality*, i.e., of a potential action that is feasible and valuable enough to be undertaken. It also involves changes in operations, organization and culture, but the new operations that become established are qualitatively different from the prior ones and usually involve different actors. In an energy efficiency policy the new operations will be related to energy use and will involve actors that are new to the energy system, such as the suppliers of electric motors, transport services or light bulbs.

[5] Developing countries are mostly adaptive social systems. Their histories may be seen as long series of adaptations to events occurring in their environments. Their cultures value and promote adaptive behavior; they are cultures of adaptation. This is significant, since the lack of adaptive capacity may imply severe losses or damage under adverse conditions.

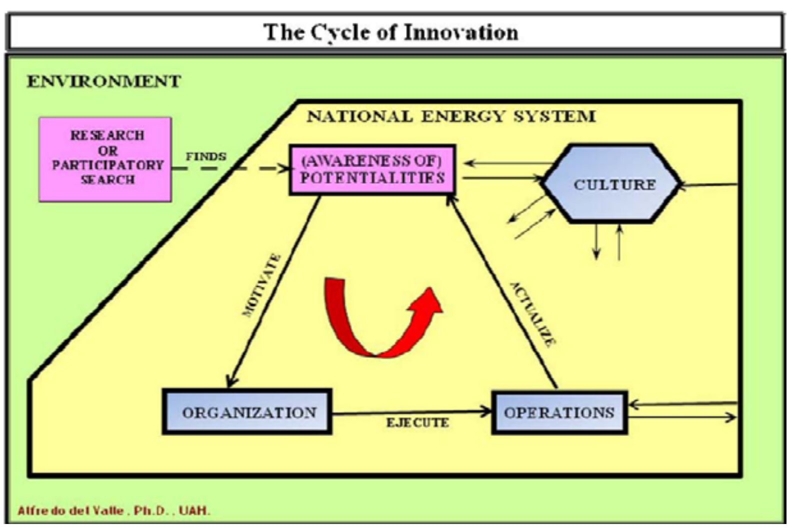
[6] The EE policy initiative was more than an adaptive reaction to the natural gas crisis, as discussed above. Its promotion did take advantage of the energy awareness raised by the crisis, but the motivation of its promoters and supporters was deeper and oriented to the long term.

Figure 3




How does the innovation process work? As shown in Figure 4, its starting point is the need to raise *awareness of the potential* and to promote that it be tapped. Such awareness should create *motivation* at the organizational level and lead to establishing a new actor, to *execute* new operations geared to the potentiality. If the operations are well designed and implemented they will show *results* that will *actualize* the potentiality and demonstrate that it indeed exists and is valuable. This should reinforce the awareness and strengthen the whole process. This is a positive feedback cycle, the *cycle of innovation*, and it runs counter-clockwise. It goes beyond saying that this is not at all an automatic process, but one that requires management and leadership.

Figure 4



### 4.3 Overcoming common sense: The complexity-participation nexus

Consider a minister of energy interested in setting up a comprehensive and high-impact energy efficiency policy in a developing country with limited experience in this field and no agency in charge. He faces a condition we characterize as *high complexity*, which typically involves: (a) a large number of inter-connected issues; (b) a large number of interrelated actors, with or without conflicts among them; (c) a large number of inter-dependent actions to be undertaken; (d) a large number of relevant disciplines and professions, with their peculiar languages and methods; and (e) several non-communicated cultures at play, such as the political, the academic, the business and the public service ones.

How could the public policy be started? *Common sense* normally advises: (a) use experts, consultants, surveys and analyses of varied sorts as sources of knowledge, and (b) take one or two highly-visible measures like introducing efficient street lamps or subsidizing lowfuel-consumption cars, with the support of a strong media campaign. This approach deals with the complexity of the situation by *simplifying* it, in order to make it manageable. The minister would not cover the whole situation, but just what he believes he can handle. Will this approach work for the long run? Hardly so, since the next minister, who needs to differentiate in order to survive politically, may not support the same measures and launch his own ones, but only if he feels that energy efficiency is still attractive at all. Such experience may leave a strong frustration among those involved, and may postpone any attention to the subject for another decade. Only as an exception might permanent capacities become established, with autonomous funding, but this is certainly not the rule.

Going beyond common sense, the key to an alternative approach –which turns out to be highly effective– is not to simplify but rather *to deal with the whole complexity of the situation and to consider it as a significant source of wealth*. In this case the minister would convene all actors to become his allies, would consider aspects of energy efficiency that could make other aspects feasible, would present energy inefficiency as the deep cultural lack it in fact is, and would not miss the details, nuances and cultural insights that make things work in practice. The minister would now be able to *describe* the real world as it actually is. He will have acquired the relevant descriptive capacity, or, in the technical terms of the systems sciences, *requisite variety* (Ashby, 1956).

The alternative way is based on a theoretical principle that was originally proposed by Del Valle (1992), which states that high complexity can be effectively matched through methodical participation. It is based on the fact that no one can better describe the real world as it is than the people who experience it day after day and know it from practice. In this approach the minister would: (a) use the real-world actors as the key source of knowledge, along with experts for technical issues, and (b) take a large number of measures at the same time, so as to cover the energy efficiency field as widely as possible. His policy-making process would apply effective methods to elicit the actors' knowledge, to systematize it and to convert it into effective action. Del Valle (1992, 1999, 2002 and 2007) has developed such *high-variety* methods and tools and has applied them in a large number of fields. They do have a high descriptive capacity because of their built-in logic, and because they use methodically the appropriate instrument for dealing with nuances, details and insights, which is human language.

A word must be said about the notion of participation in this approach, which is labeled *strong participation* (Del Valle, 2009). Notice first that a common usage of the term participation refers to situations such as attending some event, being consulted about a specific subject, voting among a few alternatives, being present at an assembly or being a member of a focus group. In such instances the ground has been defined in advance by the conveners, so that the individual has no chance of making any significant difference; such are instances of *weak* participation. *Strong participation*, on the contrary, is what happens when people are convened to create a future relevant to them, in a context of free and effective interaction with other people similarly convened. It is the *interactive co-creation of reality by its relevant actors*. It is a process that multiplies capabilities, enriches ideas, humanizes people and dignifies them. With appropriate methods and tools it can be highly effective and yield realistic outputs, and can be very attractive and fun for those convened.

### 4.4 Ten managerial principles: Building innovation systems and cultures

The discussions of the preceding sections are now brought together. The challenge is not just to carry out one or two innovations but a large number of them, and to carry them out synergically. This leads to a central question: *How to build up an effective and sustainable innovation system for energy efficiency as a whole, which may generate a permanent stream of diversified and effective innovations?* The focus is now the whole energy efficiency system rather than individual measures. It is not even possible to separate individual impacts, since the number of projects and initiatives is normally large[7] and strong and permanent interactions take place among them and among the actors in charge. It is the joint effect of these interacting projects which brings about the overall impact of the policy, rather than the separate effects of specific projects.

The answer to the above question is practical, and is found by applying a set of ten managerial principles that make it possible to *match* the real-world complexity –rather than ignoring, missing or simplifying it– by building up a capability for effective action that is equally complex. Such principles are:

1 **Understand energy efficiency as a social system – not a physical or technical one:** The physical effects of energy efficiency actions, in any particular situation, take place in the context of broader interactions in the political, social, economic and cultural spheres of society. The action capability to be built should be able to impact upon such broader spheres and should be understood as a system of social actors rather than a physical or technical system.

2 **Declare the political intention to build a wide action system:** This is a key act of leadership. It was accomplished in this case by coining the name National Energy

[7] Around 100 projects and initiatives were actually designed and implemented by the NEEP, at different degrees of completion, in the period under consideration. Some details are provided in section 8.

Efficiency Program[8] and by stating that the central objective was to build such a wide-ranging system. This idea proved motivating and provided a concrete and practical focus for generating political will and for mobilizing action capabilities from many areas of Chilean society.

1 **Aim at knowing and actualizing the whole potential involved:** There is always a huge development potential behind any complex social system, which is latent and in principle can be materialized. According to the nature of the field, it is often visualized via idealized goal-setting (e.g., zero accident, scientific limits), benchmarking studies or other procedures[9]. Visualizing the whole system potential provides strong motivation for the actors to participate.

2 **Mobilize a large and diverse number of people around this future-building task:** This is the most effective way to make sure that the whole complexity of energy efficiency will be considered and no aspect of it will be missed. The people's stock of knowledge, experience and valuable insights is huge. Moreover, people are normally willing to contribute, provided they will be respected and acknowledged, and not exploited.

3 **Apply an enabling leadership style – not a domineering one:** A truly effective leader in the complex world is the enabler of people to contribute proposals and actions, not the controller of people. By facilitating the rise of new actors, such a leader will have wide coverage of the field and faithful allies. A usual excuse for the domineering style, i.e., the supposed ineffectiveness of participation, is based on a confusion of participation with assembly-like activities.

4 **Let the real-world actors create – not just the technicians:** All interested ones should be allowed to make proposals and contribute to implementation. Experts usually know more about means, but real-world actors –managers, operations engineers, architects, teachers, road designers, health officers– know better the ends to be pursued and know the practical details.

5 **Use specialized tools to externalize people's knowledge:** Non-expert knowledge, though huge, is rarely tapped because it is not formalized and readily-available, or *explicit*. In knowledge-management terms it is *tacit*, and needs to be externalized. This difficulty is solved through the special methods and tools of *Participatory Innovation*, the outputs of which will be presented further on. In systems terms, they are high-variety methods and tools.

6 **Generate via participation a clear blueprint for the system to be built:** The blueprint is provided by a strategic agenda which is prepared through the *action map* tool (see section 7). It facilitates the leadership and coherence of the process by providing a clear vision of future for the system to be built. This map provides a

[8] In Spanish the name is "Programa País de Eficiencia Energética"; in literal terms it means Country Energy Efficiency Program. It carries the added connotation of a program belonging to all citizens.

[9] Benchmarking studies are common in energy efficiency.

content-rich structure for achieving a common understanding of the system to be built and for managing in practice the process of building it up, i.e., the design and implementation of the policy and its specific projects.

9. **Implement a large number of inter-related and realistic projects:** The high complexity of energy efficiency, –which is a multi-dimensional challenge– can only be matched with a large number of projects that cover all dimensions. No “star” project can match such complexity by itself. Projects are identified via participation to secure their realism, are designed in mutual interaction to secure their overall impact, and are normally implemented as joint-ventures with participating actors.

10. **Set up a multi-actor management system:** An integrated management system for the whole process is essential, but should not be built until the blueprint of the system and the first significant group of projects are well defined. Otherwise it may become just another instance of power struggles. It should have a management team with systemic vision and social and technical strengths, deal with both strategy and operations, and evaluate and re-design periodically the system through participation.

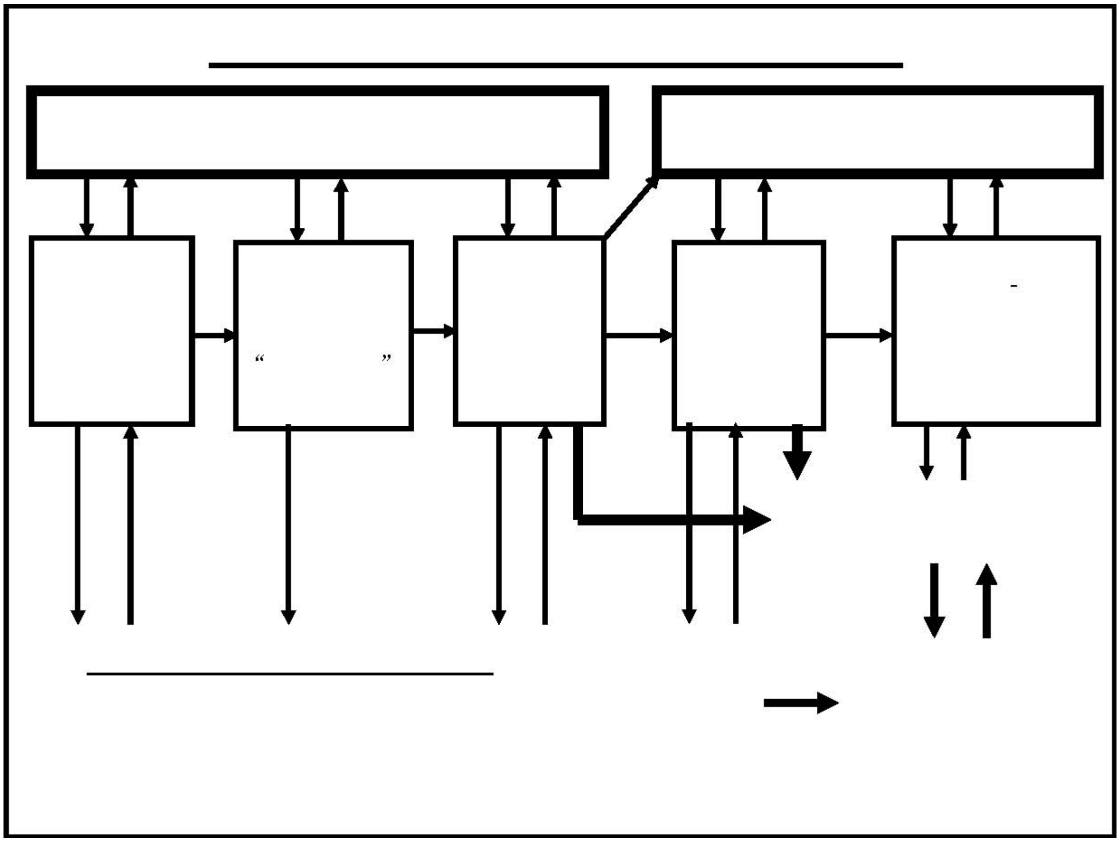
It may be clear that a consistent application of the above principles over an extended period of time should produce not only a permanent stream of innovations, but also a coherent system of innovations that are mutually reinforcing. At a deeper level it should produce qualitative changes of great significance in the National Energy System:

- The performance of *new operations*, such energy labeling of appliances, energy efficiency audits or large-scale co-generation projects.
- The entry of *new actors* into the system, such as energy efficiency consultants, ESCOs or government programs that subsidize energy efficiency investments.
- The incorporation of *new contents into the culture* of the system, such as the new assumption that every family and every business company is responsible for the efficiency of its energy use, and can actually do something about it.

### 4.5 The methodological steps of *Participatory Innovation*

The Participatory Innovation model involves four key methodological steps, which bring to practice the principles of the preceding section. They are shown on Figure 5 and will now be described in general terms. The specific situations occurred in the design and the initial implementation of the NEEP are described in the respective sections of the paper.

Figure 5



1. **Constitution of a Convening Capacity:** The participatory process to build up the public policy must be *convened* by a high-level group of actors. Such actors should jointly cover *all key themes* of the field of action *and all key types of actors* in order to provide legitimacy to the process. In this first step a systemic conception of the process is proposed, the actors who could convene it are identified, a Group of Conveners is formally established and this group takes over the strategic management of the process. The key practical tasks of the conveners are to select the actors that will participate in the process, to define implementation priorities and to contribute to the design of the management system.

2. **Creation of the Vision of Development:** In this step an attractive and viable vision of the future of energy efficiency in the country is created. It arises from the knowledge, experience and visions of the participating actors. It is practical, action-oriented and content-rich. It fully respects the complexity energy efficiency, and makes it understandable and manageable. By doing so, it facilitates the motivation and commitment of the actors to build up such a future. It also provides a diagnosis the current level of development. It is carried out through a workshop of 25-30 participants, by using the *Action Map* tool and its building techniques.

3. **Generation of the Project Portfolio:** The set of projects that could be undertaken, in order to achieve the future envisaged in the Vision of Development, is identified and defined conceptually in this step via participation. Implementation priorities are also proposed. Participants apply the already-mentioned concept of potentiality, which refers to the sustainable action capacity that lies behind any successful innovation, by means of a tool of the model called *Potentiality Profile*. They do so in a series of methodical workshops that may involve hundreds of participants and may identify hundreds of potentialities. Each priority project is defined conceptually in a methodical session with people who know its subject in depth, in which a Potentiality Profile is prepared.

4. **Design of the Management System:** Projects are given priorities and a design is prepared for the system that will provide long-term management to the process. It should make sure that the priority projects be effectively implemented and that innovation will continue taking place in the future. Its contents come from the preceding steps and its outputs involve policies and management criteria, structure of responsibilities and mechanisms for follow-up, evaluation and re-programming. Once implementation starts, this management system takes over the duties of the Group of Conveners.

The above steps yield not only the tangible outputs that were just described. As a central consequence of *strong participation* they also produce a key set of *intangible outputs* that belong to the cultural sphere and are essential for the success and sustainability of any highcomplexity process. Such outputs are also shown on Figure 5: awareness of the potential, motivation, trust, consensus, a common language, leaderships, alliances, networks and permanent innovation capacities. As a practical way for strengthening such outputs and facilitating the whole process, all participants are often linked together on line, through an inter-personal network supported by another tool of the model, called the Participatory Workspace (PWS).

## 5.-The strategy in practice 1: Mandate and organization

The strategy for the National Energy Efficiency Program (NEEP) was defined and started to be implemented at late 2004 and early 2005 under particularly favorable conditions in the government structure, since the Minister of Economy, under whose aegis the NEEP was established, was at the same time chairman of the National Energy Commission (NEC). This fact was significant since:

- The institutional mandate of the Ministry of Economy involves the key energysupply-policy role of setting prices for electricity and hydrocarbons. It is also in charge of several agencies whose active role was essential for this policy, such as the Economic Development Agency (CORFO) that promotes innovation, the Superintendence of Electricity and Fuels (SEC), the National Consumer's Service (SERNAC) and the National Standardization Institute (INN). It has a transversal mandate and had no difficulty in establishing links with sectoral ministries and agencies.

- The mandate of the National Energy Commission NEC was sectoral, focused on the energy sources and the energy supply system. It was also in charge of the studies required for price setting. Nevertheless, it did carry out some activities related to energy efficiency in the context of its environment unit; it had dealt with efficient public lighting in the past, with German cooperation support, and had recently carried out studies of the energy efficiency potential.

Following the considerations that were presented in section 3, a political mandate and an organizational structure were established for the NEEP, with the following characteristics:

- The Minister of Economy and Energy was given, by the President of the Republic, the responsibility for developing and implementing an energy efficiency program, and for coordinating all relevant government agencies in this task.
- The management unit of this initiative, under the NEEP name, was established at the Minister's cabinet.
- A group of key actors of government agencies, the private sector and civil society was invited to become conveners of the NEEP by appointing the members of the Operational Committee, which would provide guidance and actively participate in the NEEP activities on a permanent basis.
- Shortly after the above group started working and the first technical activities took place, the NEEP was officially launched at the Presidential Palace. The ceremony was chaired the by Vice-President because the President was travelling abroad.

## 6.- The strategy in practice 2: Building a multi-actor political base

The *enabling leadership* style that characterized the NEEP was established from the outset and was kept consistently in force throughout the period covered by this paper. Key aspects were the broad membership in the Operational Committee of the NEEP and the open management style. Table 1 presents the actors that were invited by the Minister of Economy and Energy to become conveners of the NEEP by appointing their representatives to the first meeting of the Operational Committee.

The membership in the Operational Committee remained basically stable over the period, with some new actors becoming members along the way. Typical sessions of the Committee took place on a monthly basis, involved some 20 to 25 participants, provided wide information about what was going on in the field, openly discussed issues and proposals in all areas in which the NEEP was getting involved, and included one or two technical presentations about projects under way or other matters.

Table 1

| Conveners of the NEEP, who appointed the initial members of its Operational Committee |
|---|
| *Ministries* Ministry of Economy and Energy (chair) Ministry of the Presidency Ministry of Finance Ministry of Public Works, Transport and Telecommunications Ministry of Housing and Urban Development Ministry of Education Ministry of Health *Business associations* National Confederation of Production and Commerce National Industry Association SOFOFA Chilean Chamber of Construction *Civil society organization* "Sustainable Chile" Program *Other government agencies* National Energy Commission National Environment Commission Economic Development Agency (CORFO) |
| Source: National Energy Efficiency Program, Ministry of Economy, 2005. |

A very significant responsibility of the Operational Committee was to broaden the reach of the NEEP by proposing who should be invited to its activities. This involved both building up mailing lists for mass invitation to seminars and open events, and carefully selecting participants to be invited to methodical workshops. The output of such workshops is the subject of the next section.

## 7.- The strategy in practice 3: Participatory design of the strategic agenda and specific projects

The formulation of the strategic agenda was the first technical activity to be undertaken by the NEEP, by means of a *Vision of Development Workshop*. The *Action Map* tool of Participatory Innovation was used for this purpose and the agenda is presented on Table 2. The resulting map is a blueprint of a real-world system the participants propose to build up in Chile, which is called National Energy Efficiency System.

The map was formulated by a workshop of 30 participants, who had been selected by the Operational Committee. Basic selection criteria were to have the widest possible representation of all relevant actors of energy efficiency in Chile, along with a few experts. Diversity in areas, regions, professions and other criteria was also sought. Designing the map took one, very intensive working day; all work was done in plenary session and the output reflects the consensus of the participants.

Table 2

*Action Map:* **National Energy Efficiency System** *UPPER CASE:* Established line of action (with a
Non-established line of action

| | | |
|---|---|---|
| **A. Generation of energy efficiency culture**<br>A-1 Public information on EE<br>A-2 Awareness-raising campaign in mass communication media<br>A-3 Dissemination of individual advantages of EE for the consumer<br>A-4 Advisory mechanisms to consumers for assessing their energy saving potentials A-5 Education program on efficient household energy use A-6 Positioning of EE in public opinion as required behavior A-7 Instruments for public recognition A-8 Energy education A-9 Dissemination of emblematic cases for education A-10 INCORPORATION OF EE INTO CURRICULAR GRIDS OF KEY UNIVERSITY PROGRAMS A-11 Incorporation of EE into curricular grids of technical education A-12 Incorporation of EE into the school curriculum A-13 Emphasis on EE in the national system for environmental certification of schools | **D. Economic policy framework**<br>D-1 Policy of free and transparent prices and Exchange rates<br>D-2 Freedom of energy trade<br>D-3 FLAT TARIFFS POLICY<br>D-4 Non-discriminatory tax policy<br>D-5 Policy for imported fuel prices reflecting importation parity<br>**E. Regulatory framework for energy efficiency** E-1 Establishment of minimal EE standards E-2 Establishment of national EE standards E-3 Coordination and complementation in regulations and legislation E-4 Adjustment of the regulatory framework of energy supply to EE E-5 Removal of entry barriers to distribution of electricity and hydrocarbons E-6 Incorporation of EE, quality and safety to regulations for medium and high tension E-7 Cogeneration and other energy integration systems E-8 Regulation of the use of minimal standards in motors and transformers E-9 Minimal standards and promotion of EE in public lighting E-10 Regulation of imports of second-hand equipment | **J. Sectoral EE po** **buildings** **and construction**<br>J-1 EE STANDARDS I<br>J-2 EE STANDARDS C<br>INTERNAL HOUSING<br>J-3 Program for retrofit buildings<br>and installations J-4 Pr<br>5 Promotion of decons<br>**Sectoral EE polic**<br>Revision of specific tax<br>OF PUBLIC TRANSPO<br>transport K-4 EE in ter<br>IN TRAFFIC MANAGE<br>fleets K-7 Efficient veh<br>**program on indu** **commerce)** |
| **B. Formulation of a national EE Policy**<br>B-1 Promotion of and integrated vision of EE which considers quality, reliability and security B-2 EVALUATION OF THE COUNTRY'S EE POTENTIAL B-3 Identification and removal of public policy obstacles to EE B-4 System of national EE goals B-5 National indicative program of EE goals and actions B-6 Policy of minimal EE standards B-7 Incorporation of EE as a source in energy supply plans B-8 Policy of support to distributed generation B-9 Policies for cogeneration and use of residual energy B-10 Incentives to the diversification in exploration and exploitation of hydrocarbons and other national primary | E-11 Energy consumption standards for stand-by equipment<br>**F. EE certification system** F-1 EE labeling and seals F-2 Energy information on the life cycle of final products F-3 Information about energy content in inputs and raw materials **G. Instruments and economic, tax and financial incentives for EE** G-1 Consideration of EE in public financing of private investment projects G-2 Development of financing instruments G-3 Development of incentives G-4 EE investment fund | L-1 Cogeneration of el<br>L-2 Use of residual the<br>synergies among comp<br>waste **M. Sectoral** **conversion** M-1 En<br>Verification by load dis<br>associated operational<br>standards for the use o<br>**policy and progra**<br>of obstacles to public s<br>public procurement po |
| energy sources B-11 Consideration of EE in the evaluation of public investment projects B-12 Policy for urban development with EE<br>B-13 Promotion of RRR (reducing, recycling and re-using)<br>B-14 Institutional structure for EE<br>B-15 Mechanisms for public-private cooperation for EE<br>**C. National system for EE monitoring and control**<br>C-1 Making transparent the contributions of EE to the reduction of externalities<br>C-2 System of indicators<br>C-3 EE auditing system<br>C-4 Enforcement of regulations<br>C-5 Dissemination of results and impacts of EE programs | G-5 Incentive to energy service companies (ESCOs) **H. Promotion of EE in business companies** H-1 Incorporation of EE in Corporate Social Responsibility<br>H-2 Voluntary EE programs<br>H-3 Incorporation of EE criteria into Clean Production Agreements<br>H-4 Voluntary diffusion on energy performance of companies<br>**I. Incorporation into international EE mechanisms**<br>I-1 MAKING USE OF KYOTO PROTOCOL AND SIMILAR MECHANISMS<br>I-2 Preparation for the incorporation of EE as an international competitiveness requirement<br>I-3 Incorporation and dissemination of international experiences | N-3 Energy efficiency i<br>policy and program in t<br>**innovation for EE**<br>O-1 RESEARCH INTO<br>O-2 Technological dev<br>O-3 Technology transf<br>O-4 DEVELOPMENT O<br>Training in companies<br>O-6 Training in other c<br>O-7 Systems for EE be<br>O-8 District heating an<br>O-9 PARTICIPATION<br>NETWORKS |

Action map generated in a Vision of Development Workshop, on 7 January 2005, by 30 actors of energy efficiency and specialists in the field. Participants were
National Energy Efficiency Program, whose members are public, private and civil society actors. The *vision of development workshop* and the *action map* are c
methodology, which facilitates the understanding of high-complexity innovation processes and makes possible their effective management.

Source: National Energy Efficiency Program, Ministry of Economy, 2005.

The structure of the map shows a large number of components that are called *lines of action*. They correspond to areas in which there are, or there should be, permanent actors carrying out activities in search for objectives implicit in the lines' names. For instance, a clear objective is implicit in the name of line H, "Promotion of EE in business companies". Lines of action are *parallel* and should be understood as *inter-dependent actions*; for instance, the EE certification system (line F) and the sectoral policy on industrial use (line L) would provide important support to the objectives of line H.

There are two kinds of lines of action, *basic and specific.* The basic lines, like those already mentioned, are on boldface and should be understood as the *dimensions* of the system to be built. The specific lines provide content, precision and detail to the basic; for instance, 13 specific lines provide content to line A, "Generation of energy efficiency culture". All names are expected to be self-explanatory. This particular map has 15 basic lines of action and 96 specific ones. Some of the lines are printed on upper-case letters and most are on lower case. The first ones are the *established* lines of action, i.e., those having actors, activities and impact at the time the map is built. The other ones are *non-established* or potential and correspond to areas that should be developed in the country.

What does this action map offer? This may be synthesized as follows:

- A conceptualization of the whole task ahead for building Chile's National Energy Efficiency System, in its full wealth and complexity, and without simplification. There are 15 basic areas to be developed in parallel, which are presented in significant detail. This is, in other words, a *vision of future* for the system.
- A *diagnostic assessment* of the progress made in this task. The map shows only 11 established lines of action at the specific level, out of 96, and not a single one at the basic level. Some lines of action such as J "Sectoral EE policy and program on housing, buildings and construction", do show some progress, but according to the participants it did not qualify as established. This is a measure of progress to the envisaged future, and it clearly shows that Chile was just at the starting level.
- A systematic basis for identifying the projects and initiatives to be undertaken in order to build up the envisaged future. Every line of action is an area where concrete potentialities exist; they should be identified and should be tapped by means of specific projects. Thus, the map provides a practical basis for project identification, which is done line by line.

On the basis of this map, a large number of specific projects were identified and prioritized in subsequent, methodical workshops, for several basic lines of the map. Such workshops typically involved 20 participants and took half a day. Table 3 shows, as an example, the project portfolio for line F, "Sectoral EE policy and program on transport", which also includes initiatives on urban management.

Table 3

| Project portfolio for line F, “Sectoral EE policy and program on transport” |
|---|
| *Basic knowledge* 1. Development of an information and statistical system on EE for decision-making in transport and territorial development, including base lines and follow-up indicators. 2. Follow-up of the state of the art in vehicle and fuel technologies. *Specific debates and proposals* 3. Debates and proposals about EE urban models and priority to public transport. 4. Generation, evaluation and discussion of alternative scenarios for specific cities with high EE potential. 5. Evaluation and discussion of EE impacts of policies related to fuel prices, taxes and subsidies. 6. Evaluation and proposals about EE in the inter-urban freight transport system (truck, rail, ship, airplane, ducts) considering externalities, with international benchmarking. 7. Generation, dissemination and application of EE management models in urban transport systems, considering externalities (congestion, environmental impacts, safety) with international benchmarking: congestion pricing, differed time schedules, timing, regulation of trip generation, parking management, traffic management, and other. 8. Generation, dissemination and application of EE management models in urban freight transport and logistics: fleet management, loading terminals, vehicle technologies, training of operators. etc. 9. Generation dissemination and application of EE management models in passenger transport: differed school time schedules, trip harmonization, incentives to multi-modality, tele-work, shared cars, etc. 10. Evaluation of impact on EE of motorcycle dissemination in several cities, including benchmarking. 11. Promotion of EE initiatives by government, private and citizen organizations, based on international experiences: incentives to public transport, incentives to bicycle, shared cars, etc. 12. Evaluation and continuous improvement of EE in transport systems of the armed forces. *Certification* 13. EE certification, labeling (seal) and dissemination for all types of motorized vehicles. *Incorporation of EE into other policies* 14. Incorporation of EE criteria in territorial planning instruments, down to the pedestrian scale. 15. Incorporation of EE criteria in the renewal of vehicle fleets of the public sector. 16. Incorporation of EE criteria in the Environmental Impact Assessment System. 17. Incorporation of EE criteria and life-cycle assessment in road infrastructure investment and its maintenance. *Incentives* 18. Incentive to energy management in business companies with transport fleets, including public transport fleets. 19. Evaluation of, and incentives to, the incorporation of district energy systems (hot water, heating, electricity, refrigeration, cogeneration, etc.) in urban, housing and industrial developments. 20. Policy to promote the use of bicycle including: segregated cycle ways, continuity and network building, safe parking, obligation in concessions, obligation in urban developments. 21. Policy to promote walking, including: space, networks and circuits for pedestrians, obligation in concessions, obligation in urban developments. *Awareness raising* 22. Awareness raising and public education on efficient vehicle driving, starting at the educational system. *Transparency* 23. Promotion of transparency in traffic information on concessional roads and infrastructure, for purposes of traffic management, planning and consumer protection 24. Development of on-line mechanisms for dissemination of transport-related information to users. |
| Source: National Energy Efficiency Program, Ministry of Economy, 2005. |

- The following actors become active members of the Operational Committee of the NEEP: 8 ministries, 4 public agencies, 6 business associations, and 3 civil society organizations.
- The NEEP was launched by the Presidency of the Republic.
-

Participatory design work was also carried out for the conceptual design of a large number of specific projects and initiatives. To this end the *Potentiality Profile* tool of Participatory Innovation was used in methodical workshops, which typically involved 10 to 15 participants and took 3 to 4 hours. As an example, Table 4 presents the profile for a project on energy efficiency in public buildings, which involves several government agencies.

Table 4

| An illustrative conceptual project design: “Energy efficiency in existing public buildings, Phase 1. Pilot case in Public Works Ministry” | | |
|---|---|---|
| Requirement | Resources | Instrument |
| To incorporate the management of energy requirements into the administration of existing public buildings | • Potential energy savings in the public buildings<br>• Knowledge at the National Energy Commission about energy saving potentials in public buildings<br>• Managerial capacities of public building administrators<br>• Capacity of the Budget Directorate (DIPRES) to decide the use of savings in public services • Managerial and technical capacities at Ministry of Public Works (MOPTT) • Managerial and technical capacities at Superintendence of Electricity and Fuels (SEC) • Managerial and technical capacities at Ministry of Housing and Urban Development (MINVU) • Potential of the ESCO model (energy service companies) for energy management of public buildings | Pilot Project at MOPTT, with the support from SEC, DIPRES and MINVU, for definition and testing of a model for managing energy efficiency in public buildings, which should involve:<br>• Inventorying of MOPTT buildings and estimation of their economic energy saving potential<br>• Review of international experiences in the field • Preliminary definition of management models, such as: ◷ Call ESCOs for competitive bidding for high-potential buildings ◷ Own energy management for buildings of medium and low potential ◷ Budgetary mechanisms which may incentive energy savings • Selection of pilot buildings and testing of the models • Evaluation and dissemination of results |

## 8.-Impacts: The achievements of the first three years

Four types of impacts will be shown: political, operational, financial and cultural.

### 8.1. Main political impacts

- The NEEP´s “Advisory Council”, with two regular meetings per year, brought together six Ministers, as well as the Presidents of two of the most relevant business associations (the National Industry Association SOFOFA, and the Chilean Chamber of Construction), and four outstanding academic experts, national and international, and non-governmental representatives, appointed by the President of the Republic. The NEEP maintained collaboration and performance agreements with ten different ministries and public services, including, amongst others, key political ministries such as the Ministry of Finance

### 8.2. Main operational impacts

Table 5 presents the areas of work of the NEEP with the different public agencies and ministries. In each case concrete products have been generated already in the years between 2005 and 2008. An example is listed in Table 6 for the case of Industry and Mining.

Table 5

Example of products generated by NEEP in Industry and Mining, 2005-2007

| Sector | Products | Actor in charge* |
|---|---|---|
| Industry and Mining | Subsidy to co-finance the implementation of energy audits in SMEs (small and medium sized enterprises) | Economic Development Agency (CORFO) |
| | Establishment of a Register for Consultants in Energy Efficiency | National Standardization Institute (INN) |
| | Incorporation of energy efficiency in eight Clean Production Agreements | National Council for Clean Production |
| | Study to characterize energy consumption at the level of SMEs | National Energy Commission (CNE) |
| | Creation of a Round Table on Energy Efficiency in Large Mining Operations | Ministry of Mining |
| | Voluntary Agreements to reduce energy consumption in the commercial sector | NEEP with different Malls |
| | Annual Energy Efficiency Award | National Confederation of Industry and Commerce |
| | Study for the design of a preferential credit system for energy efficiency projects | NEEP, with CORFO and German Technical Cooperation |
| | Implementation of promotion and discount for energy efficient motors | NEEP with ABB, WEG, Siemens |
| | Study and design of subsidy for energy efficient motors | NEEP |
| | Industry survey (forestry, metal and metal-finishing industry, wine industry) | NEEP |

Source: Own elaboration based on presentations by directors of the NEEP *NEEP participates in the respective initiatives

Table 6

| Areas of work of NEEP with different public agencies and ministries, 2005-2007 | | |
|---|---|---|
| Sector or Area | Line of work | Actor in charge |
| Housing and buildings | Insulation of houses | Housing Ministry |
| | Certification of energy consumption in houses | |
| | Energy efficiency in social housing | |
| Transport | Management of transport | Ministry of Transport |
| | Certification of energy consumption in vehicles | |
| | Policy instruments for increasing energy efficiency in passenger and freight transport | |
| Public administration | Energy efficiency in public works and infrastructure | Ministry of Public Works |
| | Energy efficiency in public buildings | Ministry of Finance |
| | Energy efficiency in government procurement | Ministry of Finance (National Procurement Service) |
| | Energy efficiency in public lighting, especially street lighting | Superintendence of Electricity and Fuels |
| Mining | Energy Efficiency in large mining companies and energy efficiency in small and medium sized mining operations | Ministry of Mining |
| Industry | Energy efficiency in large companies | NEEP, with Industry Associations |
| | Energy efficiency in SMEs | NEEP, with National Industry Association as well as Economic Development Agency (CORFO), and National Council for Clean Production |
| | Promotion of an energy efficiency service industry (concept of Energy Service Companies, ESCOs) | NEEP |
| Household devices | Energy efficiency labeling of household appliances (starting with refrigerators and light bulbs) | Superintendence of Electricity and Fuels; National Consumer's Service |
| General public | Awareness campaigns, integration of energy efficiency into education at primary, secondary and tertiary level | National Environment Commission and Ministry of Education |
| Source: Own elaboration based on presentations by directors of the NEEP | | |

## 8.3 Main financial impacts

[10] This trend is continued in 2009, with a total approved budget of about US$30 million (exchange rate of 650 pesos to the dollar).

Table 7

| Funds mobilized by the National Energy Efficiency Program, 2005-2008 (in million US$) | | | | | |
|---|---|---|---|---|---|
| Source of funds | 2005 | 2006 | 2007 | 2008 | Total |
| Chilean public funds (National Budget) | 0 | 1 | 3 | 13 | 17 |
| German Technical Cooperation (GTZ) | 0.2 | 0.3 | 0.4 | 0.4 | 1.3 (total commitment of US$2 million over six years) |
| Inter-American Development Bank | | | | 0.35 | 0.35 (total commitment of 0.6 over 18 months) |
| Global Environment Facility | | | | | A total of US$ 2.6 million approved in Project Identification Form, for 2009-2012 |
| German Financial Cooperation | | | | | A total of 80 million Euros is committed for credits in energy efficiency and renewable energy projects |
| International and national private funds (Renewable Energy and Energy Efficiency Program, together with the Energy Agency of Berlin, Procobre, numerous private Chilean companies) | 0.1 | 0.1 | 0.2 | 0.2 | 0.6 |
| Source: National Budget Law, years 2005, 2006, 2007, 2008. Numbers are approximate, with a fixed Exchange rate of 500 pesos to the dollar. | | | | | |

Additional funds were committed by several public agencies in charge of different areas related to energy efficiency. For example, the Economic Development Agency (CORFO) financed directly the subsidy for co-financing energy audits in industry, and the National Council for Clean Production financed directly the design, implementation and monitoring of the Clean Production Agreements, which integrated energy efficiency as one of their main elements. Certainly, most of the public funds leveraged considerable additional financing on behalf of private companies and institutions. Estimates for these leveraged funds are not available. However, the case of Spain indicates that the ratio between public and private funds can vary considerable between the different sectors that are intervened, at 1 to 3.4 in the case of industry in general, up to 1 to 155 in the case of the energy sector (IDAE, 2005).

**8.4 Main cultural impacts**

At the point of initiation of the NEEP, the concept of “energy efficiency” was hardly known to the general public, and in the media it was too often confused with and taken to be identical to the notion of energy saving.[11] Over the course of the first two years of

[11] See press releases at the time of launching the Program in early 2005.

operation of the Program the media changed its perspective and understanding, emphasizing the technological changes implied by energy efficiency initiatives. This is reflected in the 220 articles and television reports published in specialized and mass media about the Program and its activities during 2007.[12] At the same time the Program established a virtual community based on the *Participatory Workspace (PWS)* tool of Participatory Innovation, which brought together more than 300 professionals during the first year of operation, as well as a webpage with around 50.000 visits per year.

A first public campaign was launched in 2007, under the slogan "Follow the current – use your energy efficiently"[13], and an energy efficiency fair was held, with over 40 companies and institutions exposing their products and services for one week on the central square in front of the Presidential Palace, containing, amongst others, an installation of two houses for visitors to understand basic concepts of energy efficiency in practice.
The International Energy Efficiency Day as well as the World Water Day were taken advantage of to launch different educational initiatives. To deepen the impact at the educational level, a program for capacity building of teachers was implemented together with the National Environment Commission, CONAMA, specifically aiming at the more than 500 schools that form part of the National System for Environmentally Certified Schools.

## 9.- Why is it necessary to keep the original principles? Towards an Energy Efficiency culture in Chile

We conclude by stating our view that the basic principles through which the NEEP was established and started its work should be kept under application in the coming years. They have been described in this paper in detail and need not be repeated. A participatory and complex (i.e., non-simplifying) vision of the Energy Efficiency action is necessary because the field is wide and interconnected, and the only way to be effective is to work at the same time and synergically in the whole action space. As demonstrated elsewhere and now in Chile, EE is necessarily a multi-actor endeavor, involving government, business and civil society, and any reductionism in this regard could be expensive for the country in the long run.

The above statement applies with particular strength to the need for a sustainable culture of EE in Chile. As discussed above, culture has to do with unconscious assumptions and it takes long time, sustained and consistent messages, and especially action-oriented efforts, to transform the existing assumptions into new ones. Under certain conditions such a cultural change might take place following a deep shock, as occurred in the developed

[12] 2007 is the first year with a quantitative monitoring regarding this aspect. Internal memo, National Energy Efficiency Program..

[13] According to the evaluation of the campaign, carried out three months after the campaign finished, 62% of the respondents still remembered specific energy efficiency measures promoted in the campaign.

countries after the international oil crises of the 1970's and 1980's, which prompted them to set up wide-ranging innovation efforts in EE. But developing countries including Chile did not learn from the same crises and did not innovate, for reasons beyond the scope of this paper. There is now a chance to bring this incipient cultural change process to maturity, by keeping in force the EE process, to which a large number of people and organizations contributed. The co-creation effort should continue and should give rise to a fully cooperational system, in order to bring EE into the culture of every public service, every business company and every family in Chile.

## 10.- References


• Ashby, W. Ross (1956), "Variety, constraint and the law of requisite variety" (From

W.R. Ashby, An introduction to cybernetics, London: Chapman and Hall, Chapter 7, pp. 123-124 and Chapter 11, pp. 202-209). Reprinted in W. Buckley (ed.), *Modern systems research for the behavioral scientist. A sourcebook.* Chicago: Aldine Publishing Company, 1968. Second printing 1969, pp. 129-136.

• Del Valle, Alfredo (1992), *Innovative planning for development: An action-oriented approach.* A dissertation in social systems sciences submitted to the University of Pennsylvania. Ann Arbor: University Microfilms International, xi + 291 p.

• Del Valle, Alfredo (1999), "Managing complexity through methodical participation: The case of air quality in Santiago de Chile", *Systemic Practice and Action Research,* Vol. 12, Nº 4 pp. 367-380.

• Del Valle, Alfredo (2002), "Development: Innovation with participation. Towards a systemic theory and practice of development". *Revista Chilena de Administración Pública,* August, pp. 29-56. [In Spanish.]

• Del Valle, Alfredo (2007), "Initiating road safety policy through participation: A successful experience with a Chilean methodology". Proceedings 14th International Conference "Road Safety in Four Continents", Bangkok, Thailand, 14 – 16 November 2007.

• Del Valle, Alfredo (2009), "The time for strong participation". *Mensaje,* Santiago, Chile, forthcoming. [In Spanish.]

• IDAE (2005), *Strategy for Energy Savings and Efficiency in Spain 2004-2012,* Institute for Energy Diversification and Savings IDAE, Ministry of Industry, Tourism and Commerce, Spain, 2005. [In Spanish.]

• Schein, Edgar H. (1984), "Coming to a new awareness of organizational culture", *Sloan Management Review*, Winter, pp. 3-16.

# 15. Energy saving and Economy energizing

**Tabaré Pagliano Baserga**

IAEE Member – AEE Member

Address: Mato Groso 5630 – Mdeo. -UY, Phone: +598 2320 9061, Fax: +598 2900 1080

Energy, Environment, Security

Abstract: During last months volatility of oil prices along with subsequent variations in other energy sources as a natural reaction of market behavior is significantly affecting the economy in all countries.

As in previous similar cases, this situation is creating opportunities in other energy fields, being renewable energy and energy efficiency the most “at hand” alternatives to think of.

While in the past it was possible to get back to previous consumption status, and even increase the consumption rate of fossil fuels, this time the world faces an energetic paradigm without precedents: the limit is not only on resource availability, but also on the ability to over stand the consequences of the current worldwide energy mix.

Meanwhile, economies around the globe are still intended to grow. The challenge for the 21$^{st}$ century is energizing the economy while saving energy. This paper includes examples and proposes an index to characterize the growth profile of the countries in the years to come.

1 – Introduction.

During year 2008 oil price rose up to values beyond most of predictions, ringing a wake up call for the entire world to remember oil is a limited source of energy.

Coal shows the major reserves availability. Oil has tremendous advantages over other energy sources, so that half of the energy needs of the world are attended with oil. Natural gas can be burnt with very low particulate emissions. Unfortunately, the use of the above mentioned fuels produce CO2, the most significant driver of the global warming effect, and this is the most important limit we are facing during the 21$^{st}$ century.

Shifting to new energy sources is not new for mankind – in fact, during the centuries, we have shifted from wood to coal, from coal to oil – and it was thought next shift would be motivated by the lack of oil reserves as to attend worldwide demand.

Thanks to the hard work of an ever increasing group of persons concerning environmental consequences of burning Fossil Fuels (FF), there is no need – let's assume – to explain how the use of FF is affecting our world.

Nowadays there is global consensus about the need to cut CO2 emissions. Mentioning the Stern Review, the conclusions of the IPCC, the Garnaut Climate Change Review, among other interesting studies and papers, should be enough as to support this statement.

In 2008 EC adopted important targets for renewable energy integration and CO2 mitigation.

In USA, 10 eastern states joined to create the RGGI, a market-based, mandatory program aiming to control greenhouse gases emissions, starting Jan 1$^{st}$ 2009.

For many decades it was common to find a close relationship between economy growth and increase of energy demand. And there is a good reason for this: growth relies on production, and the later on energy consumption.

There is a compromise between growth and energy consumption, but not only because of energy cost.

A major difference with previous generations of Economists exists: current climate situation calls for today's Economist getting more and more involved in the environmental aspects of production and economy, forcing to evaluate really carefully what are the most appropriate means of generating earnings while attending best environmental practices.

The world needs to reduce CO2 net emissions, this is basically reducing FF consumption levels, and meanwhile, economies of all countries around the globe are still intended to grow. Among the mechanisms for attending both conditions we find Energy Efficiency and Renewable Energy Integration. This paper is not intended to further analyze those subjects, in fact, there are lot of programs and people working on the before mentioned tools; and their work well deserve to be highly recognized and supported.

The G8 - 8 biggest economies agreed on cutting greenhouse emissions 50% by 2050. Within the coming 30 years we will need to adjust our energy mix by substitution of an important share of FF, meaning an average between 20 and 30% of the entire energy matrix. This implies quite a change, as nearly 2% of the FF consumption should be substituted a year.

2 - Carbon Sustainability Index (CSI).

Every nation will have to strive on cutting CO2, as we are in the same boat: our planet.

It is not longer only a question of how much we grow, but mainly on *how* we grow.

It is not a question of how small or big a country is; instead, it is more about *who* grows *how*.

All countries have the right to look for growth, but also the social responsibility to do it on a sustainable way.

Idea is having an index able to give a quick reference about commitment, effort and capability of each country on growing while fighting climate change by cutting $CO_2$ net emissions.

This index could be used by international community, including multilateral banking entities, funding programs, environmental agencies, international organizations, and countries themselves for establishing targets or references for growth vs. variation rate of emissions from FF.

We are proposing a rather simple formula for defining a Carbon Sustainability Index which creates a correlation between growth and emissions from FF, according to two situations, as follows:

a – Growth % > 0,5%, in this case:

$$CSI = \frac{\text{Growth \%} - (E_{FF}\ \%)}{\text{Growth \%}}$$

Where:

Growth (%) – refers to positive values of growth ratio expressed in percentage

$E_{FF}$ (%) - variation of Emissions from Fossil Fuels expressed in percentage (+ or -)

b – Growth % < 0,5%, for this case:

CSI = (-1) * (EFF %)

NOTES:

b1: Negative growth is a problem more likely affecting the nation of reference, and not so for the rest of the countries. In this case emissions variations is what matters.

b2: For an appropriate range of CSI values, in the case of growth values between 0 and 0,5% the CSI should be expressed as (-1)*EFF(%) , otherwise as Growth tends to zero, CSI tends to infinite.

Let us present some examples:

Case 1 - One country growths 4% and increases emissions from FF in 2%, then:

$CSI = \frac{4\% - 2\%}{4} = +0,5$ (here we have a positive value of the CSI, meaning commitment)

Case 2 – One country growths 3% and increases emissions from FF in 6%, then:

$CSI = \frac{3\% - 6\%}{3} = -1$ (here we have a negative value of the CSI, meaning insufficient effort)

Case 3 – One country growths 1% and reduces emissions from FF by 3%, then:

$CSI = \frac{1\% - (-3\%)}{1} = +4$ (here we have a higher positive value of CSI, meaning high commitment)

Case 4 – The country growths 2% and increases emissions from FF by 2%, then:

$$CSI = \frac{2\% - 2\%}{2} = 0$$ (here we have null value of CSI, meaning not enough effort)

With this few examples it is possible to see how the CSI works: reflects attitude and capability on fighting CO2 emissions, defined by the sign of the index: *positive value means positive attitude, with best performance found for values higher than 1; in the other hand, negative value means negative attitude or limited capability as to reduce emissions.*

3 - Case Studies.

Based on information obtained at the International Energy Annual website of the Department of Energy (USA), the following Table 1 has been produced as an example. While figures might eventually differ from real ones depending on accounting criteria, it helps to understand the use of the CSI Carbon Sustainability Index as indication of sustainable growth.

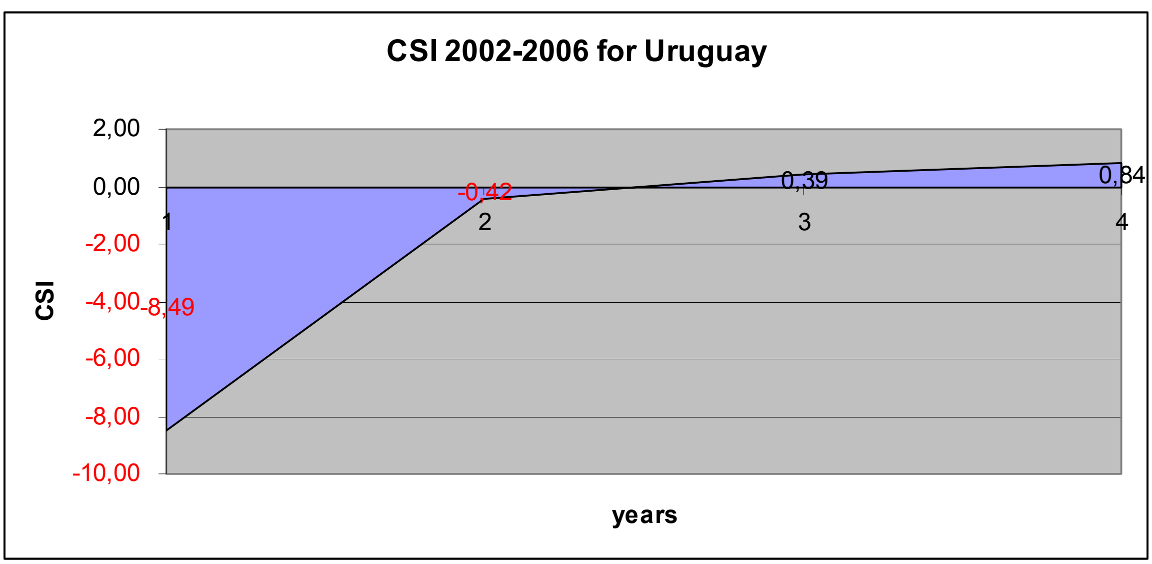
| Country | Year | Growth | Emission rate | CSI |
|---|---|---|---|---|
| Uruguay | (1) 2002 | -10,80 | 8,49 | -8,49 |
| Uruguay | (2) 2003 | 2,50 | 3,54 | -0,42 |
| Uruguay | (3) 2005 | 6,80 | 4,12 | 0,39 |
| Uruguay | (4) 2006 | 7,00 | 1,09 | 0,84 |
| USA | (1) 2002 | 2,40 | 1,26 | 0,47 |

| | | | | |
|---|---|---|---|---|
| USA | (2) 2003 | 3,10 | 1,30 | 0,58 |
| USA | (3) 2005 | 3,20 | 0,92 | 0,71 |
| USA | (4) 2006 | 2,90 | -1,14 | 1,39 |
| Denmark | (1) 2002 | 1,60 | -5,20 | 4,25 |
| Denmark | (2) 2003 | 0,00 | 16,24 | -16,24 |
| Denmark | (3) 2005 | 3,20 | -8,21 | 3,57 |
| Denmark | (4) 2006 | 3,50 | 13,88 | -2,96 |

Table 1

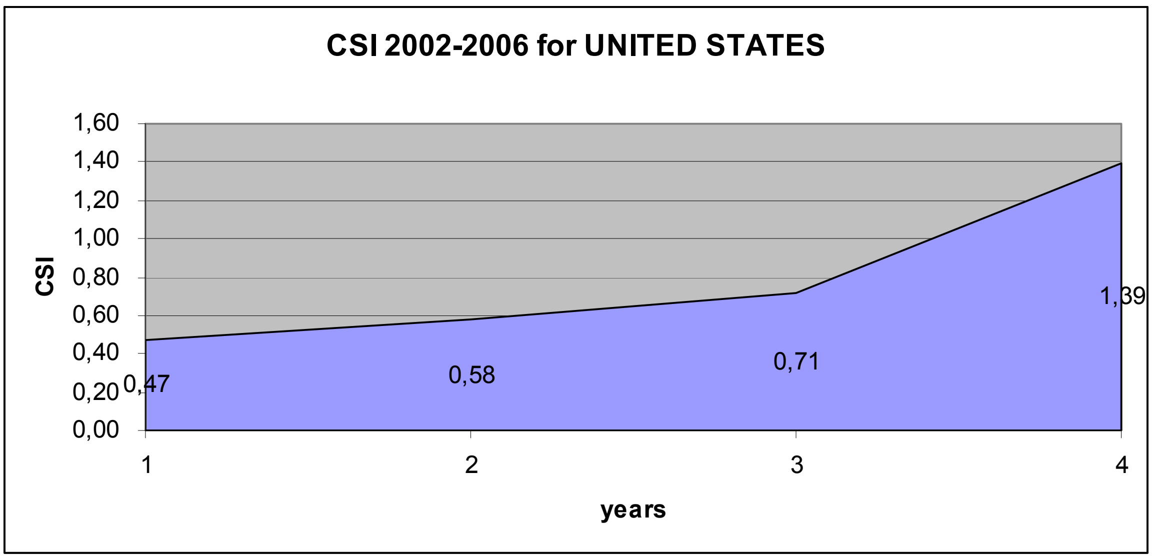
Uruguay

In this case we can see that during 2002 as there was a difficult economic situation, Growth was negative, thus CSI gets a value equal to EFF% *(-1). It is interesting to note that emissions increased even though the growth shown negative results. In the following years the CSI tends to positive values and approaching to 1, which is something positive.



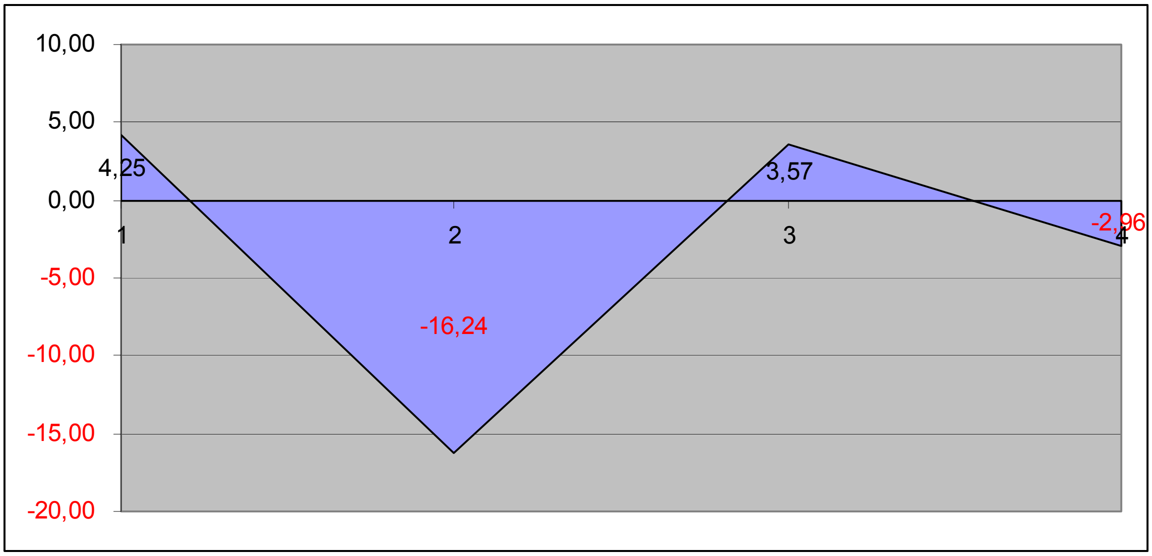
United States of America.

The behavior of the index in this case looks more consistent, showing positive values along the period of reference, and even became higher than one for year 2006, denoting that reduction of emissions was higher than growth.



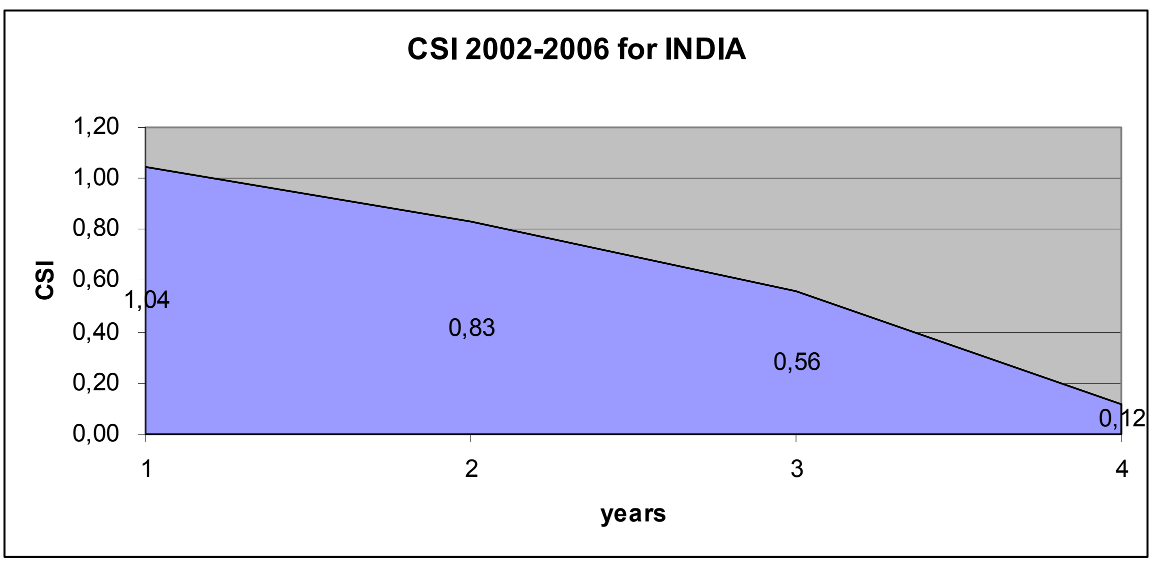

Denmark.

While this country shows one of the most positive CSI worldwide values during 2002 and 2005, there has been a more erratic behavior, especially, during year 2003 this country imported almost 50% more Coal, and this might explain higher emissions level for that year. At the same time, during 2003 Growth was zero, so CSI shows a value equal to $E_{FF}$% *(-1).



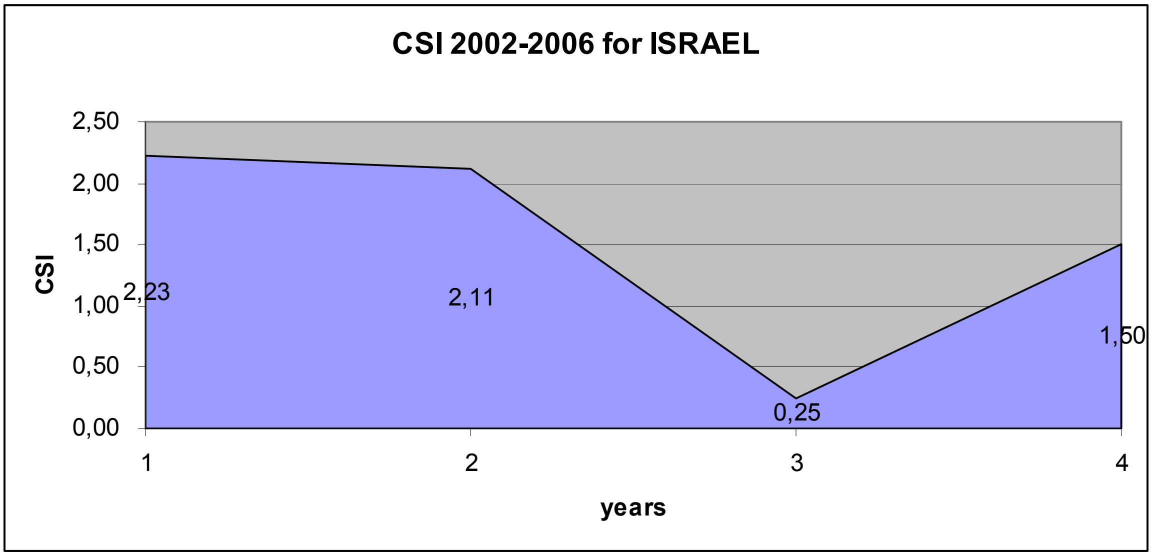

India

Having had remarkable growth levels during last years, it is interesting to see how in this case Growth is associated to higher emissions, as CSI tends to zero. It would be convenient to analyze if there are mechanisms for adjusting this tendency in a way of growing while taking more care of emission levels at the same time.




Israel.

This country shows the most positive and consistent behavior in reference to Growth and emissions level. It is possible to see how CSI values during the period of reference keep mostly above 1, meaning reduction of emissions, in percentage, had more significance than Growth, which is something highly positive.




4 - Further analysis on the Carbon Sustainability Index.

When there is positive growth, it is possible to point out following specific characteristics according to the different values of CSI :

a. CSI = 1 ; this means that $E_{FF\%}$ was zero, meaning the country presented positive Growth while keeping same emission level from FF. Basically, this is something positive as emissions did not grow.

b. 0<CSI<1 ; in other words, $0<E_{FF\%}<$Growth; thus, emissions level increased but at lower rate than that of Growth. This is not so good, but still growth was not completely supported by or reflected on the emissions factor.

c. 0 > CSI ; this means $E_{FF\%}$ > Growth, a clearly negative situation for the environment.

d. CSI > 1 ; this situation indicates that emissions have been reduced in reference to previous level.

e. CSI > 2 ; for values higher than 2, it means that the percentage of reduction of emissions is higher than the growth rate.

CSI target values for coming years should be evaluated and defined by International Community as to encompass the process to a definitely worldwide sustainable growth.

## 6 – References.

1. Stern Review:

The Stern Review on the Economics of Climate Change, was published on October 30 2006 and was lead by Lord Stern, the then Head of the Government Economic Service and former World Bank Chief Economist.

Website: http://www.occ.gov.uk/activities/stern.htm

2. Garnaut Review:

The Garnaut Climate Change Review was an independent study conducted by Professor Ross Garnaut was established on 30 April 2007, and concluded on 30 September 2008.

Website: http://www.garnautreview.org.au/CA25734E0016A131/pages/about

3. IPCC - Intergovernmental Panel on Climate Change:

The IPCC was established to provide the decision-makers and others interested in climate change with an objective source of information about climate change.

Website: http://www.ipcc.ch/about/index.htm

4. RGGI – Regional Greenhouse Gas Initiative:

The Regional Greenhouse Gas Initiative (RGGI) is the first mandatory, market-based effort in the United States to reduce greenhouse gas emissions. Website: http://www.rggi.org/home

5. G8 News link:

http://www.america.gov/st/peacesec-english/2008/July/20080708122719dmslahrellek0.7311518.html

5 – Appendix I – CSI calculation for different countries.

| | 2006 | | 2005 | | 2003 | | 2002 | |
|---|---|---|---|---|---|---|---|---|
| | Growth% | 344misión % | Growth % | 344misión % | Growth % | 344misión % | Growth % | 344misión % |
| JAPAN | 2,20 | -0,23 | 2,60 | -0,66 | 2,70 | 4,15 | 0,20 | 0,52 |
| NORTHKOREA | -1,10 | 2,79 | 1,00 | 4,29 | 1,00 | 2,33 | 1,00 | -3,83 |
| JAMAICA | 2,50 | 7,03 | 1,80 | -3,27 | 1,90 | 3,83 | 1,00 | 2,31 |
| CHINA | 11,10 | 10,84 | 10,20 | 12,01 | 9,10 | 18,05 | 8,00 | 10,70 |
| UAE | 8,90 | 6,96 | 8,80 | 4,70 | 5,20 | 2,69 | 1,80 | 7,35 |
| RUSSIA | 6,70 | 0,34 | 6,40 | 2,11 | 7,30 | 3,50 | 4,30 | 0,04 |
| ARGENTINA | 8,50 | 6,76 | 9,20 | 7,86 | 8,70 | 10,71 | -10,90 | -5,58 |
| VENEZUELA | 10,30 | 1,03 | 9,30 | 5,30 | -9,20 | -8,90 | -8,90 | -1,34 |
| FINLAND | 4,90 | 11,84 | 3,00 | -15,70 | 1,90 | 24,91 | 1,60 | 0,66 |
| AUSTRALIA | 2,70 | 0,04 | 2,70 | 6,61 | 3,00 | -0,52 | 3,60 | 2,30 |
| INDIA | 9,40 | 8,30 | 8,40 | 3,71 | 8,30 | 1,41 | 4,30 | -0,18 |
| VIETNAM | 8,20 | 11,65 | 8,50 | -0,13 | 7,20 | 7,78 | 7,00 | 16,82 |
| ISRAEL | 5,10 | -2,54 | 5,20 | 3,90 | 1,30 | -1,44 | -0,80 | -2,23 |
| CHILE | 4,00 | -6,78 | 6,30 | 7,99 | 3,30 | 7,78 | 2,10 | -1,22 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| MEXICO | 4,80 | 7,15 | 3,00 | 5,66 | 1,30 | 1,38 | 0,70 | 0,91 |
| NETHERLANDS | 3,00 | -4,49 | 1,50 | 0,79 | -0,70 | 0,87 | 0,20 | -6,93 |
| SPAIN | 3,90 | -2,97 | 3,50 | 3,53 | 2,40 | 2,38 | 2,00 | 5,26 |
| UK | 2,80 | 0,18 | 1,90 | 0,41 | 2,20 | 2,00 | 1,80 | -1,97 |
| GERMANY | 2,80 | 0,59 | 0,90 | -2,21 | -0,10 | 1,95 | 0,20 | -2,32 |
| BRAZIL | 3,70 | 1,81 | 2,30 | 3,99 | -0,20 | -0,23 | 1,50 | -0,54 |
| SOUTH AFRICA | 5,00 | 1,33 | 4,90 | -2,22 | 1,90 | 8,57 | 3,00 | -3,50 |
| ICELAND | 2,60 | 3,59 | 5,60 | -0,00 | 2,60 | 0,58 | -0,60 | 4,32 |
| FRANCE | 2,20 | 0,82 | 1,20 | -0,46 | 0,50 | 1,63 | 1,20 | -0,93 |

| | Carbon Sustainability Index | | | |
|---|---|---|---|---|
| | 2002 | 2003 | 2005 | 2006 |
| JAPAN | -0,52 | -0,54 | 1,25 | 1,10 |
| NORTH Korea | 4,83 | -1,33 | -3,29 | -2,79 |
| JAMAICA | -1,31 | -1,01 | 2,82 | -1,81 |
| CHINA | -0,34 | -0,98 | -0,18 | 0,02 |
| UAE | -3,08 | 0,48 | 0,47 | 0,22 |
| RUSSIA | 0,99 | 0,52 | 0,67 | 0,95 |
| ARGENTINA | 5,58 | -0,23 | 0,15 | 0,21 |
| VENEZUELA | 1,34 | 8,90 | 0,43 | 0,90 |
| FINLAND | 0,59 | -12,11 | 6,23 | -1,42 |
| AUSTRALIA | 0,36 | 1,17 | -1,45 | 0,98 |
| INDIA | 1,04 | 0,83 | 0,56 | 0,12 |
| VIETNAM | -1,40 | -0,08 | 1,02 | -0,42 |
| ISRAEL | 2,23 | 2,11 | 0,25 | 1,50 |
| CHILE | 1,58 | -1,36 | -0,27 | 2,69 |

| | | | | |
|---|---|---|---|---|
| MEXICO | -0,30 | -0,06 | -0,89 | -0,49 |
| NETHERLANDS | 6,93 | -0,87 | 0,47 | 2,50 |
| SPAIN | -1,63 | 0,01 | -0,01 | 1,76 |
| UK | 2,09 | 0,09 | 0,79 | 0,94 |
| GERMANY | 2,32 | -1,95 | 3,46 | 0,79 |
| BRAZIL | 1,36 | 0,23 | -0,74 | 0,51 |
| SOUTH AFRICA | 2,17 | -3,51 | 1,45 | 0,73 |
| ICELAND | -4,32 | 0,78 | 1,00 | -0,38 |
| FRANCE | 1,77 | -2,27 | 1,38 | 0,63 |

-

# 16. Energy Interaction between Lighting and Air Conditioning in a Library Building

**Claudio Olivera Fuentes[1], Aminta Villegas de Olivera[2]**

[1]Departamento de Termodinámica y Fenómenos de Transferencia

[2]Departamento de Conversión y Transporte de Energía

Universidad Simón Bolívar

Apartado Postal 89000, Caracas 1080, Venezuela

Tel: +58-212-9063756, Fax: +58-212-9063743, E-mail: claudio@usb.ve

Keywords: Energy savings, Lighting, Library.

Abstract: In 2002, the Energy Savings Program (Programa de Ahorro Energético, PAE) of Simón Bolívar University de la USB took on the task of cutting down on the electricity consumption in the Main Library building, through the gradual phasing out of conventional fluorescent tubes, to be replaced by more efficient equipment, and the complete switching off of lights during Library closing hours. The purpose of the present study was to evaluate the impact that these actions have had on the average temperature and humidity levels in the premises. These variables were measured over 24-hour periods with lights off during the night, and also with lights permanently on. The thermal loads of the building were estimated using a free-access software package. It was concluded that keeping the lights on may reduce the relative humidity by 3 to 5 percent points and increase the temperature by 1 to 2 °C, but these changes are insufficient to guarantee ambient conditions that meet the standards for preservation of the bibliographic collections and human comfort.

## Introduction

The Main Library of Simón Bolívar University is located in a four-story building with a total floor area of 3,500 $m^2$. By the year 2001, its electrical energy consumption accounted for 13% of the University's electricity bill. Reducing this expenditure was therefore one of the first main goals of the Energy Savings Program (Programa de Ahorro Energético, PAE) of the University, to which purpose two actions have been undertaken since the beginning of 2002:

Substitution of the old fluorescent lamps (4 x 40 W with electromagnetic ballast) by newer, more energy efficient lamps (3 x 32 W with electronic ballast) that provide better lighting with less power consumption. This replacement program has proceeded only gradually, because of persistent financial limitations.

Switching off the Library lights by night, which was previously avoided because of the difficulty in getting the old lamps to turn back on each morning, and also because the heating effect (Joule dissipation) of the lamps was believed to be beneficial for the library collections, in the sense that it helped maintain higher temperatures and lower relative humidities in the building.

The net effect of the PAE initiatives has been a 60% reduction of the average electricity consumption, from about 5300 kWh/day to 2100 kWh/day. However, there is still concern that these changes may be having an undesirable impact on the ambient conditions in the building, with possible danger to the library collections, particularly given the high humidity and (for Venezuela) low temperature conditions that typically prevail in the University campus. A first study conducted in 2005 (Arnal et al., 2005) showed that this effect actually existed but was very small, and could be neglected by comparison with other contributions, such as imperfect roof waterproofing. Since that date, however, lamp replacement that was then limited to the ground floor has been extended to the first and second floors. It was deemed convenient therefore to update the previous study, in order to assess the continuing impact of the PAE measures. The present paper reports the results of the new study.

A series of temperature and humidity measurements were performed in each floor of the Library, in two stages. The first stage consisted of measurements for the current "lights off" policy during closing hours. The second stage repeated the measurements reverting to the previous policy (prior to 2002) of "lights on" at night. In addition to this experimental study, a computational analysis was carried out in order to estimate the absolute and relative thermal loads in each floor, using the CoolPack® software package. This application requires as input information the number of occupants, dimensions of each building area, and characteristic heat transfer parameters such as coefficients of thermal conduction and convection, room and surface (walls, floors and ceilings) temperatures, incident solar radiation, incoming air flow rates, and others. Building data were obtained from the appropriate University offices, and physical data were collected from literature references.

## Technical Background

### Temperature and humidity.

Atmospheric air normally contains a certain amount of water vapor. This water contents is known as the humidity of the air and can be expressed in absolute or relative terms. Absolute humidity is the mass of water vapor per unit mass of dry air. Relative humidity is the ratio of the amount of water vapor to the maximum amount that could be contained by the same mass of air, if it became saturated with vapor at the prevailing temperature and pressure. This ratio is usually expressed as a percent value, and is strongly affected by the temperature, which alters the maximum water carrying capacity of the air. In general, for the same amount of vapor in air (constant absolute humidity), the relative humidity increases as the temperature is lowered and the humid air approaches its condensation or dew point.

### Air conditioning system.

The air conditioning system of the Main Library building is of the chilled water type, consisting of three central units that cool water down to approximately 5 °C, for subsequent heat exchange with the ambient air that is to be conditioned. The main equipment in the AC system are the central water chillers, and the air handling units (unidades manejadoras de aire, UMAs).

### Chillers.

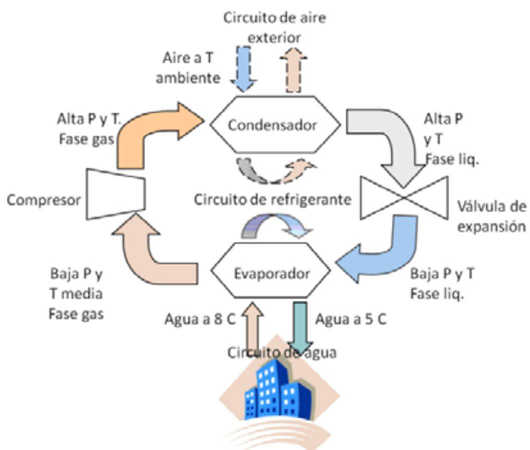
The operating diagram of a vapor compression refrigeration cycle is shown schematically in Figure 1. Its main components are:

- Evaporator: This is a shell-and-tube heat exchanger in which the warmer water coming out of the UMAs is cooled down by thermal contact with the cold refrigerant of the chiller loop. The cooling effect is provided by the evaporation of the refrigerant. The water enters at about 8 °C and exits at about 5 °C, going back into the UMAs where it in turn cools down the circulating air, and cycling back to the chiller in a closed circuit.

- Compressor: The refrigerant vapor leaving the evaporator flows to the compressor where its pressure

Figure 1

Process diagram of a chiller.




and temperature are raised while still in the gaseous state. Each chiller includes five semi-hermetic reciprocating six-cylinder compressors in blocks of two and three units in series. In normal working conditions, only two compressors operate per chiller.

- Condenser: The refrigerant vapor from the compressor enters an air-cooled condenser, where it is returned to the liquid state while keeping its high pressure.

- Expansion valve: The high-pressure liquid refrigerant undergoes a sudden expansion in a throttling valve. As a consequence, its pressure and temperature drop back to the appropriate values for returning to the evaporator, thus completing the refrigeration cycle.

Air handling units (UMAs).

The UMAs are heat exchangers where the warm air coming out of the building is cooled by water from the chillers. This recirculating air is mixed with fresh air from the surroundings, and the mixture of both is sent back into the building. The intake of external air is necessary to replenish the oxygen which is being used up by the building occupants. Inside the UMAs, as illustrated in Figure 2, the air goes through several processes, which include the mixing of recirculating and fresh air, filtration to remove dust and dirt particles, the actual cooling in the heat exchanger coils (which might lead to a decrease in absolute humidity if some water vapor condenses out of the air as a consequence of cooling), and finally distribution by forced convection into the premises.

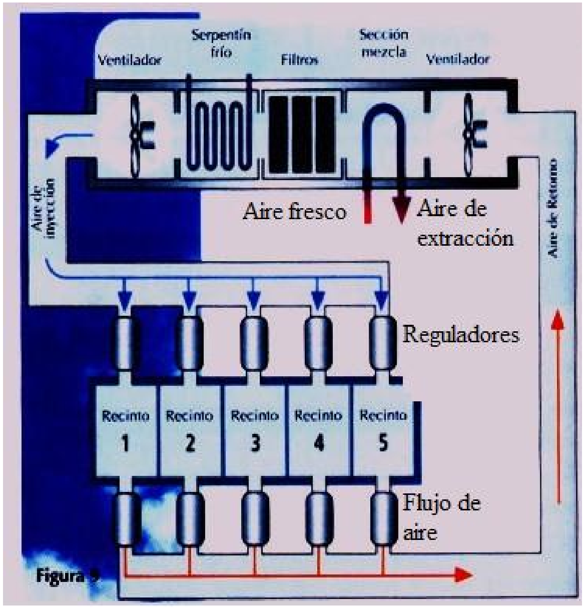
There are two UMAs per floor in the Library building. Each UMA has a control system composed of a thermostat, which sets the air conditioning temperature, and a three-way valve which acts to decrease the chilled water flow if air temperature falls below the set point, or to increase it in the opposite case.

Refrigerant.

The refrigerant is R-22 (chlorodifluoromethane, $CHClF_2$), which is still usual in commercial and residential AC equipment. It is an odorless, nonflammable fluid with a normal boiling temperature of – 40.6 ºC. It is a member of the family of chloro-fluorinated hydrocarbons (HCFCs), which are known to damage the ozone layer because of their chlorine contents. Under the directives of the Montreal Protocol, these coumpounds should be phased out in the near future, although first priority was accorded to the elimination of chloro-fluorocarbons (CFCs) which have the largest chlorine contents. R-22 production in Europe has been steadily decreasing since 2004 and is expected to be minimal by

Figure 2

Schematic diagram of an air handling unit




2015. The use of R-22 is now forbidden in mobile refrigeration units (trucks or trains), and in any case beyond a certain refirigeration capacity.

Thermal load.

The amount of heat energy that must be supplied or removed per unit time by an AC system (depending on whether the air heating or cooling is required) is known as its thermal load. During operation, the system may go through periods of maximum load or of partial load. The former correspond to conditions that impose the most demands on the system, whereas the latter represent the average or normal operating conditions which the system should handle by design.

A difference must be made between instantaneous (or apparent) and effective (or true) thermal loads. The instantaneous load is the heat flux entering or leaving the air conditioned space or “room”. The effective load is the heat flux actually absorbed or ceded by the air, which is almost always less than the apparent flux, because part of the energy is stored by the building materials and physical objects in the room, which define its thermal inertia (or heat capacity). The heating effect of electrical lights, for example, is an instantaneous load. Before the circulating air can remove all this energy, a part is transmitted to the room walls by radiation and convection. The walls will in turn absorb part of the transmitted energy, and distribute the rest by heat conduction. There will now be a temperature difference between the walls and the air, and part of the energy will transfer from the walls to the air by convection. The net heat gained by the air in the room is the effective thermal load that must actually be removed by the AC system. Clearly, systems based on the apparent heat load will most likely be overdesigned.

Thermal loads can be estimated by well established procedures found in reference manuals and handbooks. In the present work we followed the methods described in the Air Conditioning Handbook published by Carrier Air Conditioning Company (1992). In addition, we used the computer program CoolPack®, which is a free-access software package for air conditioning calculations.

Sensible heat factor.

Thermal loads can be classified as sensible or latent. Sensible loads are heat fluxes that act to change the temperature of the inside air. Latent loads are water vapor fluxes (into or out of the room) which do not alter the air temperature, but are tantamount to a thermal gain because they alter the thermodynamic energy of the air (actually, its enthalpy). For example, if the absolute humidity of the air increases due to an influx of water vapor, heat will have be extracted in order to dehumidify the air, i.e. to restore the original humidity by condensing the extra vapor. The sensible heat factor (SHF) is defined as the ratio of sensible to total (i.e. sensible plus latent) heat load. The SHF value gives a clear indication of the fractions of the heat load that must be destined for heating or cooling, and for humidification or dehumidification, respectively.

2.8 Library standards.

Relative humidity in libraries must lie between 45 and 50 % (Carrier Air Conditioning Company, 1992). A value inside this range will ensure comfortable conditions for the library users, at the same time helping reduce and delay (although not completely eliminate) possible damage to the bibliographic materials.

Experimental Procedure

Experimental temperatures and humidities were measured with two Nomad Data Loggers, model OM-DLTH by Omega Co. The software package OM-DP3 Data Logger was used for configuring the instruments and downloading the information registers. A Fluke thermocouple, model 52 K/J Thermometer, was used for temperature measurements in the building surfaces (walls, floors and ceilings). All instruments were loaned by the Transport Phenomena Section of the University Laboratory “A”.

Measurements in each of the four Library floors were taken at ten points conveniently chosen on the floor plan (two points per day, thus five days per floor). The instruments were programmed to register the data at intervals of 5 seconds for 24 continuous hours at each point. These measurements were performed in two stages: (1) “Lights off” mode (modalidad luces apagadas, MLA), which is the current Library policy. Lights are on for 11 hours, from 08:30 am to 19:30 pm, and switched off during closing hours; (2) “Lights on” mode (modalidad luces encendidas, MLA) during the entire 24 hours. Each stage took approximately five weeks to complete.

Additional temperature and humidity measurements were made outside of the Library building, using the same instruments but programmed for intervals of 5 minutes. These readings took one further week to complete.

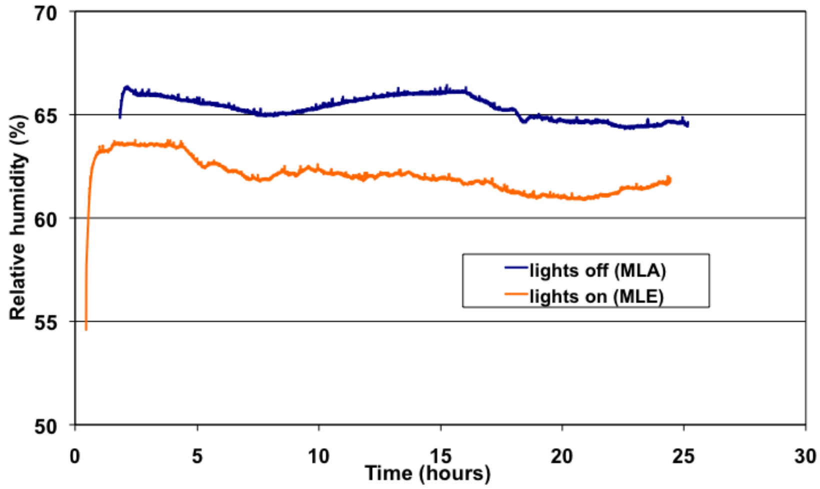
## Results and Discussion

In Figure 3 we show an example of the humidity readings, corresponding to the position identified as point 7 of floor 1, for both lighting modes. The time scale in the horizontal axis begins at 4:00 pm (time zero). An initial period of about 5 to 10 minutes can be observed in both curves, corresponding to stabilization of the instrument readings. Comparison of the two curves shows that relative humidities for MLA (“lights off”) tend to be higher than those for MLE (“lights on”), and that this difference is maintained consistently throughout the interval of measurement, not just during the time that the lights were off in MLA, which is from about 4 (8:00 pm) to 16 (8:00 am) on the abscissa. It must be kept in mind, however, that both sets of measurements were conducted on different days, Dec 12, 2007 for

Figure 3

Measured relative humidities

[Floor 1, point 7, both lighting modes]




MLA and Feb 14, 2008 for MLE, and this might imply a different influence of the external ambient conditions. In any case, the most relevant information in Figure 3 is that, even if a “lights on” policy may introduce a moderating factor in the humidity levels, this effect is plainly insufficient to reach the humidity levels required in library buildings, which by norm must lie between 45 and 50%.

Figure 4 shows measurements for the same point as above, as obtained in our previous study of 2004 (Arnal et al., 2005). “Time zero” in this plot corresponds to 8:00 am, and the dates of measurement were Feb 12, 2004 for MLA and Mar 25, 2004 for MLE. One can clearly see that the two curves in this graph are more widely apart than those in the previous Figure 3, i.e. the effect of keeping the lights on was even more noticeable at that time. This is consistent with the fact that the lamps in this floor had not yet been replaced in 2004, and were of the older type having twice the power consumption (and thermal dissipation) of the newer ones. Once again, however, it must be remarked that even with this increased heating effect, relative humidities exceeded the acceptable limits for library facilities.

Similar curves were obtained both for humidities and for temperatures in each of the ten points, each of the four floors, and both lighting policies. It is obviously impossible to present all the results in the available space here. In general, besides the humidity fluctuations along the day at each point, we observed significant differences among readings at different points on the same floor, which indicated that conditions are not uniform across the floor, hence no single point can be taken as representative of the entire floor. In order to simplify the analysis, therefore, the minimum, average and maximum values of the humidity were computed from the complete set of data for each floor and lighting mode. Figure 5 shows an example corresponding to measurements on the ground floor. Individual symbols indicate the day average humidity at each point; continuous lines represent the floor average, and dashed lines are drawn at plus and minus one standard deviation from the mean. As in the previous cases, the first observation here is that humidities are well above the required standards. It may also be seen that humidities in MLA are not always higher than those in MLE, depending on the point under consideration. Although the floor average follows the expected behavior, being greater in MLA than in MLE, it is no less true that the difference between the two averages falls within the error band of one standard deviation. Put another way, the humidity decrease supposedly caused by a “lights on” policy

Figure 4

Measured relative humidities, 2004

[Floor 1, point 7, both lighting modes]

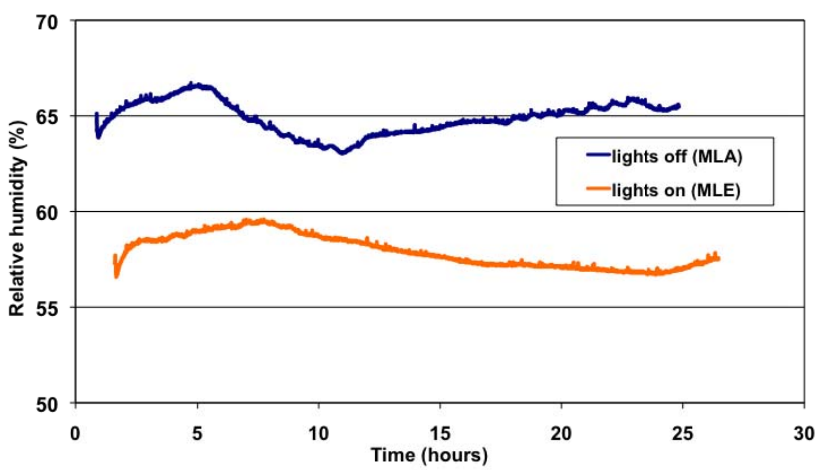
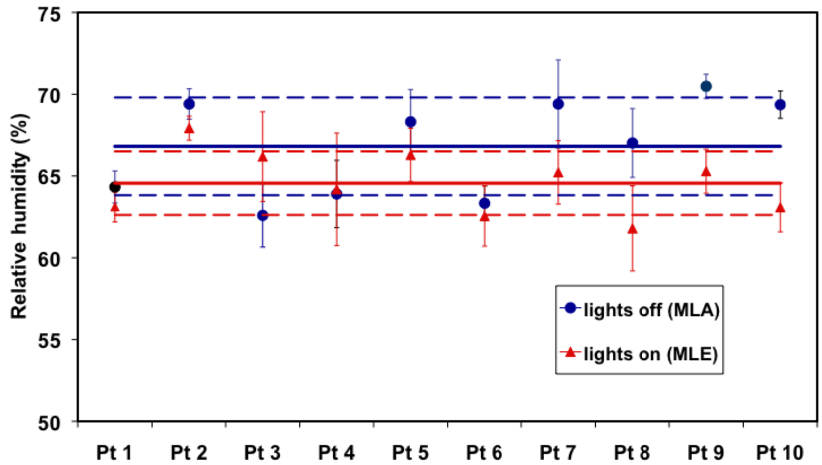



Figure 5

Point and floor average relative humidities on the ground floor.

[Error bars indicate standard deviations for each point. Continuous line is the floor average.

Dashed lines are drawn at minus and plus one standard deviation from the mean.]



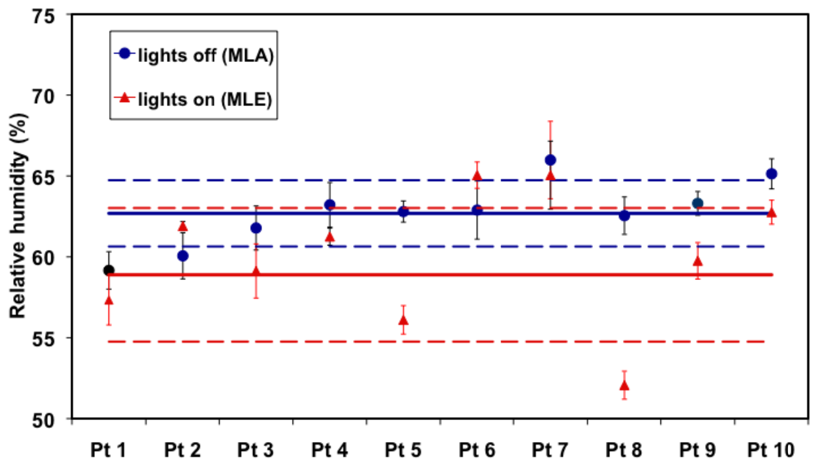

is less conclusive when the precision of the instruments and the fluctuations in the ambient conditions, both in time and space, are taken into consideration.

It might be argued that the small, inconclusive differences observed in the above example are a consequence that the ground floor lamps are of the newer type and have a consequently smaller heating effect. However, as shown in Figure 6, the data obtained for the same floor in the previous study of 2004 (when lamps had not yet been replaced) exhibit an almost identical behavior, only with somewhat lower humidity levels for both lighting modes. Thus, it seems reasonable to conclude that the effect of MLA on the humidity, if it exists at all, is difficult to quantify in view of the experimental dispersion.

Figure 6

Point and floor average humidities on the ground floor, 2004.

[Symbols and lines have the same meaning as in Figure 5.]




By analyzing the entire set of data gathered in this study, we estimate that the “lights off” policy may result in an increase of about 3 to 5 percent points in the average relative humidity of the building.

Analogous conclusions may be obtained from an analysis of the temperature measurements in each point and floor for both lighting modes. The overall results suggest that an increase of 1 or at most 2 °C can be attributed to MLE, as illustrated by Table 1 that shows the average temperature at the ten points on the ground floor, together with the corresponding floor average. It can be seen that the standard deviation of this floor average for MLE is slightly lower than for MLA, suggesting that keeping the lights constantly on may help keep a steadier temperature along the day. Once more, however, the difference between temperatures in both modes is less than the order of magnitude of the precision of measurement, as represented by one standard deviation. In fact, at some individual points we fopund that temperatures in MLE could actually be lower than those in MLA, e.g. at point 7 of floor 1 as shown in Figure 7. Once again, it is relevant to point out that measurements were taken on different days, under possibly different external ambient conditions.

Finally, we proceeded to estimate the thermal loads per floor, using the CoolPack® software package and following the procedures established in the air conditioning handbook of Carrier Air Conditiong Co. (1992). For this purpose, detailed information was gathered on the external and internal characteristics of the Library building, such as:

- Dimensions of walls, floors, ceilings, columns and windows;

- Typical number of occupants per floor, depending on its uses and services (reference rooms, reading rooms, administrative offices, study cubicles, collection shelves, etc.);

- Number and type of lamps, computers, photocopiers and other heat dissipating equipment;

- Infiltration of external air through doors and windows;

- Heat transfer parameters (thermal conductivities, heat transfer coefficients from internal and external surfaces, temperature of the surroundings, solar radiation.)

The computed thermal loads and sensible heat factors (SHF) are summarized in Table 2. These values will be important for future stages of this study, which will consider the possible modifications of the AC system to comply with humidity standards, while providing for user comfort.

Table 1

Point and floor average temperatures on the ground floor

($\sigma$ = standard deviation)

| | MLA | | MLE | |
|---|---|---|---|---|
| | $T_{av}$ | $\sigma$ | $T_{av}$ | $\sigma$ |
| Point 1 | 19,6 | 0,4 | 20,2 | 0,3 |
| Point 2 | 20,7 | 0,4 | 21,0 | 0,3 |
| Point 3 | 18,8 | 1,1 | 20,8 | 0,2 |
| Point 4 | 18,8 | 0,5 | 21,4 | 0,4 |
| Point 5 | 20,1 | 0,7 | 21,1 | 0,6 |
| Point 6 | 21,2 | 0,6 | 22,2 | 0,5 |
| Point 7 | 20,0 | 0,6 | 19,8 | 0,6 |
| Point 8 | 21,5 | 1,0 | 21,0 | 1,0 |
| Point 9 | 19,0 | 0,2 | 19,7 | 0,4 |
| Point 10 | 18,9 | 0,2 | 19,9 | 0,5 |

| | | | | |
|---|---|---|---|---|
| Floor | 19,9 | 0,9<br>6 | 20,7 | 0,76 |

Figure 7

Measured temperatures

Floor 1, point 7, both lighting modes

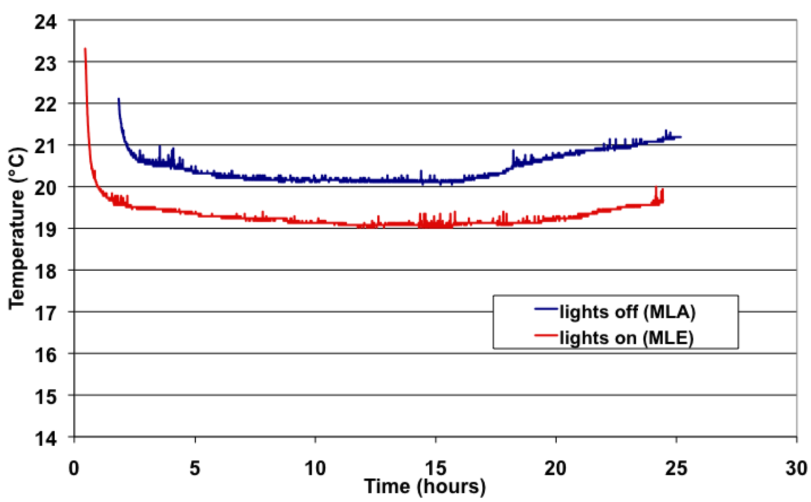



Table 2

Thermal loads and sensible heat factors

| Piso | Thermal load (Kw) | SHF (%) |
|---|---|---|
| PB | 136,20 | 90,2 |
| 1 | 83,99 | 100,0 |
| 2 | 252,48 | 100,0 |
| 3 | 311,95 | 100,0 |

Conclusions

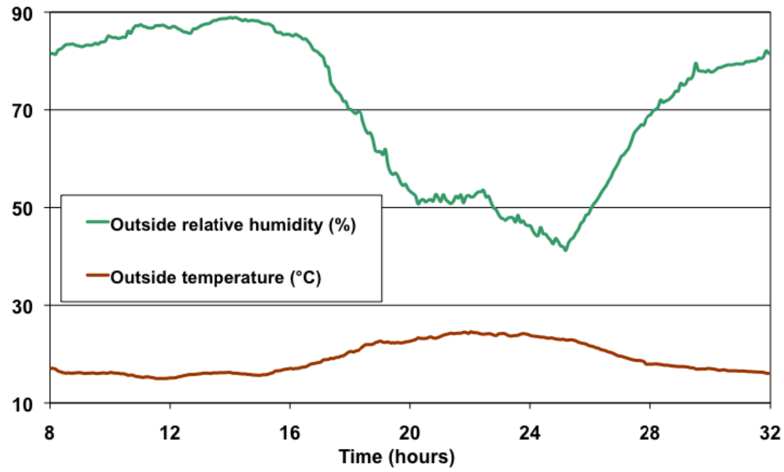
The results of the present study show that, in average terms, the PAE initiatives of lamps replacement and lights off in the Main Library building may have resulted in an increase of 3 to 5 percent points in relative humidities and a decrease of 1 to 2 degrees in temperature. These values must be approached with some caution, because time and space fluctuations of the relevant external and internal conditions introduce significant dispersion in the measured values. The experimental evidence also indicates that the effect of the lighting policy becomes much less important after lamps of the older type are replaced by new equipment having less power consumption and accordingly less heat dissipation.

From an energy efficiency perspective, in any case, it would be quite wrong to use the thermal dissipation of the lighting fixtures as a control mechanism of the humidity and temperature levels in the Library premises. To date, and with lamp replacement in the third floor still pending, the PAE actions have resulted in a reduction of approximately 60 % of the electricity consumption of the building (see Appendix), while improving the quality of illumination, eliminating the problems of switching on the lights at the beginning of each day, and significantly reducing the costs of maintenance and replacement of lamptubes and ballasts.

It is obviously the AC system that must next be adapted to the new working conditions in the building. Above all, the results of the present study, as well as those of the previous study of 2004, clearly show that the prevailing humidity and temperature levels are alarmingly outside of the standard ranges required in library facilities. In future stages of this study, we shall be using the present results to propose the necessary changes in the AC system's setup and operation. A main factor to be taken into account is the typical weather conditions of the Sartenejas Valley where the University is located. Figure 8 shows that on a given day the relative humidity may reach almost 90%, with temperatures descending almost to 14 °C. These are dramatic conditions for the Main Library building, which is not especially insulated from air infiltration and thermal losses, and must serve a large number of users, which has increased in the last few years and will most likely continue to do so. Assuring a comfortable environment for these users and protecting the library collections is the continuing goal of this project.

Figure 8

Relative humidity and temperature of the external environment




References

Arnal, S. E., C. A. Sosa, C. Olivera Fuentes and A.Villegas de Olivera (2005). “Estudio del impacto del apagado de luces y cambio de luminarias sobre la humedad en el Edificio de Biblioteca USB”, X Congreso Latinoamericano de Transferencia de Calor y Materia, LATCYM 2005, Caracas.

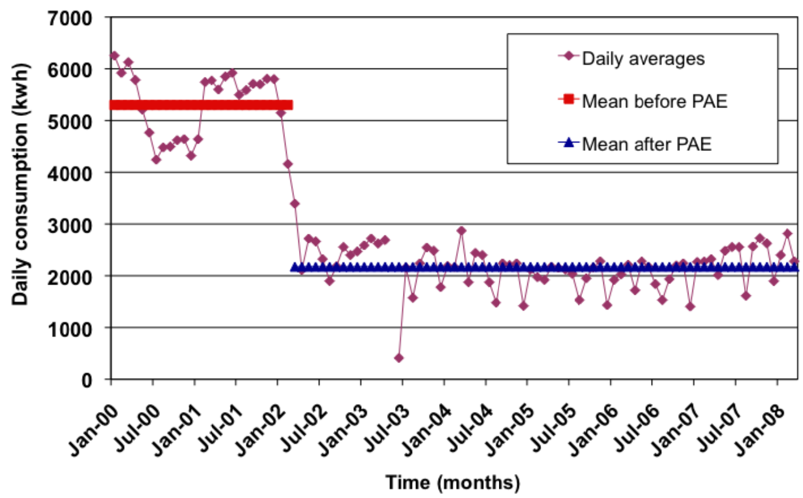
Carrier Air Conditioning Company. 1992. *Manual del Aire Acondicionado de Carrier*, Boixareu, Barcelona.

Appendix

Figure A.1

Historical evolution of electrical energy consumption

in the Main Library building of Simón Bolívar University



7000
6000
5000
4000
3000
2000
1000
0
Daily consumption (kwh)
Daily averages
Mean before PAE
Mean after PAE
Jan-00
Jul-00
Jan-01
Jul-01
Jan-02
Jul-02
Jan-03
Jul-03
Jan-04
Jul-04
Jan-05
Jul-05
Jan-06
Jul-06
Jan-07
Jul-07
Jan-08
Time (months)

## 17. «Renewable Energy for Sustainable Development in Reunion Island”

**Julien Baddour - Jacques Percebois**

Summary: Because it is renewable, environment-friendly and better distributed on a worldwide scale, renewable energy (RNE) is an excellent means to meet the world energy challenge, i.e. guarantee the development of southern countries without damaging the environment. Better adapted to the profile of island territories and their local needs, renewable energy sources are also a perfect tool for overseas territories (DOM-TOM) to reduce energy dependency, preserve their environment and guarantee sustainable development. In Reunion Island, RNE benefits from strong political and very favourable financial and institutional support—which has made the Reunion Regional Council a trailblazer at national level for thermal and photovoltaic energy development. However, renewable energy is no panacea as it suffers from a certain number of weaknesses: to this day, it is expensive, not very competitive and intermittent; its output is low; and it is not always available according to demand. This explains why the aim of renewable energy is not to replace fossil fuels completely. Both energy types complement each other in the regional energy mix.

**Julien Baddour**

CERESUR, University of Reunion Island

**Jacques Percebois**

CREDEN, University of Montpellier (France)

This paper has been presented in five international colloquia:

“Environmental Balance, Renewable Energy and Urban Development,” Reunion Island, March 1-2, 2007

International Field Workshop on “Renewable Energy for Sustainable Development in Africa”, Mauritius, June 18-21, 2007

"Energy Patriotism: An Answer to Market Globalization," Rabat, January 9-11, 2008

"Knowledge Economy and Development" Saint Louis du Sénégal, May 20-22, 2008

"How to Make Development More Sustainable?" Cedimes, Paris, May 21-23, 2008

# 18. On Models to Estimate the Efficient Operational Costs of

Electrical Energy Utilities

**Marcus V. Pereira de Souza, Madiagne Diallo, Reinaldo C. Souza and Tara K. Baidya**

Abstract : This paper presents some results of an empirical study in which Data Envelopment Analysis (DEA) is used in order to evaluate the cost efficiency of the Brazilian electricity distribution utilities. Such an technique can reduce the information asymmetry and improve the regulator's skill to compare the performance of the utilities, a fundamental aspect in incentive regulation frameworks. Since DEA models are very sensitive to outliers, here it is proposed the use of the Wilson method and Boxplot in order to identify the set of utilities. Next, the cost efficiency scores of the electricity distribution utilities are evaluated by two DEA models. In both models the only input variable is the operational expenditures (OPEX) and so, the efficiency measure reflects the operational costs reduction potential of each utility. The outputs are the cost-drivers of the OPEX: the number of customers, the total electric power supplied and the distribution network size.

Keywords—Data Envelopment Analysis, Outliers Detection, Economic Regulation, Energy Distribution, Wilson method, Boxplot, Cost efficiency

Introduction

I

N the Brazilian electrical sector (SEB for short), the supply of energy tariffs is periodically revised within a period of 4 to 5 years, depending on the distributing utility contract. On the very year of the periodical revision, the tariffs are brought back to levels compatibles to its operational costs and to guarantee the adequate payback of the investments made by the utility, therefore, maintaining its financial and economical equilibrium (EEF for short). Over the period spanned between two revisions, the tariffs are annually readjusted by an index named IRT given by:

$$\mathrm{IRT} = \frac{\mathrm{VPA1} + \mathrm{VPB0} \cdot (\mathrm{IGPM} - \mathrm{X})}{\mathrm{RA0}} \qquad (1)$$

Where, VPA1 stands for the quantity related to the utility non-manageable costs (acquisition of energy and electrical sector taxes) at the date of the readjustment; RA0 stands for the utility annual revenue estimated with the existing tariff (free of the ICMS tax) at the previous reference date IGPM (market prices index) and VPB0 stands for the quantity related to the utility manageable costs (labor, third part contracts, depreciations, adequate payback of invested assets and working capital) on the previous reference date (VPB0 = RA0 – VPA0).

As shown in (1), the non-manageable costs (VPA) are entirely passed through to the final tariffs, while the amount related to the manageable costs (VPB) is updated using the IGPM index discounted by the X factor. This factor applies only to the manageable costs and constitutes the way whereby the productivity gains of the utilities are shared with the final consumers due to the tariff reduction they introduce. The ANEEL (National Electrical Energy Agency) resolution 55/2004 defines the X factor as the combination of the 3 components ($X_e$, $X_a$ and $X_c$), according to the expression below:

$$X = (X_e + X_c) \cdot (IGPM - X_a) + X_a \qquad (2)$$

The component $X_a$ accounts for the effects of the application of the IPCA index (prices to consumer index) on the labor component of the VPB. The $X_c$ component is related to the consumer perceived quality of the utility service and the $X_e$ component accounts for the productivity expected gains of the utility due to the natural growth of its market. The latter is the most important and its definition is based on the discounted cash flow method of the forward looking type, in such a way to equal the present cash flow value of the utility during the period of the revision, added of its residual value, to the utility assets at the beginning of the revision period.

$$A_0 = \sum_{t=1}^{N} \left[ \frac{\left(RO_t \cdot (1 - X_e)^{t-1} - T_t - OM_t - d_t\right) \cdot (1 - g) + d_t - I_t}{(1 + r_{WACC})^t} \right] + \frac{A_N}{(1 + r_{WACC})^N} \qquad (3)$$

Where, $N$ is the period, in years, between the two revisions; $A_0$ is the value of the utility assets on the date of the revision, $A_n$ is the utility assets value at the end of the revision period; $g$ stands for both; the income tax percentage and the compulsory social contribution of the utility applied to the utility liquid profit; $r_{WACC}$ is the average capital cost; $RO_i$ is the utility operational revenue; $T_t$ represents the various taxes (PIS/PASEP, COFINS and P&D); $OM$ are the operational and maintenance utility costs; It is the amount corresponding to the investments realized and $d_t$ is the depreciation, all of them related to year t.

The quantities that form the cash flow in (3) are projected according to the criteria proposed by ANEEL, resolution 55/204. As an example, the projected operational revenue is obtained as the product between the predicted marked and the average updated tariff; while the operational costs (operational plus maintenance, administration and management costs) are projected based on the costs of the "Reference Utility", all related to the date of the tariff revision.

The "Reference Utility" is a virtual utility where the services provided to the users of the utility under study are simulated precisely under the same conditions. For a given required quality level of services the "Reference Utility" is designed to use efficiently the resource, this way acting as a "benchmark" to be pursuit by the real utility under revision. This strategy follows the argument of regulation by comparison (yardstick competition) and, this way, it stimulates, in a sense, competition between the real and the virtual utility.

The methodology of "Reference Utility" adopted in the first cycle of tariff revisions in Brazil (ANEEL, 2006) follows the bottom-up approach, which starts with the identification of all processes related to the activities of a distribution utility considering the commercial and technical aspects, then moves to the definition of the efficient costs to each one of these processes and ends with an estimate for the total efficient costs. Therefore, it constitutes a complex approach and clearly open opportunities to the regulator to get involved in a kind of micro-management of the utility under revision, which is not at all recommended as a good regulation practice.

To avoid the complexity of the "Reference Utility" approach and in order to produce an objective way to obtain efficient operational costs, ANEEL envisages the possibility of using benchmarking techniques, among them, the efficient frontier method, as adopted by the same ANEEL to quantify the efficient operational costs of the Brazilian transmission lines utilities (ANEEL, 2007). The frontier is the geometric locus of the best performances. The straightforward comparison of the frontier with the position of the utilities allows the quantification of the amount of improvement each utility should work on in order to improve its performance with respect to the others.

The international review conducted by Jasmab and Pollit (2000) shows that the most important benchmarking approaches used in regulation of the electricity services provided by utilities are based on DEA (Data Envelopment Analysis, Cooper *et al*., 2000, a technique founded on linear programming) and econometric based models, particularly the SFA (Stochastic Frontier Analysis, Kumbhakar and Lovell, 2000).

Studying cases of the Brazilian Electrical Sector, authors such as Resende (2001), Vidal and Tavora Junior (2003), Pessanha *et al.* (2004) and Sollero and Lins (2004) have used different DEA models to evaluate the efficiency of the Brazilian distributing utilities. On the other hand, Zanini (2004) and Arcoverde *et al.* (2005) have also obtained efficient indices for the Brazilian distributing utilities using SFA models. Recently, Souza (2008) has proposed to compute estimates of cost efficiency using Bayesian Markov Chain Monte Carlo (MCMC) algorithm.

The DEA and the SFA approaches have distinct assumptions on their inner concept and present pros and cons, depending on the specific application. Therefore, there is no such statement as “the best” overall frontier analysis method.

In order to measure the efficiency (rather than inefficiency), and to make measurement of efficiency across comparable firms, it is recommended to investigate efficiency indices obtained by several methods on the same data set, as carried out in the present work, where three DEA models were used to evaluate the operational costs efficiency of 60 Brazilian distributing utilities.

The paper outline is as follows. In section 2 the economic concept of returns to scale (RTS) is discussed and the DEA formulation is described in section 3. The specifications of DEA models, as well as, outliers detection and the main results obtained by their application using the Brazilian data are presented and discussed in section 4. The paper ends with a conclusion and some research perspective.

## Returns to Scale

Empirical analysis have typically investigated returns to scale based upon total elasticity $(\mathbf{e})$. Thereby, frequently are determined the partial elasticity estimates $(\mathrm{E}_i)$ that are provided in (Cooper *et al.*, 2000) by:

$$\mathrm{E}_i = \frac{\partial y}{\partial x_i} \cdot \frac{x_i}{y} \qquad (4)$$

Thus, the total elasticity $(\mathbf{e})$ is expressed as: $\mathbf{e} = E_1 + E_2 + \ldots + E_i$
(5)

Once the value of the total elasticity $(\mathbf{e})$ is measured, immediately it is possible to identify the returns to scale type. Three possible cases are associated with (5):

$\mathbf{e} = 1 \Rightarrow$ Constant Returns-to-Scale (CRS)

$\mathbf{e} > 1 \Rightarrow$ Non-Decreasing Returns-to-Scale (NDRS)

$\mathbf{e} < 1 \Rightarrow$ Non-Increasing Returns-to-Scale (NIRS)

Considering the above discussion, in the next section, it will be shown that it is possible to determine the best-practice frontier type. According to Zhu (2003) this issue has been the source of considerable debate in the literature. However, it is worthwhile noting that in this study case has been used Cobb-Douglas econometric models.

Data Envelopment Analysis

Consider a production technology that transforms an input vector $X=\{x_1 ,..., x_s\}\in R^+_S$ into an output vector (or production vector) $Y =\{y_1 ,..., y_m\}\in R^+_m$. The union of all possible ways of transforming $X$ into $Y$ composes the Set of Production Possibilities (SPP for short), defined by:

$T(X,Y) = \{ (X,Y) \mid \text{it is feasible to produce } Y \text{ from } X \}$ (6)

By adopting the resources conservation approach (input orientation), the technical efficiency of a particular DMU $(X,Y)$ is defined as the maximum radial contraction of the input vector that allows the production of the same quantities of output, i.e.:

Technical efficiency = $\text{Min} \{\theta \mid (\theta X,Y)\in T(X,Y) \}$ (7)

The variable $\theta$ assumes values between 0 and 1. A unity value means that it is not possible to reduce the input quantities and keep the same production. In this case, a DMU is said to be technically efficient. On the other hand, If there is an excess of input that has to be reduced (θ<1), then the DMU is regarded as technically inefficient.

Table 1 – Input oriented DEA models

| CRS Model | VRS Model |
|---|---|
| $\underset{\theta,\lambda}{Min}\,\theta$ (8)<br><br>s.t.<br><br>$\theta X_{j0} \geq \sum_{j=1}^{N} \lambda_j X_j$<br><br>$\boldsymbol{Y}_{j0} \leq \sum_{j=1}^{N} \lambda_j \boldsymbol{Y}_j$<br><br>$\lambda_j \geq 0 \forall j = 1, N$ | $\underset{\theta,\lambda}{Min}\,\theta$ (9)<br><br>s.t.<br><br>$\theta \boldsymbol{X}_{j0} \geq \sum_{j=1}^{N} \lambda_j \boldsymbol{X}_j$<br><br>$\boldsymbol{Y}_{j0} \leq \sum_{j=1}^{N} \lambda_j \boldsymbol{Y}_j$<br><br>$\sum_{j=1}^{N} \lambda_j = 1$<br><br>$\lambda_j \geq 0 \forall j = 1, N$ |

Based on these results and assuming the hypothesis of Constant Returns-to-Scale (CRS) and convex technology, Charnes *et al.* (1978) proposed the DEA-CRS model. In this model, the efficiency is formulated as a linear programming problem which objective function is the maximum concentration of input (input orientation) and the constraints represent the SPP. Later on, *Banker et al.* (1984) added a convex combination constraint to the CRS model, and thus, introduced a model that includes a hypothesis of variable return to scale, denoted by DEA-VRS. In Table 1 the input oriented DEA models on both approaches, CRS and VRS are presented, where *N* is the total number of DMUs considered in the problem. The pair ($X_j, Y_j$) represents the input and production vector of the *j*-th DMU, respectively, *j*=1,2, …, *N* and *j0* denotes the DMU being evaluated. Note that under (9), if it is replaced $\sum_{j=1}^{N} \lambda_j = 1$ by $\sum_{j=1}^{N} \lambda_j \geq 1$, then it is obtained Non-Decreasing Returns-to-Scale (NDRS) envelopment model, alternatively, if it is replaced $\sum_{j=1}^{N} \lambda_j = 1$ by $\sum_{j=1}^{N} \lambda_j \leq 1$, then it is obtained Non-Increasing Returns-to-Scale (NIRS) envelopment model.

Let $\theta^*, \lambda^*_1, \ldots, \lambda^*_N$ be the optimal solution of models (8) and (9), the DMU *j0* is efficient if and only if $\theta^* = 1$ and all slack variables constraints are null. If $\theta^* < 1$

or $\theta^*$ = 1 but existing a positive constraint excess, then, DMU *j0* is inefficient. In this case, the reference set (benchmarks) of the DMU *j0* is composed by the DMUs associated to the coefficients $\lambda^*_j > 0$.

Finally, it is interesting to point out that the envelopment DEA models are very sensitive to the presence of outliers. Thus, in this article, two approaches have been used for detecting outliers: (i) Wilson (1993) method and (ii) Boxplot.

Numerical Results

The first purpose of this section is to identify outliers among the utilities under study. To do so, the information on 60 Brazilian utilities were processed by the FEAR 1.11 (a software library that can be linked to the general-purpose statistical package R) and Boxplot. The FEAR package is available at: http://www.economics.clemson.edu/faculty/wilson/Software/FEAR.

Figures 1 and 2 illustrate respectively the Wilson method (log-ratio plot) and Boxplot.

Figure 1 – Wilson method

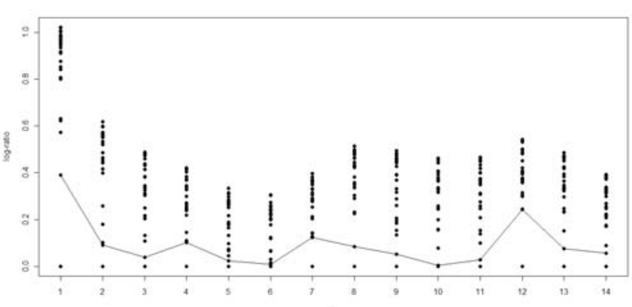
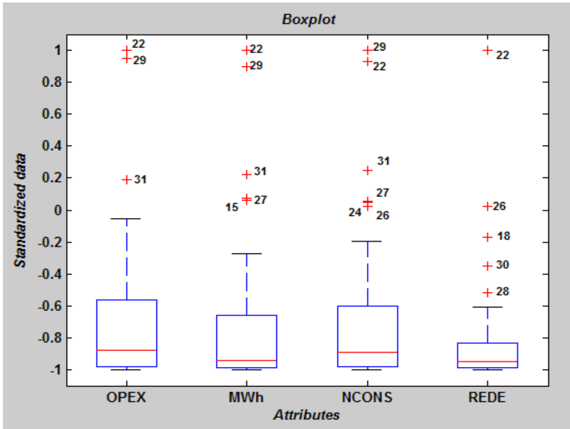


Figure 2 - Boxplot




Based upon Wilson (1993) method, the following utilities have been considered outliers: CEEE, CELPA, PIRATININGA, BANDEIRANTES, CEB, CELESC, CELG, CEMAT, CEMIG, COPEL, CPFL, ELETROPAULO, ENERSUL, LIGHT. With respect to the Boxplot, it has selected as outlier: BANDEIRANTES, CELG, CEMIG, COELBA, COPEL, CPFL, ELEKTRO, ELETROPAULO, ENERSUL, LIGHT.

It is very clear that both the techniques have classified the utilities with the largest markets, with geographical concentration and a strong industrial share of participation. For instance: BANDEIRANTES, CEMIG, COPEL, CPFL, ELEKTRO, ELETROPAULO, ENERSUL, LIGHT.

At this point, as for efficiency evaluation, the utilities were characterized by the 4 attributes marked in Table 2. The products are the cost drivers of the operational costs. The amount of energy distributed (MWh) is a proxy of the total production, the number of consumer units (NCONS) is a proxy for the quantity of services provided and the grid extension attribute (REDE) reflects the spread out of consumers within the concession area, an important element of the operational costs.

Table 2 – Input and Outputs variables

| Type | Variable | Description |
|---|---|---|
| Input (DEA) | OPEX | Operational Expenditure (R$ 1.000); |
| Output (DEA) | MWh | Energy distributed (MWh); |
| | NCONS | Units consumers |
| | REDE | Network Distribution Lenght (Km) |

The measurement of efficiency obtained by the DEA models should express the reduction in operational costs, i.e., it has to do with an input oriented measurement. Denoting the measurements of efficiency by $\theta$, the potential reduction of the operational costs for the i-th utility, i.e., the operational cost recognized by the regulator is equal to a $OPEX_i$ $(1-\theta_i)$.

The DEA models are input oriented, and the OPEX is the unique input. In specifying this model, it was also considered a NIRS model, since the total elasticity $(\mathbf{e})$ is less than 1.

The scores for each of the 60 DMUs resumed in Table 3, was calculated using the DEA Excel Solver (Zhu, 2003). By analyzing the first column of Table 3, it can be observed that nine companies are on the best-practice frontier. Note also that seven were labeled as outliers. Given these results, it is meaningful to develop the sensitivity analysis. So, the Non-Increasing Returns-to-Scale (NIRS) model has been used on both the set of outlier DMUs (16 companies) and the remaining DMUs, as indicated in Table 3 (last column).

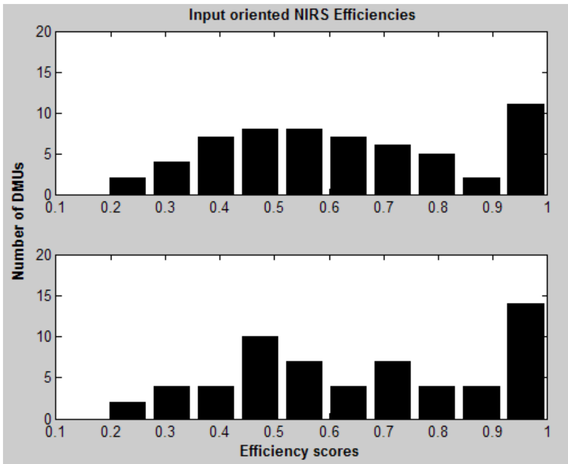
Focusing attention on the efficiencies scores displayed in Table 3, it is worth emphasizing that the performance of inefficient DMUs, which has as efficient peers the outlier companies, is very affected. That is, the average range of efficiency to this set of DMUs is 10% while for others inefficient DMUs it is in a range of 1%.

Table 3 – Efficiency scores ($\theta$i)

| DMU name | Input oriented NIRS Efficiencies | |
|---|---|---|
| AES-SUL | **1,000** | **1,000** |
| CEAL | 0,603 | 0,605 |
| CEEE | 0,273 | 0,295 |
| CELPA | 0,362 | 0,379 |
| CELTINS | 0,377 | 0,457 |
| CEPISA | 0,657 | 0,678 |
| CERON | 0,431 | 0,503 |
| COSERN | 0,832 | 0,835 |
| ENERGIPE | 0,698 | 0,698 |
| ESCELSA | 0,680 | 0,682 |
| MANAUS | 0,381 | 0,381 |
| PIRATININGA | **1,000** | **1,000** |
| RGE | 0,997 | **1,000** |
| SAELPA | 0,881 | 0,889 |
| BANDEIRANTES | **1,000** | **1,000** |
| CEB | 0,287 | 0,314 |
| CELESC | 0,576 | 0,595 |
| CELG | 0,532 | 0,533 |
| CELPE | **1,000** | **1,000** |
| CEMAR | 0,675 | 0,688 |
| CEMAT | 0,458 | 0,485 |
| CEMIG | **1,000** | **1,000** |
| CERJ | 0,744 | 0,744 |
| COELBA | 0,757 | 0,758 |
| COELCE | 0,795 | **1,000** |
| COPEL | **1,000** | **1,000** |
| CPFL | **1,000** | **1,000** |
| ELEKTRO | 0,968 | **1,000** |
| ELETROPAULO | **1,000** | **1,000** |
| ENERSUL | **1,000** | **1,000** |
| LIGHT | 0,856 | 0,856 |
| BOA VISTA | 0,190 | 0,190 |
| BRAGANTINA | 0,433 | 0,433 |
| CAUIÁ | 0,449 | 0,449 |
| CAT-LEO | 0,611 | 0,841 |
| CEA | 0,315 | 0,315 |
| CELB | 0,706 | 0,706 |
| CENF | 0,505 | 0,505 |
| CFLO | 0,521 | 0,521 |
| CHESP | 0,807 | **1,000** |
| COCEL | 0,508 | 0,509 |
| CPEE | 0,516 | 0,536 |
| CSPE | 0,621 | 0,645 |
| DEMEI | 0,621 | 0,621 |
| ELETROACRE | 0,570 | 0,570 |
| ELETROCAR | 0,479 | 0,526 |
| JAGUARI | 0,594 | 0,594 |
| JOÃO CESA | 0,493 | 0,493 |
| MOCOCA | 0,501 | 0,501 |
| MUXFELDT | 0,760 | 0,760 |
| NACIONAL | 0,588 | 0,588 |
| NOVA PALMA | 0,721 | 0,830 |
| PANAMBI | 0,375 | 0,375 |
| POÇOS DE CALDAS | 0,662 | **1,000** |
| SANTA CRUZ | 0,483 | 0,511 |
| SANTA MARIA | 0,573 | 0,719 |
| SULGIPE | 0,812 | 0,915 |
| URUSSANGA | 0,268 | 0,268 |
| V. PARANAPANEMA | 0,398 | 0,407 |
| XANXERÊ | 0,315 | 0,325 |

In order to complete the analysis, Figure 3 depicts the distributions of NIRS efficiency scores. As demonstrated. Initially, most NIRS scores are distributed in [0.4,0.8]. In second analysis, the NIRS scores are almost evenly distributed in [0.2,1].

Figure 3 – NIRS Efficiency Distribution




Conclusion

For the next tariff revision cycles, the Brazilian regulator ANEEL has signalized with the possibility of using DEA models in the estimation of the efficient operational costs, an important element in the determination of the X-factor of the utilities. However, the DEA methodology is deterministic and deviations with respect to the efficient frontier are assumed to be solely due to the utilities inefficiency. Besides, DEA is very sensitive to outliers as it has been shown here. In this manner, it is useful to use the SFA which has a stochastic nature and provides estimates of the efficiency, free of the uncontrollable impacts of random factors that affect the DMUs. Anyway, independently of the adopted method by ANEEL, it is interesting to try the two approaches, as one complements the other and allows a robustness check of the results.

As a final word, on passing through the efficiency indices to the efficient operational costs, ANEEL could adopt a similar criterion as that of the transmission lines, where, at least 80% of the operational costs are recognized. This implies on the following standardization of the efficiency indices (ANEEL, 2007) $\theta_i$ obtained by the two DEA models, before their application in the estimation of the efficient operational costs:

$$\theta_i^* = 0.20 \cdot [\theta_i - \min(\theta_i)]/[\max(\theta_i) - \min(\theta_i)] + 0.80 \quad (10)$$

References


ANEEL. 19/10/2006. Nota Técnica nº 262/2006 – SRE/SFF/SRD/SFE/SRC/ANEEL.

ANEEL. 11/05/2007. Nota Técnica nª 125/2007 – SRE/ANEEL.

ARCOVERDE, F.D., TANNURI-PIANTO M.E. & SOUSA, M.C.S. 2005. Mensuração das eficiências das distribuidoras do setor energético brasileiro usando fronteiras estocásticas, XXXIII Encontro Nacional de Economia, Natal.

BANKER, R.D., CHARNES, A. & COOPER, W.W..1984. *Some Models for Estimating Technical and Scale Inefficiencies*, Management Science 30(9): 1078-1093.

CHARNES, A., COOPER, W.W. & RHODES, E. .1978. *Measuring the Efficiency of Decision Making Units*, in European Journal of Operational Research 2: 429-444.

COOPER, W.W., SEIFORD, L.M., TONE, K..2000. Data Envelopment Analysis, A Comprehensive Text with Models Applications, Reference and DEA-Solver Software, Kluwer Academic Publishers.

JASMAB, T. & POLLIT, M..2000. *Benchmarking and regulation: international electricity experience*, Utilities Policy 9(3): 107-130.

KUMBHAKAR, S.C., LOVELL, C.A.K. . 2000. *Stochastic Frontier Analysis*, Cambridge.

PESSANHA, J.F.M., SOUZA, R.C. & LAURENCEL, L.C..2004. *Usando DEA na avaliação da eficiência operacional das distribuidoras do setor elétrico brasileiro*, XII Congreso Latino-Iberoamericano de Investigación de Operaciones y Sistemas, Ciudad de La Havana, Cuba.

RESENDE, M. .2001. *Relative efficiency measurement and prospects for yardstick competition in Brazilian electricity distribution*, Energy Policy 30(8), June : 637-647.

SOLLERO, M.K.V. & LINS, M.P.E. .2004.Avaliação de eficiência de distribuidoras de energia elétrica através da análise envoltória de dados com restrições aos pesos, XXXVI Simpósio Brasileiro de Pesquisa Operacional, São João del Rei.

SOUZA, M.V.P. .2008. Uma abordagem bayesiana para o cálculo dos custos operacionais eficientes das distribuidoras de energia elétrica, Tese de Doutorado em Engenharia Elétrica, PUC-Rio, Rio de Janeiro.

VIDAL, D.N.A. & TÁVORA JUNIOR, J.L. .2003. Avaliação da eficiência técnica das empresas de distribuição de energia elétrica brasileiras utilizando a metodologia DEA, XXXV Simpósio Brasileiro de Pesquisa Operacional, Natal.

WILSON, P. W. .1993. Detecting outliers in deterministic nonparametric frontier models with multiple outputs, in Journal of Business and Economic Statistics 11: 319-323.

ZANINI, A..2004. Regulação econômica no setor elétrico brasileiro: uma metodologia para definição de fronteiras de eficiência e cálculo do fator X para empresas distribuidoras de energia elétrica, Tese de Doutorado em Engenharia Elétrica, PUC-Rio, Rio de Janeiro.

ZHU, J.. 2003. Data Envelopment Analysis with Spreadsheets and DEA Excel Solver, Springer Science+Business Media, LLC.

# 19. Distribution System Voltage Conversion A way for economic and energetic efficiency and sustainability in distribution utilities

**Daniel González Sarkis, - Rodrigo Maldonado,- Alberto Trigueros, - Bernardo Bravo Méndez**

Chilectra S.A.

Santa Rosa 76, Piso 4, Santiago Chile; Phone (56-2) 675 2653; Fax (56-2) 675 2982 dags@chilectra.cl

Key Words:

Voltage conversion, power distribution economics, power distribution planning.

Power distribution utilities serving high density areas, must confront rising investment costs in feeders that supply its concession zone. In high growing areas this situation is particularly critical, because it is required the construction of many feeders, in insufficient routes.

To solve this problem, it is possible the conversion of the distribution system voltage in some areas of the distribution system, into a higher voltage level, producing technical and economical benefits, especially in high electric density areas.

The voltage conversion of the distribution system is a great complexity project that requires high capital expenditures. To develop this project it is necessary to carry on several technical and economics analyses, such as:

Technical and economic feasibility

Energy efficiency (because of the decreasing energy losses)

Legislation compatibility

Implementation feasibility

Chilectra S.A. has developed these analyses, and nowadays is carrying on this project in the Metropolitan Zone of Santiago City, the capital of Chile. The project has been developed in three particular zones of Santiago. The first stage is based on a 10 year implementation period.

The project is on its second year of implementation, and basically consists in increasing the voltage level from 12 kV to 23 kV in three specific zones.

The main benefit of the project is related to reduce the quantity of feeders constructed in the period, because an equal quantity of energy is delivered in a higher voltage level. In addition, there are other benefits, such as: less routes and ways out for feeders, energy losses reduction, lower voltage drop, and energy sales increasing.

In addition, the project contributes to the sustainability of the distribution business, reducing the visual impact of the feeders in the streets, decreasing the quantity of interventions in feeders, improving the use of distribution routes, and allowing the efficient use of the energy by reducing energy losses.

Introducción

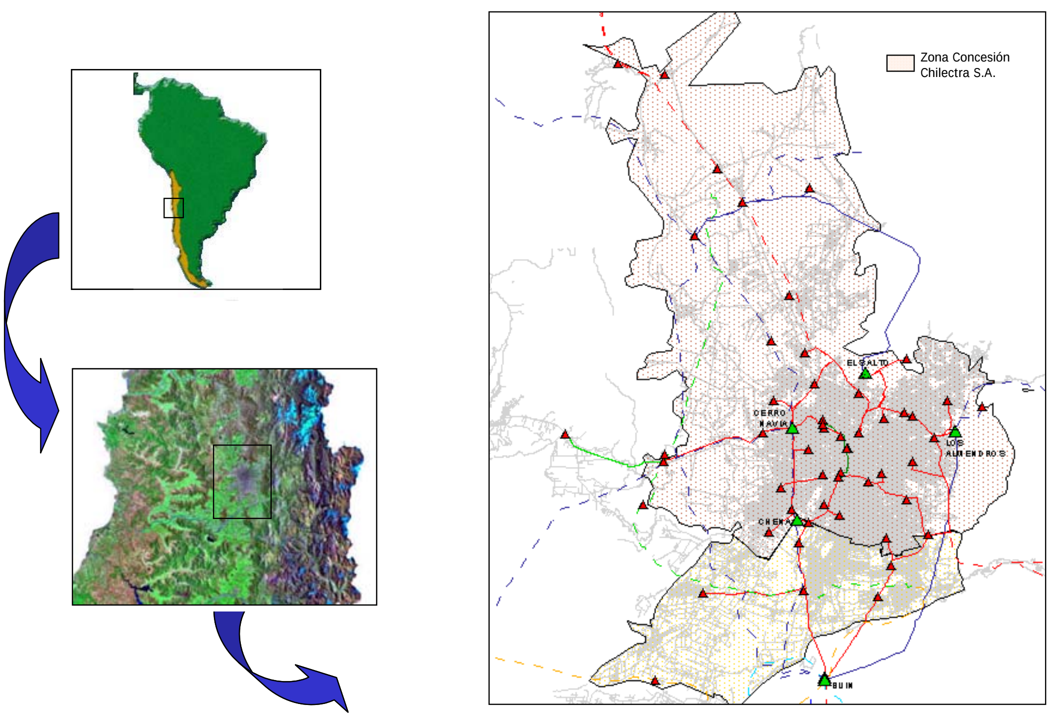
Descripción de Chilectra

Chilectra S.A. es la empresa concesionaria de la distribución de energía eléctrica en la Región Metropolitana de Chile, dando servicio a un mercado constituido por los consumidores finales ubicados en su zona de concesión. La figura 1 muestra la ubicación de Chilectra y su zona de concesión.

Chilectra S.A. cubre un área de concesión de 2.118 km², atendiendo a un total de 1.500.000 clientes. Las operaciones de Chilectra S.A. representan aproximadamente el 44% del mercado distribuidor eléctrico chileno. La demanda máxima que suministra Chilectra es de 2.400 MVA.

Figura 1

Ubicación de Chilectra



Situación actual del desarrollo de redes de distribución en Zonas Urbanas

Las empresas de distribución de energía eléctrica que abastecen zonas urbanas de alta densidad poblacional, deben enfrentar crecientes costos de inversión para la construcción de los alimentadores que abastecen sus zonas de concesión. Esta situación es de especial importancia en sectores con alto crecimiento de demanda, ya que ello exige la construcción de una gran cantidad de alimentadores cada año, a través de escasas vías disponibles en la ciudad.

Como alternativa de solución, surge la posibilidad de redefinir el nivel de tensión de las redes y desarrollar el sistema de distribución en un nivel de tensión mayor, produciendo beneficios técnico-económicos, especialmente en sectores que presentan altos costos de desarrollo de redes.

Un cambio de nivel de tensión es un proyecto de alta complejidad e intensivo en inversiones, cuya materialización requiere del desarrollo de un conjunto de estudios que se relacionan con las siguientes materias:

Factibilidad Técnica

Factibilidad Económica

Eficiencia energética (Reducción de pérdidas)

Compatibilidad con la regulación vigente

Factibilidad de implementación (logística)

Chilectra S.A. ha desarrollado estos estudios y se encuentra impulsando un proyecto de cambio de nivel de tensión para la Región Metropolitana. El proyecto se encuentra en desarrollo en tres zonas específicas de la ciudad de Santiago, considera en su primera etapa de implementación un horizonte de 10 años.

La decisión de cambiar el nivel de tensión para algunas zonas es compleja, ya que el costo de conversión resulta muy elevado con respecto a los beneficios de menores pérdidas, mejor regulación, mayores ventas y menores inversiones en alimentadores nuevos en el corto plazo. La decisión se debe basar en un análisis de desarrollo de largo plazo que evalúe la relación beneficio – costo de realizar esta alternativa, considerando también factores como la congestión de rutas, los problemas de espacios aéreos y subterráneos y los permisos de construcción.

Antecedentes

Problemática General

El actual crecimiento de demanda de Chilectra en el largo plazo, es del orden de un 5% anual. Con esta tasa de crecimiento, se deberá duplicar la cantidad de Alimentadores, en aproximadamente 14 años.

El costo de los alimentadores de Media Tensión se ha ido incrementando en el tiempo, producto de mayores zonas soterradas, requerimientos de calidad de suministro, equipos de operación, permisos viales o municipales, etc.

Además, la construcción de nuevas redes presenta una complejidad creciente, ya que las modificaciones urbanas y viales que se deben realizar mientras se realiza la construcción de los alimentadores son de gran impacto en el entorno.

Por otro lado, las rutas disponibles para la construcción de los nuevos Alimentadores son cada vez más escasas, ya que la gran cantidad de redes produce una saturación de las vías, además de la creciente demanda de rutas para otros servicios, lo que limita la disponibilidad.

Se debe agregar la problemática asociada a la salida de los alimentadores desde las subestaciones de poder. La gran cantidad de alimentadores en algunas zonas ha provocado una alta congestión en la evacuación de la potencia de las subestaciones, ya que muchas de ellas poseen pocas vías a su alrededor capaces de albergar rutas de nuevos alimentadores.

Con respecto a la demanda de la zona de concesión, el efecto de la densificación de los consumos requiere de más potencia eléctrica a inyectar en los mismos sectores geográficos.

Por último, las exigencias municipales y de entes públicos son cada vez más restrictivas, en la construcción e instalación de nuevas obras. Sumado a esto, la construcción de nuevas carreteras en el interior de la ciudad, limita el desarrollo del sistema de distribución, ya que los cruces con estas vías son limitados en cantidad y en sectores muy específicos de las mismas.

En este escenario se debe visualizar a largo plazo la alternativa de desarrollo más conveniente para la zona, desde una perspectiva técnico-económica.

En este ámbito, se han analizado y comparado dos alternativas para el desarrollo de ciertos sectores de la red eléctrica de 12 kV de Chilectra:

Desarrollo del sistema de 12 kV bajo el actual esquema de suministro (todos los alimentadores en 12 kV).

El cambio de nivel de tensión de distribución de algunas zonas, desde 12 kV a 23 kV.

Se ha escogido el voltaje de 23 kV como opción de ampliación de las redes, ya que corresponde al nivel de tensión máximo establecido en la legislación vigente como nivel de distribución de energía, siendo los superiores niveles de transmisión de energía.

Beneficios y desventajas del Cambio de Nivel de Tensión.

La alternativa de cambio del nivel de tensión en sectores específicos de la Compañía puede ser atractiva en un escenario de largo plazo, ya que tiene asociados una serie de beneficios:

Menor cantidad de rutas para alimentadores. Un alimentador en 23 kV podrá entregar una mayor potencia que en el caso de 12 kV, por ende con menor cantidad de alimentadores en 23 kV es posible suministrar la demanda.

Inversiones en subestaciones de poder: Serán necesarias menos posiciones de alimentadores en 23 kV que en 12 kV.

Disminución de pérdidas: Al aumentar el nivel de tensión las pérdidas disminuyen en forma cuadrática con respecto a la relación de tensión.

Mejor regulación de tensión: Para un determinado nivel de consumo, al aumentar el nivel de tensión, la corriente disminuye en forma inversa a la relación de tensión, lo que implica una mejora en la regulación de tensión.

Adicionalmente, el Cambio de Nivel de tensión se enmarca dentro de las iniciativas de sostenibilidad que impulsa Chilectra, ya que:

Existe una reducción del impacto visual de redes en la ciudad, ya que se construyen menos redes en el tiempo.

Uso más eficiente de la energía al reducir pérdidas

Oportunidad de proyecto MDL, por reducción de pérdidas

Menor cantidad de intervenciones en la ciudad

Uso más eficiente de vías de distribución

No obstante, el Cambio de nivel de tensión también presenta algunas desventajas:

Mayor inversión, especialmente al inicio del proyecto.

Incremento en las desconexiones programadas. Las fases iniciales del proyecto requieren realizar muchas intervenciones en las redes.

Coexistencia de zonas de 12 kV y 23 kV: problemas de respaldo, mantenimiento, operación.

Desarrollo de SSEE: Cambio en los planes de desarrollo, etapa híbrida de crecimiento (12 y 23 kV coexistiendo en forma simultánea), diseño de la S/E poder para el respaldo.

El análisis de los beneficios y costos en el tiempo indicará la mejor alternativa de desarrollo del sistema de Distribución.

Zonas de 12 y 23 kV Actuales

Chilectra actualmente cuenta con redes de distribución de 12 y de 23 kV. La zona de 23 kV corresponde principalmente al sector norte de la zona de concesión, denominado “rural”. A continuación en las figuras 2 y 3 se presentan los niveles de tensión de las redes de distribución de Chilectra.

Figura 2

Zona Norte

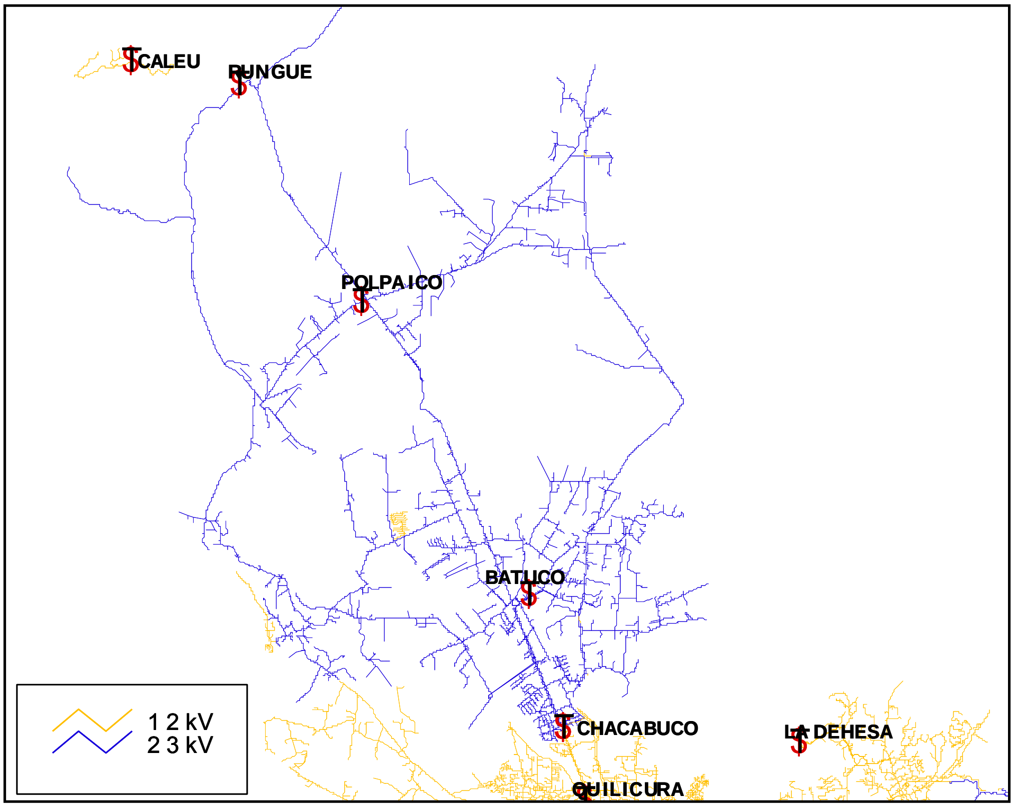
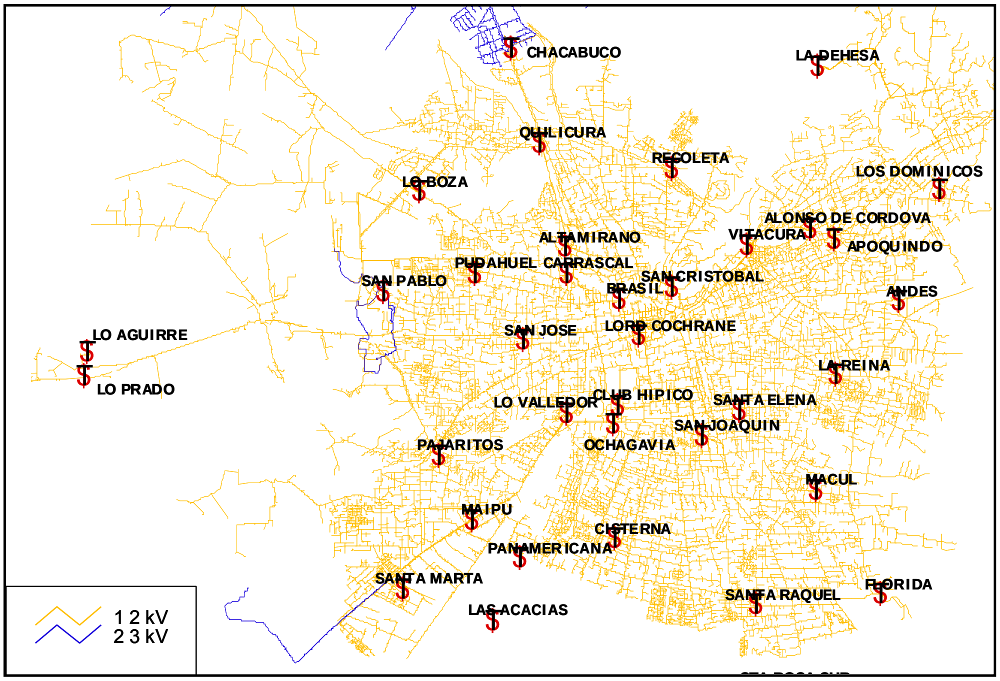



Figura 3

Zona Centro




Política de Adecuación de Instalaciones para el Cambio del Nivel de Tensión

Realizar un cambio de nivel de tensión en una zona determinada, involucra una alta inversión, debido principalmente a los siguientes aspectos:

Se requiere cambiar los transformadores de distribución 12/0.38 kV por otros cuya aislación les permita funcionar al nuevo nivel de tensión. Conjuntamente, aquellos clientes que son propietarios de instalaciones con clase 12 kV provocan un aumento en el costo del proyecto de cambio de tensión, por la necesidad de reemplazar instalaciones privadas, equipos y transformadores particulares a costo de la compañía.

Junto con ello, es necesario modificar o reemplazar las redes eléctricas, esto consiste en aumentar la separación entre conductores aéreos; reemplazar en algunos casos los conductores, al igual que los cables subterráneos.

Los equipos de protección, operación y funcionales existentes, deberán ser modificados por otros de similares características pero clase 23 kV.

Se deben adecuar las subestaciones de poder de modo tal que permitan suministrar energía en el nuevo nivel de tensión y, además, se mantengan los criterios de respaldo que se han establecido.

Para lograr esto Chilectra ha estado preparando las instalaciones de modo tal de adecuar el sistema para 23 kV pero manteniendo el funcionamiento en clase 12 kV, hasta que se desarrolle el proyecto de cambio formal de voltaje.

En base a esta política, se han establecido los siguientes criterios de diseño de subestaciones de poder y alimentadores:

Transformadores de Poder: Se compran unidades que cuenten con doble devanado en el lado de media tensión, esto es, 110/12–23 kV. Esta característica técnica permitirá utilizar el transformador de poder en clase 12 kV mientras las redes se van modificando a clase 23 kV y una vez que la red este preparada para cambiar de nivel de tensión, sólo será necesario cambiar la conexión secundaria del transformador para que cambien su relación de transformación de 110/12 kV a 110/23 kV.

Patio de Media Tensión: Su diseño y los equipos que allí se instalen, deberán tener aislación apta para 23 kV, pero capaces de funcionar en 12 kV, teniendo en consideración los niveles de cortocircuito.

Celdas de Media Tensión: En zonas de Cambio de Nivel de tensión, estos equipos deberán ser de clase de aislación apta para 23 kV, pero aptos para operar en 12 kV.

Alimentadores: Las redes deberán disponer de aislación apta para 23 kV, operables en 12 kV.

Equipos en Alimentadores: Los equipos que se instalen deberán tener aislación apta para 23 kV junto con ser capaces de funcionar en 12 kV, considerando los niveles de cortocircuito.

Transformadores de Distribución: En las zonas potenciales de Cambio de Nivel de Tensión se instalarán transformadores de distribución con doble devanado en el lado de alta tensión, es decir, 23-12/0.38kV.

Aspectos Técnicos del Cambio de Nivel de Tensión.

El nivel de tensión en la distribución de energía eléctrica es de gran importancia en el comportamiento y operación del sistema. La mayor influencia se plasma en el perfil de tensión del alimentador, en las pérdidas y en la capacidad de potencia a transmitir por el alimentador. Por otro lado, al modificar el nivel de tensión de un alimentador, es necesario realizar una serie de modificaciones técnicas para dar cumplimiento a la normativa existente, junto con la reubicación o adaptación de los equipos y transformadores en caso que corresponda.

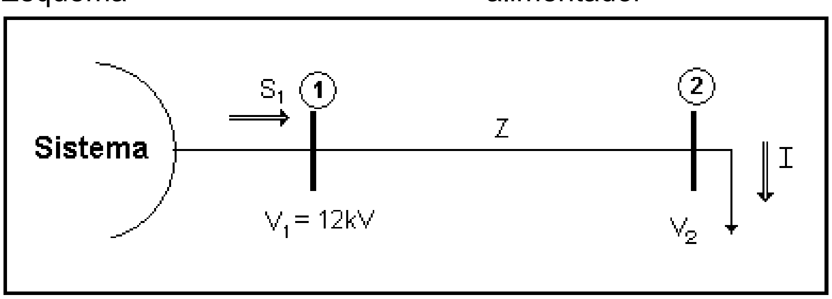
Variación de Corriente.

La capacidad del conductor de transmitir energía es determinada por sus características físicas. Sin embargo, al variar el nivel de tensión, dada una cierta potencia de carga, la magnitud de corriente variará. Por esto, al cambiar el nivel de tensión de las redes de distribución se obtendrá una mayor o menor capacidad de transportar potencia debido al nivel de corriente que circulará por la línea.

Supongamos un alimentador base con carga concentrada en su extremo, como se muestra en la figura 4.

Figura 4

Esquema alimentador base




La potencia transmitida del nudo 1 a 2 viene dada por:

$$S = \sqrt{3} \cdot V_1 \cdot I \qquad (1)$$

Ecuación 19.1

Reemplazando para cada nivel de tensión se tendrán dos situaciones:

Nivel de tensión actual (12 kV)

$$S_{12} = \sqrt{3} \cdot 12(kV) \cdot I_1 \qquad (2)$$

Nuevo nivel de tensión (23 kV)

$$S_{23} = \sqrt{3} \cdot 23(kV) \cdot I_2 \qquad (3)$$

En estas dos posibilidades de operación (12 kV o 23 kV), la magnitud de la corriente que circulará por el alimentador, para transmitir la misma potencia, es decir $S_{12} = S_{23}$, será:

$$I_2 = 0.52 \cdot I_1 \qquad (4)$$

Se aprecia que por el aumento del nivel de tensión de 12 kV a 23 kV y manteniendo la misma potencia consumida, la corriente que circula por el alimentador se reduce casi un 50%.

Capacidad de Transporte

Analizando de forma similar al caso anterior, y considerando la misma corriente por el alimentador, se logra un aumento en la capacidad de potencia que se puede transportar.

$$S_{23} = 1.92 \cdot S_{12} \qquad (5)$$

2

En 23 kV, el aumento en la capacidad de potencia que se puede transmitir por las redes, teniendo en consideración las características técnicas de ellos, es cercano al doble de la capacidad en 12 kV, alcanzando un 92% de aumento.

Pérdidas de Potencia y Energía

En esta sección se analizan las pérdidas que se producen en alimentadores y transformadores de distribución, en relación con el nivel de tensión empleado.

### 3.3.1 Pérdidas en Redes de Distribución de Media Tensión

Las pérdidas de potencia debido al efecto Joule, están directamente ligadas a la corriente que circula por el alimentador y considerando que la carga esta concentrada en su extremo, las pérdidas vienen dadas por

$$P_{perd} = 3 \cdot R \cdot I^2 \qquad (6)$$

Luego

$$P_{P23} = 0.27 \cdot P_{P12} \qquad (7)$$

Así, se logra una reducción en las pérdidas en 23 kV, siendo estas, un 27% de las pérdidas que se producen en 12 kV.

### 3.3.2 Pérdidas en Transformadores de Distribución

Las pérdidas de potencia debido a transformación vienen dadas por la siguiente ecuación

$$\Delta P = \Delta P_{FE} + \Delta P_{CU} \qquad (8)$$

La cual se descompone en dos tipos:

Pérdidas en el núcleo ($\Delta P_{FE}$): Corresponden a las pérdidas en el fierro y se pueden considerar constantes respecto a la variación de carga.

Pérdida en el cobre ($\Delta P_{CU}$): Corresponden a las pérdidas en los enrollados y dependen de la carga. Se calculan por medio de:

$$\Delta P_{CU} = \Delta P_{CUnom} \cdot F_U^2 \qquad (9)$$

Donde:

$F_U$: Factor de utilización ($F_U = P_{carga} / P_{nominal}$)

$\Delta P_{Cunom}$ : Pérdida nominal en el cobre

De acuerdo con la expresión de pérdidas, y de acuerdo con el equipamiento que utiliza Chilectra, se aprecia que:

La pérdida en el núcleo aumenta levemente para las potencias de 150 kVA y superiores, para las unidades con lado de alta tensión de 23 kV.

Las pérdidas en cobre en 23 kV se reducen a un 27% de las pérdidas en 12 kV, por depender del cuadrado del factor de utilización.

Ambos aspectos de las pérdidas deben ser considerados en la valorización final de las pérdidas en las condiciones de cambio de nivel de tensión.

Caída de Tensión

La caída de tensión depende directamente de la corriente que circula por el alimentador. Como se experimenta una disminución en la corriente al elevar el nivel de tensión, se espera una disminución en la caída de tensión.

Para una línea corta, la caída de tensión esta dada por

$$\Delta V = \left(R \cdot \cos\varphi + Xsen\varphi\right) \cdot I \qquad (10)$$

Con esto, al usar las relaciones anteriormente expuestas, la relación entre las caídas de tensión para una operación en 12 y 23 kV, a igual demanda es la siguiente:

$$\Delta V_{23} = 0.52 \cdot \Delta V_{12} \qquad (11)$$

Se aprecia que la caída de tensión disminuye casi al 50% cuando se eleva el nivel de tensión de 12 kV a 23 kV, para una misma potencia de la carga.

Niveles de Cortocircuito

El nivel de cortocircuito del alimentador se verá alterado al realizar el cambio de nivel de tensión. Un parámetro importante de los equipos de protección es el nivel de cortocircuito de la red, por lo cual es necesario, para su adecuado funcionamiento, conocer la nueva corriente de cortocircuito y así dimensionar los equipos e instalaciones para este nuevo nivel.

Al simular, para la misma red (dado que los transformadores de poder se diseñan para operar en 12 ó 23 kV en el secundario), se obtiene que en 23 kV hay una reducción del nivel de cortocircuito a aproximadamente un 52% del valor de 12 kV. Esto es:

Icc 12 kV: 11 kA.

Icc 23 kV: 5.7 kA.

Metodología Constructiva del Cambio de Nivel de Tensión.

Para determinar la estrategia de realización física del cambio de tensión, se debe considerar una serie de factores, tales como:

Proyección de demanda del sector.

Tipo de consumo alimentado.

Capacidad de potencia de la subestación de poder.

Dificultades para la construcción de alimentadores.

Ubicación de la S/E y puntos de respaldo con S/E vecinas, durante el proceso de cambio de voltaje.

Existencia de redes operando en 23 kV.

En la zona de concesión de Chilectra, existen dos sectores de características particulares que deben ser considerados en el desarrollo y construcción de un proyecto de Cambio de Nivel de Tensión: zonas periféricas, zonas centrales.

Características Zonas Periféricas

La mayor parte de ellas presenta dificultad para respaldar carga entre alimentadores vecinos, ya que cuentan con menos puntos de respaldo con otros alimentadores que en zonas centrales, incluso muchas veces los puntos de interconexión son con sólo con un alimentador.

Gran parte de los alimentadores presentan una gran longitud, lo que en algunos casos se traduce en problemas de regulación.

Se presentan dificultades para satisfacer la energía solicitada por algún nuevo gran cliente (Proyectos Inmobiliarios o de Grandes Clientes), debido principalmente a los dos puntos presentados anteriormente, capacidad de respaldo y longitud de alimentadores, así como por una menor capacidad de reestructuración de las redes.

Mayor cantidad de clientes industriales que los sectores interiores de la zona de concesión.

Características Zonas Centrales

Fuerte concentración de carga. La menor cantidad de industrias en el sector interior de la zona de concesión, da paso a un número mucho mayor de clientes (pero de menor consumo individual), que en su mayoría son residenciales, comercio y pequeñas industrias.

Consecuencia de la alta concentración de carga, generalmente al momento de construir o modificar las redes de distribución, estos sectores presentan mayores problemas de rutas disponibles para extender las redes, permisos municipales para efectuar los trabajos y su respectivo horario, entre otros.

Dado que los alimentadores y la propia Subestación de poder tienen puntos de apoyo en todo su alrededor, se presenta una mayor capacidad de respaldo en comparación con zonas periféricas. Esta condición provee a la red de mayor flexibilidad para maniobrarla en caso de incorporación de nuevos clientes, contingencias en la red o desconexiones programadas.

Respaldo entre redes con distinto nivel de tensión

Para tener puntos de respaldo entre redes de distinto nivel de tensión (en este caso, 12 kV y 23 kV), la mejor opción es la utilización de bancos de autotransformadores.

La instalación de estos equipos es complicada por dos aspectos:

El gran espacio que se requiere para la instalación. El tamaño del conjunto alcanza una longitud de 12 metros.

La contaminación visual que provocan.

Debido a las dificultades que existen en la instalación de estos equipos, y considerando que ellos son vitales para crear puntos de respaldos en redes de distinto nivel de tensión, es más conveniente iniciar el cambio de nivel de tensión desde los sectores periféricos, en donde, por un lado se deberían encontrar menores obstáculos para la instalación de los bancos de autotransformadores (dificultades Municipales, Espacio, Vecinos, etc.)

Complementariamente, se podrían construir redes de 23 kV que nazcan en la periferia y que vayan penetrando paulatinamente el sector de 12 kV, siempre manteniendo niveles de respaldo apropiados para cada nivel de tensión, entre redes de un mismo nivel de voltaje.

De esta manera, se ha definido realizar el Cambio de Nivel de tensión en los sectores periféricos de la zona de concesión de Chilectra, para luego, en etapas posteriores continuar el desarrollo hacia el centro de la zona de concesión[63].

Bajo esta condición, llevar a cabo el cambio de voltaje es más sencillo y se realizaría con la construcción de un nuevo alimentador 23 kV desde las subestaciones existentes de la periferia que poseen este nivel de tensión, o bien instalando nuevas unidades de transformación de 23 kV.

Este nuevo alimentador de 23 kV paulatinamente quitará carga a las redes de 12 kV, principalmente a sus derivaciones y ramas terminales en una primera etapa, para continuar con las troncales e interconexiones en etapas posteriores.

Así, el nivel de tensión 23 kV “avanza” hacia la zona de 12 kV en forma paulatina, debiéndose mantener siempre los niveles de respaldo en cada voltaje.

---

[63] Además, se deben cumplir distintos criterios para la selección de la zona a realizar, los que se explican más adelante en el documento.

De esta manera, se evitan desconexiones reiteradas en un sector específico, además de reducir la utilización de autotransformadores para mantener el suministro, siendo considerados sólo como alternativa de respaldo si es la única opción.

La longitud del alimentador clase 23 kV aumentará en la medida en que él tome carga de las redes de 12 kV, ante lo cual, será necesario además prestar atención a la regulación de tensión en el alimentador. La ampliación de la zona de 23 kV debe realizarse estrictamente cumpliendo los requerimientos de demanda de las zonas en cambio.

De no existir redes de 23 kV en los sectores periféricos escogidos, como opción al uso de autotransformadores, se debiera realizar la construcción simultánea de al menos dos alimentadores de 23 kV para garantizar los niveles de respaldo entre redes de igual voltaje.

Este esquema permite descargar las redes de 12 kV, manteniendo las troncales de este voltaje, disminuyendo los tiempos de desconexión, las obras adicionales para el respaldo durante la construcción, y la instalación de autotransformadores.

Metodología de Evaluación para Determinar Plan de Inversiones

La optimalidad económica de las obras en el sistema transformación – distribución se debe visualizar desde un punto de vista de largo plazo, considerando distintos planes de obras que permitan satisfacer los requerimientos de la demanda del sistema en forma integral.

Para lograr esto Chilectra utiliza un algoritmo de optimización, que genera como resultado un plan de desarrollo de obras a largo plazo, tanto en transformación como en distribución, seleccionando las obras de menor costo de inversión y operación, que son capaces de satisfacer las necesidades del sistema.

Con las obras propuestas por el algoritmo de optimización se verifica que se cumplan los criterios de planificación definidos por Chilectra en todo el sistema. Con todo esto, se definen las obras en los sistemas de transformación y distribución, y que corresponden a un óptimo global que considera los diferentes criterios de planificación utilizados.

Para el análisis del cambio de nivel de tensión, se analizarán zonas actualmente abastecidas en media tensión en el voltaje de 12 kV. Las alternativas de desarrollo que se plantean consisten en la posibilidad de:

Alternativa Convencional

Continuar el desarrollo del sector en 12 kV, cumpliendo los criterios de respaldo y calidad establecidos por la Compañía. Se consideran:

Construcción de nuevos alimentadores

Ampliación de las Subestaciones de Poder de los sectores.

Alternativa Cambio de Nivel de Tensión.

Esta alternativa consiste en:

Instalar unidades de transformación 110/23 kV en las subestaciones de poder, o eventualmente reemplazar las 110/12 kV existentes. Se deben considerar además los requerimientos de respaldo en SSEE de poder.

Construir nuevos alimentadores 23 kV en la zona

Cambiar el nivel de tensión de los alimentadores 12 kV existentes.

En esta alternativa de desarrollo, el cambio de transformadores de distribución (T/D) y de equipos de distribución de 12 a 23 kV es uno de los costos más significativos, sin embargo, tiene el beneficio que los T/D y equipos recuperados pueden ser utilizados para abastecer el crecimiento de la demanda en 12 kV de otros sectores.

Para la correcta evaluación económica del proyecto se deben considerar muy detalladamente los siguientes componentes de costos para la cuantificación de la inversión requerida:

Extensión, Refuerzo y Reemplazo de aislación aéreo

Extensión, Refuerzo subterráneo.

Obras Civiles

Equipos y transformadores de distribución a cambiar de tensión.

Con respecto a los costos de operación y mantenimiento, el abastecimiento de la demanda con alimentadores de 12 kV tiene un valor mayor que con alimentadores de 23 kV (en sectores con los respectivos niveles de tensión), debido al efecto de las pérdidas y a la mayor cantidad de alimentadores para distribuir la misma demanda. Estos efectos deben ser apropiadamente cuantificados y considerados en la evaluación.

No obstante, los alimentadores de 23 kV que se desarrollan en sectores de 12 kV son de mayor costo de inversión (por MVA instalado) en las fases iniciales, ya que además se debe realizar el cambio del nivel de tensión de redes existentes.

El horizonte de evaluación del proyecto se considera en 20 años, de modo de considerar los beneficios del Cambio de Nivel de Tensión, los que son más fuertes hacia el final del período de evaluación, y que principalmente están dados por el ahorro en la construcción de alimentadores en 12 kV.

Determinación de Zonas a Desarrollar el Proyecto

Si bien el análisis del cambio de nivel de tensión puede desarrollarse a todo el sistema actualmente en 12 kV, se reconocen sectores en que la decisión de cambio resulta prioritaria. Estos sectores presentan algunas de estas características:

Problemas de salida de alimentadores desde las subestaciones de poder.

En varias de las subestaciones de la Compañía se deben realizar nuevas canalizaciones para la salida de los alimentadores. Estas nuevas canalizaciones pueden corresponder en algunos casos a un túnel para la evacuación de los cables de salida.

Además, varias subestaciones presentan pocas calles a su alrededor para la salida de los alimentadores, en varios casos se cuenta sólo con una calle de salida. Esto provoca una congestión de las rutas, y en muchos casos la necesidad de construcción de obras civiles de gran extensión para la evacuación subterránea de alimentadores.

Estas limitaciones en la salida de los alimentadores obligan a la realización de altas inversiones para lograr evacuar la potencia de las subestaciones.

Problemas de rutas de alimentadores

Los sectores que concentran una alta cantidad de alimentadores presentan una natural congestión de rutas. Además, la disponibilidad de las mismas disminuye con el tiempo, ya sea por los mismos alimentadores construidos o bien, por otros servicios que se posicionan en los posibles trazados de alimentadores.

Esta congestión de rutas afecta directamente sobre el costo de los alimentadores, puesto que los trazados que se utilizan se alejan de los que son más eficientes, por estar ocupados. Adicionalmente, la ocupación de rutas conlleva la subterranización de redes, impactando fuertemente sobre el costo de desarrollo.

Además de la disponibilidad de rutas, es un hecho que en los sectores más congestionados las obras en alimentadores resultan más complejas, por el gran impacto vial que ocasionan. Por otro lado, los permisos municipales para ejecutar las obras son de mayor costo.

Alimentadores de gran extensión

Existen sectores que abastece Chilectra que presentan alimentadores de largas extensiones.

Lo anterior se explica por factores como: ausencia de subestaciones en las cercanías de los centros de carga, baja densidad de las zonas, conjuntos de clientes alejados de los centros de consumo.

Estos alimentadores típicamente presentan problemas de calidad de suministro:

Problemas con la regulación de tensión

Pocos puntos de respaldo de redes, lo que acarrea mayores indisponibilidades de servicio ante fallas en la red.

Tiempos de reparación de fallas mayores a los usuales, por las distancias a recorrer y a la mayor cantidad de redes que deben ser revisadas para detectar las fallas.

Además, el costo de nuevos alimentadores en estos sectores se ve aumentado por las extensiones que deben ser cubiertas, y además las pérdidas en ellos son comparativamente mayores por las misma razón.

Altos crecimientos

Los altos crecimientos de los requerimientos de los clientes provocan el natural aumento de las instalaciones de distribución para su suministro.

Se visualizan dos casos:

*Altos crecimientos en zonas que se están consolidando*: En este caso se produce la construcción de nuevos alimentadores, que implican gran porcentaje de extensión de redes. Los alimentadores se posicionan en sectores con muy pocas o sin redes existentes.

*Altos crecimientos en zonas ya consolidadas*: usualmente en estos casos los altos crecimientos significan grandes bloques de potencia demandada adicional al sistema, ya que una zona consolidada en general posee una alta densidad y alto consumo.

En este caso se realiza una construcción sostenida en el tiempo de nuevos alimentadores, cuyo desarrollo está asociado en gran medida a refuerzos de redes y reestructuraciones de carga. Lo anterior acarrea altos costos de desarrollo por congestión de rutas, constantes trabajos en las mismas zonas, saturación de salidas, etcétera.

Zonas con factibilidad técnica de cambio de nivel de tensión

Además de los factores anteriores, las zonas en que se comience a realizar el cambio de nivel de tensión, deben presentar las factibilidades técnicas siguientes:

Posibilidad de interconexión de redes mientras duren los trabajos, ya que el reemplazo es gradual necesitándose de realimentaciones mientras se desarrollan las obras.

Existencia de potencia en transformación en SSEE de poder aledañas durante los trabajos, ya que posiblemente parte de la carga será traspasada de una S/E a otra mientras duran las obras.

Posibilidad de respaldo en 23 kV luego de realizado el cambio de tensión.

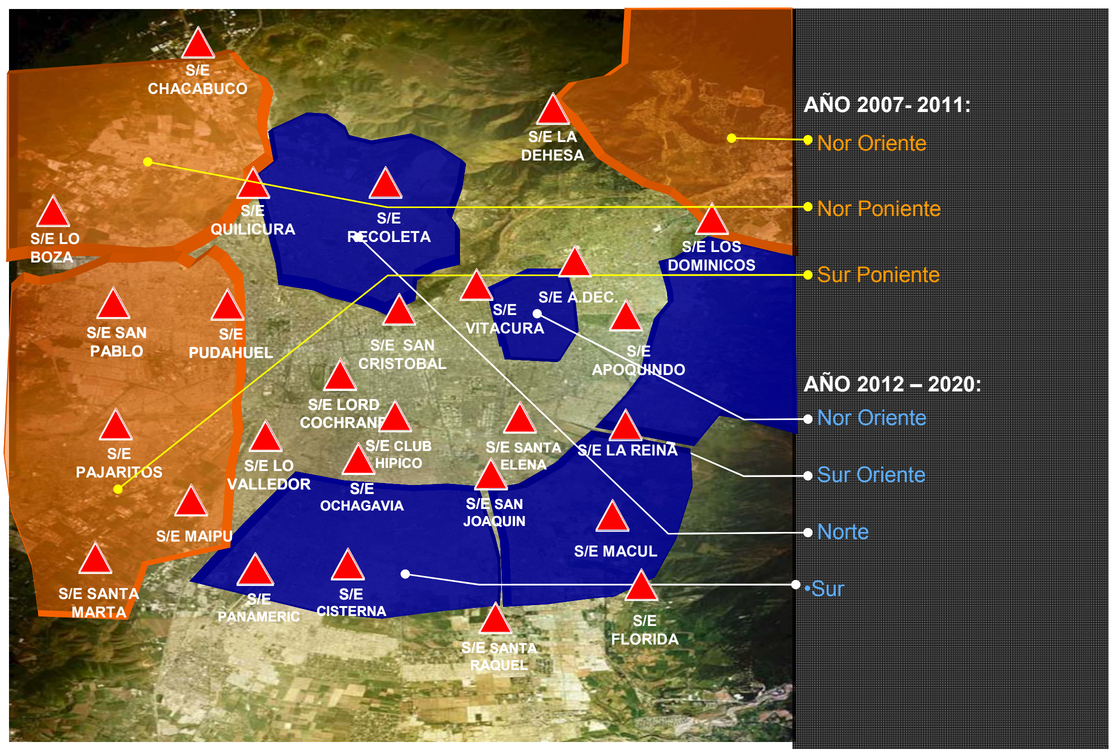
A lo anterior es posible agregar la mayor facilidad constructiva en los sectores que ya poseen redes con aislación en 23 kV, o bien colindan con zonas de 23 kV.

De esta manera, al considerar los aspectos anteriores, es posible definir las zonas prioritarias para el Cambio de Nivel de Tensión. En cada una de ellas se deberá evaluar técnico-económicamente la conveniencia de desarrollar el proyecto.

La figura 5 muestra los sectores definidos como prioritarios en Chilectra y el período de comienzo del proyecto en cada una de ellas.

Figura 5

Sectores Prioritarios a Desarrollar el Proyecto



Planes de Obra para las Zonas Analizadas

Tal como se ha mencionado, en las zonas seleccionadas se ha simulado su operación y desarrollo en 20 años, determinando las mejores opciones técnicas económicas de expansión conjunta de Subestaciones de Poder y de alimentadores para las dos alternativas mencionadas:

Alternativa Convencional

Continuar el desarrollo del sector en 12 kV, cumpliendo los criterios de respaldo y calidad establecidos por la Compañía.

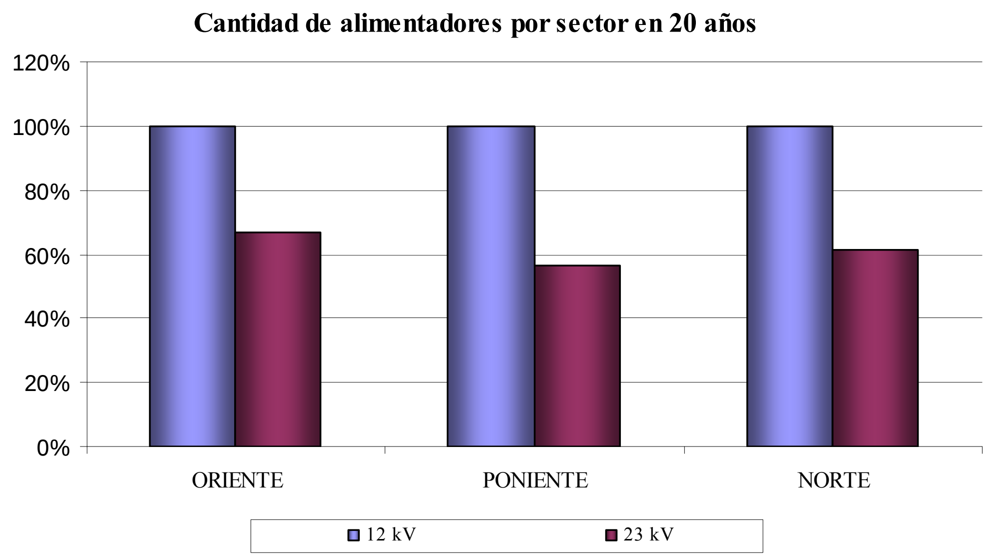
Alternativa Cambio de Nivel de Tensión.

Desarrollar sectores específicos de Chilectra cambiando el voltaje de distribución de 12 kV a 23 kV, tal como se explicó anteriormente.

De esta manera, los resultados de la evaluación son los siguientes:

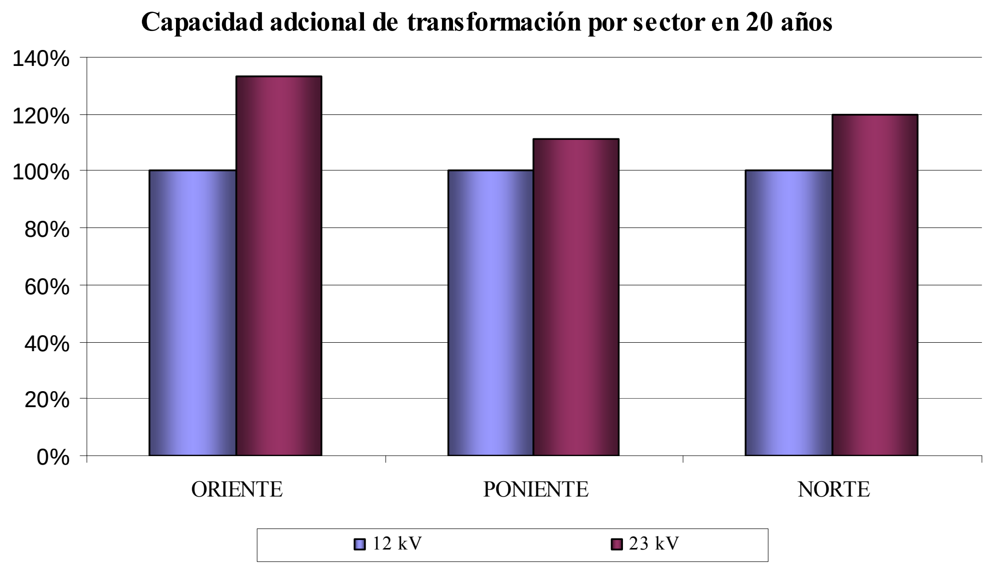
La simulación a largo plazo indica que en 20 años se deben construir en promedio por zona, un 65% más de alimentadores en 12 kV respecto de los alimentadores 23 kV. Esta componente de la evaluación resulta ser la principal en el ahorro de costos de este proyecto. Estos resultados se muestran en la Figura 6.

Figura 6



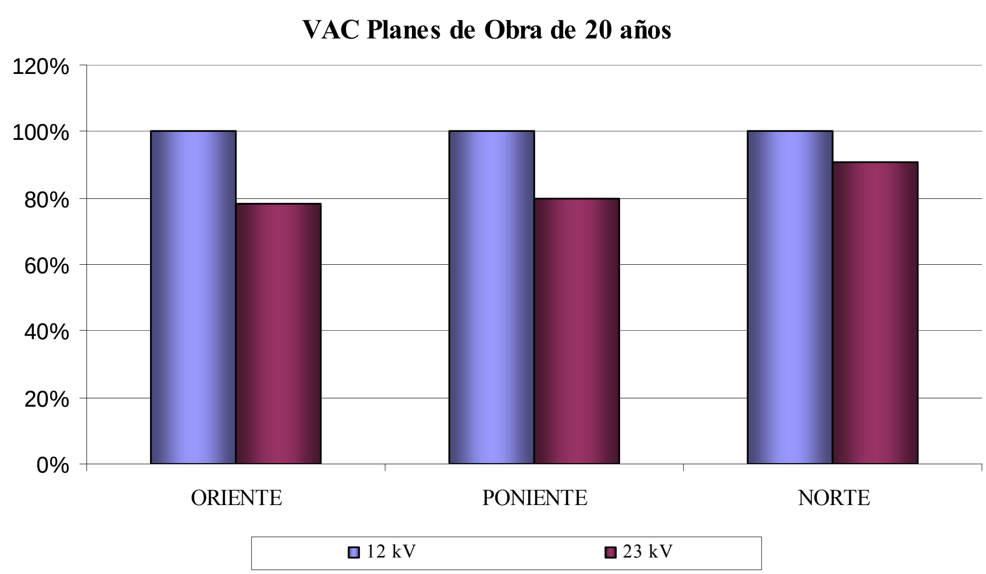

Con respecto al plan de obras en subestaciones de poder para 23 kV, el plan indica la instalación de más transformadores respecto al Plan de 12 kV como se puede ver en la Figura 7, debido a las unidades de transformación de respaldo que deben ser considerados para subestaciones que presentarán los dos niveles de tensión. En promedio se debe instalar un 20% de capacidad adicional en transformadores de poder en la opción de cambio de tensión.

Figura 7




Finalmente, se aprecia en la Figura 8 que el cambio de Nivel de Tensión es aproximadamente un 18% más conveniente en VAC que su alternativa en 12 KV para cada zona.

Figura 8



De esta manera se observa que al comparar las alternativas de desarrollo, resulta más conveniente en el largo plazo realizar el cambio de nivel de tensión de los sectores en consideración.

Avance actual de las obras de Cambio de Nivel de Tensión en Chilectra.

El proyecto se encuentra en desarrollo hace 2 años en las tres zonas específicas de la ciudad de Santiago que se han mostrado, y considera en su primera etapa de implementación un horizonte de 10 años.

A la fecha ya se han realizado obras de cambio de tensión de redes que han implicado:

220 MVA Instalados en Transformación AT/MT.

84 MVA Capacidad Nominal en Alimentadores.

87 MVA Instalados en Transformadores de Distribución.

COMENTARIOS FINALES

Para enfrentar la creciente complejidad y costos de crecimiento del sistema de distribución en zonas urbanas, el aumento del nivel de tensión de las redes surge como una alternativa de desarrollo del sistema, que además produce beneficios económicos, especialmente en los sectores con altos costos de desarrollo.

Al comparar las alternativas de desarrollo en sectores específicos, resulta más conveniente en el largo plazo realizar el cambio de nivel de tensión, siendo el principal beneficio la menor cantidad de alimentadores que se construyen en el tiempo en comparación con la alternativa de desarrollo en 12 kV.

Para complementar la visión de desarrollo de la red, y como siguientes etapas de este proyecto, Chilectra está analizando los futuros sectores de cambio de niveles de tensión, además de determinar nuevas tecnologías que sean eficientes para ello, junto con nuevos procedimientos y criterios para la distribución, considerando las necesidades de los clientes y los requerimientos legales, municipales y medioambientales.

# 20. Entering Rural Electrification Cooperatives into the Regulated Market: Policies and Prices

**Carmen Silvia Sanches - Erick Elysio Reis Amorim**

Carmen Silvia Sanches

Agência Nacional de Energia Elétrica - ANEEL
cssanches@aneel.gov.br

Erick Elysio Reis AMORIM

Universidade de Brasília – UnB, Agência Nacional de Energia Elétrica – ANEEL

erick@aneel.gov.br

Agência Nacional de Energia Elétrica – ANEEL

SGAN 603, Módulo J, Brasília, DF, 70830-030 Brazil

Tel: 55 61 2192-8291, Fax: 55 61 2192-8679

KEYWORDS: utilities pricing, economic regulation, rural electrification cooperatives

ABSTRACT: The rural electrification cooperatives arose in Brazil in the beginning of the 40´s, in the South of the country, by the initiative of small population *nuclei*. Initially intending to provide electricity for small towns or residences in isolated areas, the cooperative system expanded, such as in other countries, in many cases due to the natural growth of the countryside and cities. In fact, the development of the country gave them opportunities to attend consumers neglected by utility companies because building power lines was considered unprofitable or difficult to access. In this manner, rural electrification

cooperatives could expand their activities and, in some cases, act as electricity utilities, although their *status quo* in the electricity sector was barely a consumer of local supplier utilities.

The Brazilian Electricity System reform initiated in the middle of 90´s, characterized by the privatization process and market regulation, brought new opportunities to the rural electrification cooperatives. Despite the sector monopolistic structure and the existence of the economies of scale, the Brazilian legal choice was for the maintenance of the rural electrification cooperatives. More than this: it was allowed the change of their legal *status*, from consumers to agents, inserting them into the regulated market. So, the legislator brought to the regulation authority an additional challenge, which was to build a price regulatory structure that could conciliate the diversity of existing cooperatives and the complexity of the electricity sector. For this, it was necessary to implement a transition process, adapting the typical regulatory instruments (to say, price levels, price structures and price regimens) to the economic regulation principles in Brazil: price moderateness, incentives to the economic efficiency and maintenance of the agents' economic and financial balance. Also, additional subsidies were conceded to the rural electrification cooperatives so they could deal with new obligations and investments. In the short time, it meant an additional financial burden to the local distribution system and its consumers. Nonetheless, the expected results are positive, involving not only the compatibility of the legislative choice with the permanence of the economic regulation principles, but also the respect to the equality and the rights of consumers as citizenships - for taking quality assurances to "new" consumers, as well as the existence of an organizational diversity allowing that diversified economic structures coexist in the electricity sector.

## 1.- Introdução

As cooperativas de eletrificação rural, no Brasil, surgiram no início da década de 1940, por iniciativa de pequenos núcleos populacionais, no sul do país, tendo como objetivo gerar energia elétrica para pequenas localidades ou residências em áreas isoladas. Com avanços na legislação agrária, bem como na regulamentação do setor elétrico e dos serviços de eletrificação rural, na década de 60, verificou-se uma expansão do sistema de eletrificação rural por cooperativas em várias regiões do país. Além do mais, em muitos casos, o crescimento natural, tanto do campo, como das cidades, propiciou oportunidades para o atendimento a consumidores que não eram atendidos, normalmente localizados em regiões com dificuldade de acesso ou de baixa lucratividade para as empresas de distribuição de energia elétrica. Dessa forma, as cooperativas de eletrificação rural se expandiram e, até o início da década de 1990, com o foco da atuação "levar a energia ao campo", ou seja, eletrificar o maior número de propriedades possível – pois esse foi o objetivo de sua criação.

Com a reforma do Sistema Elétrico Brasileiro, iniciada na metade dos anos 1990, que promoveu a desverticalização do setor e a privatização de empresas públicas, também se adotou medidas complementares, como a regulação por incentivos e a regularização do status jurídico das concessões. Nesse contexto, também ficou prevista a compatibilização das áreas concedidas às empresas distribuidoras com as áreas de atuação de cooperativas de eletrificação rural e o reconhecimento do atendimento "de fato" a público indistinto, localizados em área urbana e rural.

Assim sendo, em atendimento às determinações legislativas que datam de 1995 (anteriores à criação da agência brasileira de regulação de energia elétrica, a ANEEL, em 1996), a ANEEL vem implementando ações necessárias à regularização das cooperativas.

O processo de regularização das cooperativas de eletrificação rural iniciou-se de fato em 2000, com a adoção de uma série de atos administrativos da ANEEL que estabeleceram as condições e os procedimentos gerais a serem adotados. Foram identificadas, até o momento, em todo o Brasil, 53 cooperativas passíveis de serem regularizadas como permissionárias. Estas cooperativas – a grande maioria das cooperativas de eletrificação rural em operação na atualidade - prestarão serviço público de energia elétrica, tendo, como característica, o atendimento, de fato, a público indistinto, localizado em área urbana e rural. Serão, portanto, agentes do setor elétrico e, nessa condição, terão tarifas de suprimento (compra) e de fornecimento (venda) homologadas pela ANEEL, bem como uma série de direitos e obrigações definidos no contrato de permissão. Além do mais, terão uma área de atuação definida, para prestação dos serviços de distribuição de energia elétrica – o que explica também a necessidade de regulação das (novas) cooperativas permissionárias, ou seja, porque passarão a atuar como monopólios naturais, que é uma característica do setor elétrico.

As regularizações ocorreram a partir de junho de 2008 e, desde então, já foram concedidas 27 outorgas de permissão.

2.- Incentivos e Expansão das Cooperativas de Eletrificação Rural: comparativos internacionais e o Brasil

Historicamente, o modelo dominante de expansão das redes de eletrificação nos países em desenvolvimento envolveu as grandes empresas publicas de distribuição, financiadas por subsídios cruzados, embutidos nas tarifas dos clientes, ou por aportes governamentais. No caso da eletrificação rural, a administração da maioria dos planos também esteve a cargo de empresas públicas centralizadas, sendo subvencionados pelos governos uma vez que os altos custos desses planos não poderiam ser cobertos pelas tarifas. Isto devido aos altos riscos e custos de transação relacionados aos baixos rendimentos rurais, que poderiam ocasionar problemas de acessibilidade econômica, à pouca densidade da população, às dificuldades de terreno e ao baixo consumo, de forma que a execução dos planos costumava (e continua a) ser mais onerosa nas zonas rurais que nas urbanas. Além disso, as grandes distâncias representam maiores perdas de eletricidade e os serviços ao cliente e a manutenção dos equipamentos são mais caros na área rural. Assim, muitas vezes houve a necessidade de subvencionar os projetos de eletrificação rural para que fossem financeiramente viáveis (RAY, 2001; REICHE ET AL., 2006).

Em muitos desses países, a participação de outros agentes no processo de eletrificação rural também foi – e tem sido - uma alternativa viável. Nesses casos, os mecanismos de financiamento são os mais diversos, embora recaindo especialmente nos mecanismos de natureza financeira, como o crédito subsidiado e o micro crédito, além da participação de comunidades organizações não governamentais e da iniciativa privada, na implantação de infra-estrutura local em pequena escala, muitas vezes sob uma coordenação institucional complementar do governo ou organismos internacionais. Isto para não mencionar o papel dos subsídios na ampliação do acesso à eletricidade no campo (CECELSKI, 2000; REICHE et al., 2006).

No caso do Brasil, ambas as alternativas foram adotadas. De um lado, o setor público subvencionando diretamente a eletrificação rural no interior do país, mediante a implementação de projetos por empresas públicas distribuidoras de energia elétrica (OLIVEIRA, 2001). De outro, fomentando a participação e a expansão do movimento cooperativista, em um movimento amplo, especialmente a partir de 1970, com a implantação do Programa Nacional de Eletrificação Rural, cuja coordenação incluía o GEER - Grupo Executivo de Eletrificação Rural das Cooperativas (PELEGRINI, 2003).

Ainda que na década de 80 os incentivos às cooperativas começassem a reduzir e as próprias distribuidoras passassem a implantar diretamente seus programas de eletrificação rural – por ser politicamente mais vantajoso -, permaneceram ativas um grande número de cooperativas de eletrificação rural no Brasil. Em geral, prestando um serviço público, em uma área de atuação mais ou menos definida. De qualquer forma, a eletrificação rural foi devidamente telada pelo poder público e mesmo pelas concessionárias que, desinteressadas pelo mercado rural e mesmo pelos programas próprios de eletrificação rural, não realizaram esforços para frear a expansão das cooperativas onde elas já tinham uma atuação significativa (JUCÁ, 2007).

Nesse ponto, observa-se que um dos principais instrumentos utilizado para a viabilização da eletrificação rural de certa forma também foi aplicado às cooperativas de eletrificação rural – o subsídio cruzado. A viabilização mais recente, mesmo com a contenção tarifária para controle da inflação a partir da década de 80, deu-se pelo fornecimento de energia das distribuidoras estatais, com desconto às cooperativas, de 50% até 85% do valor aplicado a consumidores de tensão equivalentes, recaindo o ônus em parte aos consumidores locais – prática que se mantém até a atualidade.

3.- O Caso Brasileiro: perfil das cooperativas na atualidade

O perfil das cooperativas permissionárias é bastante variado, começando pela origem. São 53 cooperativas permissionárias, das quais 13 de São Paulo, 21 de Santa Catarina, 12 do Rio Grande do Sul, 2 do Paraná, 4 do Rio de Janeiro e apenas 1 do Nordeste – de Sergipe. Ou seja, são predominantemente do Sul do país, onde a tradição do cooperativismo é mais forte e onde houve um forte desenvolvimento, com modificação de áreas rurais em urbanas.

Quanto ao porte das cooperativas, os dados relativos a 2006 indicam que a menor cooperativa, que é do PR, possui até 491 unidades consumidoras, enquanto a maior, do RS, atende 44.190 unidades consumidoras. A maior parte desses consumidores atuais são cooperados (quase 100%). Esse perfil, porém, deverá mudar já que o que caracteriza uma cooperativa a permissionária de outras (autorizadas, que permanecerão como consumidores) é o atendimento a público indistinto.

Um quadro geral, considerando dados do ano de 2006, é o seguinte:

Tabela 1 – Cooperativas de eletrificação rural, por número de consumidores em 2006.

| nº de consumidores | Quantidade de cooperativas |
|---|---|
| Até 1.000 | 5 |
| Entre 1.000 e 5.000 | 20 |
| Entre 5.000 e 10.000 | 12 |
| Entre 10.000 e 21.000 | 13 |
| Maiores que 21.000 | 3 |

Como comparação, tem-se que a menor distribuidora de energia do Brasil, e que não é cooperativa, que é a João Cesar, do RS, que atendeu 2.326 consumidores em 2006. Outras distribuidoras do porte das maiores cooperativas são a CJE - Jaguari e a CLFM - Companhia Luz e Força Mococa, ambas no interior de São Paulo – com cerca de 35.000 consumidores.

O mercado (em MWh) das cooperativas variou de 4.855 MWh até 235.631 MWh em 2006. No total, foram 2.010.409,40 MWh de fornecimento e 445.596 unidades consumidoras nesse mesmo ano. A receita auferida com a distribuição de energia no período, de cada cooperativa, variou de US$ 495 mil a US$ 23.638 mil, totalizando uma receita agregada de cerca de US$ 243,1 milhões em 2006[64]. Em termos comparativos, isso representou cerca de 1,3%

[64] Dólar médio utilizado para o ano de 2006: R$ 2,17/US$.

do mercado e 0,6% da receita das supridoras naquele perídio (distribuidoras que fornecem energia às cooperativas).

Quanto ao perfil dos consumidores, tem-se que cerca de 44% são consumidores rurais e 28%, consumidores residenciais. O restante contempla o setor público (iluminação pública), comércio e indústria. Apesar de uma pequena participação no total das unidades consumidoras, o setor industrial é a principal aposta das cooperativas para seu crescimento futuro.

4.- Abordagem Política x Econômica

Do ponto de vista da regulação, a existência das cooperativas no mercado regulado não seguem a lógica econômica. Mas, a despeito da existência das economias de escala e de alcance do setor elétrico, a escolha legal foi pela manutenção da existência das cooperativas de eletrificação rural, bem como pela alteração do status jurídico - de consumidores para agentes - daquelas que tivessem o atendimento “de fato” a público indistinto, localizados em área urbana e rural. Restou à agência reguladora a construção de um arcabouço regulatório que lidasse com os desafios relacionados, especialmente os de natureza tarifária, e que considerasse também a diversidade de características das cooperativas e a própria complexidade do setor elétrico – o que está em andamento (este é o desafio da agência reguladora).

Uma dificuldade quanto à existência das cooperativas é que gozam de benefícios econômicos, como subsídios na compra de energia, benefícios estes que são suportados pelos consumidores da distribuidora de energia local. No caso das cooperativas permissionárias, estão sendo dados descontos adicionais na compra de energia, na “entrada do mercado regulado”, descontos estes que começarão a ser retirados dentro de cerca de 6 anos, com extinção em até 10 anos, a fim de promover a busca pela eficiência econômica. Enquanto isso, mantém-se o subsídio cruzado atualmente vigente.

O processo de regularização foi lento e bastante difícil, especialmente nas fases iniciais e no estabelecimento das políticas tarifárias e de qualidade. Esse relacionamento está bastante aperfeiçoado na atualidade, especialmente no estabelecimento do atual formato do contrato de permissão, onde consta inclusive o atendimento à legislação cooperativista, se couber.

## 5.- Regulação Econômica da Distribuição de Energia

O arranjo para a geração de energia é potencialmente competitivo, mas a distribuição de energia, por meio das redes, é um monopólio natural e deve continuar sendo regulada (SULVAJES & TIJOTA, 1998). Isso se deve uma vez que o monopólio natural ocorre, como o próprio nome sugere, quando em um mercado, a competição não é possível ou é indesejável. Em uma indústria que ocorre monopólio natural, o custo médio de produção é minimizado quando há apenas um produtor.

É importante ressaltar que a determinação se uma indústria é monopólio natural depende da interação da demanda pelo serviço e da tecnologia empregada. Na indústria de distribuição elétrica, economias de escala são uma constante. Quando ocorrem economias de escala, o custo médio diminui quando aumenta a produção, e é condição suficiente para um monopólio natural. As economias de escala implicam que o custo de construir uma rede duplicada, incluindo seus postes, fios e condutores, são indícios bastantes forte que a construção uma segunda rede de distribuição não é custo-eficiente. Dessa forma, a eficiência em termos de custo requer uma única firma. As forças do mercado, entretanto, não irão trazer o resultado socialmente desejado. Portanto, na presença de economias de escala significativas, a racionalidade da regulação será o de controlar o poder de mercado do monopolista[65].

Outra característica que enfatiza a necessidade de regulação para esse tipo de indústria é a necessidade de se realizar grandes investimentos, que muitas vezes são *sunk costs.* De fato, os ativos específicos adquiridos pela empresa de distribuição de energia não encontram uma valor alternativo relevante em qualquer outra indústria.

---

[65] No caso do monopolista, a indústria é monopolista tanto no sentido normativo quanto positive. Enquanto economias de escala limitam o numero de empresas da indústria, a existência das mesmas não implicam necessariamente que haverá apenas um produtor (CHURCH & WARE, 2000)

Nesse tipo de indústria, o objetivo principal do regulador é determinar uma tarifa que fixe o nível adequado de oferta de serviço, de investimentos e que seja socialmente aceito e lucrativo para a firma que presta o serviço.

## 6.- Regulação econômica no Brasil

A regulação econômica das tarifas de distribuição elétrica em vigor no Brasil é baseada no modelo de regulação por incentivos de preços máximos (*price-cap*). Para os custos de compra de energia, é dado total reconhecimento, uma vez que tais custos dependem da oferta e demanda de energia, não sendo, portanto, da capacidade gerencial da empresa de distribuição de energia.

Para os custos de gerenciável da empresa são definidos alguns parâmetros para incentivar a eficiência da empresa. Os principais parâmetros são a Empresa de Referência, o Fator X e o WACC (*Weighted Average Cost of Capital*).

A empresa de referencia consiste em definir os "custos operacionais eficientes" da firma, que sejam aderentes às reais condições geo-econômicas do ambiente no qual a empresa desenvolve sua atividade de prestação dos serviços de distribuição de energia elétrica. Para dirimir os efeitos da assimetria de informação são apenas utilizados dados gerais da empresa, como numero de consumidores, mercado. Dessa forma, esse parâmetro não utiliza as informações da firma para definir os custos operacionais eficientes.

O Fator X [66] é necessário no caso do serviço de distribuição de energia elétrica, no qual a evolução tecnológica é gradual (diferentemente de setores como o de telecomunicações), pois ganhos de produtividade projetados têm como causa principal alterações na escala do negócio. Durante o período tarifário se produzirão incrementos nas vendas da empresa, tanto pelo maior consumo dos clientes existentes (crescimento vertical) como pela incorporação de novos clientes na área servida (crescimento horizontal). Esse incremento nas vendas será atendido pela empresa com custos incrementais decrescentes com relação aos definidos no reposicionamento tarifário. Esse ganho de produtividade do negócio, que não decorre de uma maior eficiência na gestão

---

[66] Para maiores detalhes sobre o fator X no setor elétrico brasileiro, ver ANEEL (2008).

da concessionária distribuidora, deve ser repassado aos consumidores mediante a aplicação de um redutor do índice que reajusta o componente gerenciável da receita (IGP-M), e esse redutor consiste no Fator X.

Por último, o regulador também define a taxa de retorno adequada para ser aplicada sobre a base de remuneração regulatória. Define-se o WACC, com base em fatores previamente definidos como estrutura ótima de capital, taxa livre de risco, e os riscos inerentes ao negócio, como risco cambial e regulatório. Esse enfoque busca proporcionar aos investidores um retorno igual ao que seria obtido sobre outros investimentos com características de risco comparáveis. Em resumo, se trata de considerar na tarifa uma remuneração que corresponda exclusivamente ao custo de oportunidade do capital do investidor.

7.- Definição da Tarifa da Cooperativa.

Como mostrado na seção anterior, os parâmetros para incentivar a eficiência na regulação da distribuição de energia no Brasil são: Empresa de referencia, Fator-X e WACC ótimo sobre a base regulatória da empresa.

Para as cooperativas de eletrificação rural, uma vez que as mesmas não estavam no Mercado regulado, não havia dados auditados em que a ANEEL poderia utilizar para construir os parâmetros de eficiência normalmente utilizados. Foi necessário, portanto, uma forma alternativa para possibilitar a entrada dessas cooperativas no mercado regulado.

De fato, CHURCH & WARE (2000) argumentam que, quando o regulador não tem certeza sobre os custos da unidade e da efetividade dos investimentos na redução de custos, a superioridade da regulação por preços máximos sobre a regulação por custo de serviço desaparece. Aumento na incerteza no que diz respeito à ocorrência dos choques ou na efetividade da redução de custos com investimentos reduzem o poder de incentivo da regulação do preço máximo. O quanto menor a previsibilidade sobre os custos ocorridos, maior terá de ser a tarifa de preço máximo que o regulador terá que fixar, para garantir a lucratividade do negócio.

Tendo essas dificuldades em mente, o regulador escolhe aceitar os custos incorridos dos componentes gerenciáveis da cooperativa, bem como a taxa interna de retorno já em curso. O referido processo de definição da tarifa começou no ano de 2005. Na época, o regulador escolheu o ano de 2003 como período base para o calculo dos custos operacionais, bem como da taxa de retorno do investimento. Para tanto, observou-se a receita real da cooperativa com o serviço de distribuição de energia elétrica ($TR_{2003}$). Desse valor, reduziu-se o valor com compra de energia para revenda ($EE_{2003}$), definindo esse resultado como Custo Gerenciável da Firma (CGC), conforme equação 1.

$$CGC = TR_{2003} - EE_{2003} \qquad (1)$$

onde,

CGC é o Custo Gerenciável da Cooperativa (R$)

$TR_{2003}$ é a receita real da cooperativa com o serviço de distribuição de energia elétrica, em 2003 (R$)

$EE_{2003}$ é a despesa com compra de energia para revenda, em 2003 (R$)

Dentro do CGC, o regulador supôs que os custos gerenciáveis da firma e a taxa de retorno sobre o investimento eram suficientes para a cooperativa manter a cooperativa funcionando, realizar os investimentos necessários e ainda pagar lucro para os acionistas[67]. Essa suposição traz algumas conseqüências regulatórias, uma vez que o regulador abriu mão de qualquer mecanismo para fixar parâmetros de eficiência neste momento do processo. É claro que, com a definição de um preço máximo, há o incentivo de reduzir custos para apropriar mais a renda adicional.

Outro desafio para o regulador era definir uma estrutura tarifária, uma vez que não existia dados sobre os custos marginais da distribuição de energia, tampouco os fluxos de energia na rede. Para resolver esse obstáculo, assumiu-se que a estrutura tarifaria seria a mesma da empresa supridora de energia para a cooperativa. Por exemplo, se uma cooperativa do rio de janeiro

---

[67] Umas das características das Cooperativas de Eletrificação Rural é que, como cooperativas, os donos das firmas são, via de regra, os mesmos usuários do serviço. Portanto, podemos assumir que o objetivo da cooperativa não é o de maximizar o lucro. Ressalta-se que isso não significa que o lucro seja zero, uma vez que os usuários podem almejar resultado positivo para realizar outros tipos de séricos, como projetos sociais para a comunidade.

comprasse energia da distribuidora local AMPLA, a estrutura tarifária seria a mesma para ambas.

O mecanismo de definição de tarifa aplica-se sobre o mercado da cooperativa em 2003 (Mi), a tarifa da supridora[68] (pi) para atingir a nova receita da cooperativa. A lógica desse mecanismo era verificar qual que seria a renda da cooperativa em 2003, se a mesma já fosse regularizada e estivesse praticando o mesmo nível de preços da sua supridora. Do lado do dispêndio, foi calculado qual seria a despesa com compra de energia para revenda, sob um regime regulado, sobre os mesmo montantes de energia comprada em 2003 (Ei). Cabe ressaltar que, mesmo em um Mercado regulado, a cooperativa continua comprando energia com uma tarifa subsidiada (qi). Por último, se a cooperativa fosse um agente do setor em 2003, teria que pagar encargos setoriais. Esse mecanismo está representado na equação abaixo.

$$k1\Sigma piMi - k2\Sigma qiEi - S = MCA \qquad (2)$$

onde,

pi = tarifa da supridora (R$/MWh)

Mi = Mercado da cooperativa em 2003 (Mwh)

qi = tarifa de compra de energia (R$/Mwh)

Ei = Compra de Energia para revenda (Mwh)

ki é um parâmetro de ajuste, e k1=k2=1 no instante t=0.

A nova receita, menos os novos gastos e os encargos setoriais é novamente os gastos gerenciáveis da firma. Dessa vez, entretanto, não foi usado nenhuma informação da firma para compor esse custo. O valor resultando é o custo Gerenciável da Firma a ser ajustado (CGA). Uma vez que o CGA é diferente do CGC, e o regulador assumiu que o CGC era o nível de custo apropriado para a Cooperativa, o objetivo principal do mecanismo de definição de tarifas é fixar uma tarifa de fornecimento e uma de compra de energia que permita à

---

[68] É evidente que quando usados os valores de um outro ano (2007, por exemplo) é aplicado sobre o mercado de 2003, deflaciona-se para o nível de 2003. Nesse caso, utilizou o IGP-M para levar aos preços de 2003.

cooperativa receber o valor do CGC em valores de hoje. Ou seja, é necessário igualar o CGC ao CGA, ou seja, igualar (1) e (2).

Para atingir tais resultados, o regulador impôs dois parâmetros de ajuste na fórmula (k1 e k2). Com base nesses parâmetros, o regulador adotou uma seqüência de procedimentos para atingir CGC=CGA. Primeiramente, permite que o preço final para os consumidores da cooperativa sejam até 20% maiores que o da sua supridora ($k_1$=1,2). Se com esse ajuste não se atingiu a igualdade desejada, permitiu-se conceder descontos sobre o preço da energia comprada até o limite de 80% ($k_2$=0,2).

$$TR_{2003} - EE_{2003} = k_1 \Sigma piMi - k_2 \Sigma qiEi - S \qquad (3)$$

onde,

1º passo, $1 \leq k1 \leq 1{,}2$

2º passo, $1 \geq k2 \geq 0{,}2$

8.- Conclusão

A manutenção do fornecimento de energia pelas cooperativas a seus consumidores, foi uma decisão política e não econômica. O legislador reconheceu a importância das cooperativas no processo de eletrificação rural brasileiro. Nesse contexto, a regulação se torna importante uma vez que considera os usuários de energia dessas cooperativas como verdadeiros consumidores, com direitos e obrigações definidos.

Não obstante, muitos desafios ainda permanecem no tocante à regularização dessas cooperativas. Em termos tarifários, espera-se que depois de se tornarem agentes regulados, o regulador tenha disponíveis dados auditados para construir parâmetros que induzam a eficiência da firma, notadamente no que se refere aos custos operacionais e à taxa de retorno adequada, levando em conta os aspectos particulares das cooperativas. Ainda dependendo dos dados, é necessário definir uma adequada estrutura tarifaria, por meio dos respectivos custos marginais da distribuição.

Entretanto, é necessário reavaliar as cooperativas como uma indústria com características de monopólio natural. A suposição de monopólio natural está fortemente relacionada com o de economias de escala, e uma vez que muitas dessas cooperativas possuem baixa densidade de clientes, a falta de economias de escala pode ocasionar em uma tarifa bastante elevada em um ambiente sem subsídio.

Cabe lembrar que, segundo REICHE et al.(2006), para casos como os das cooperativas de eletrificação rural, é necessário que se adote medidas simplificadoras, uma vez que o custo de adquirir informações confiáveis, por meio de fiscalização, pode ser muito custoso tanto para o regulador quanto para o regulado. O desafio principal para o regulador, portanto, é achar um método de regulação econômica que alcance os princípios de eficiência desejados, ao mesmo tempo que seja simples e teoricamente correto.

## 9.- Referências


ANEEL. 2008. Nota Técnica no. 352/2008-SRE/ANEEL.

CECELSKI, E. 2000. *Enabling Equitable Access to rural electrification: Current Thinking and Major Activities in Energy, Poverty and Gender*. The World Bank, Asia Alternative Energy Unit, Briefing Paper prepared for a Brainstorming Meeting on Asia Alternative Energy Policy and Project Development Support: Emphasis on Poverty Alleviation and Women.

CHURCH, J.; R. WARE. 2000. *Industrial Organization: A Strategic Approach.* Boston: Irwin cGraw-Hill.

JUCÁ, A.S., 2007. O Custo da regularização das cooperativas de eletrificação rural como permissionárias de serviço público de distribuição de energia elétrica. Escola Politécnica da Universidade de São Paulo (POLI-USP), Monografia de MBA.

OLIVEIRA, L.C. 2001. Perspectivas para a Eletrificação rural no novo cenário econômico institucional do setor elétrico brasileiro. Universidade Federal do Rio de Janeiro – UFRJ, Tese de mestrado.

PELEGRINI, M.A. 2003. *A regulação das cooperativas de Eletrificação Rural*. Escola Politécnica da Universidade de São Paulo- POLI-USP, Tese de Doutorado.

RAY, T. 2001. A*mpliación de la Electrificación Rural* – estudio de algunas iniciativas innovadoras. World Bank Publications.

REICHE, K.; B. TENENBAUM; C.T. DE MÄSTLE. 2006. *Electrification and Regulation: Principles and a Model Law*. The World Bank, Energy and Mining Sector Board Discussion Paper no. 18.

SALVANES, K.,; S. TIJOTTA. 1998 . Test for Natural Monopoly with Application to Norwegian Electricity Distribution. *Review of industrial Organization* 13.

# 21. O impacto da introdução do sistema de medição centralizada no Brasil na redução de perdas energia elétrica

**José A. Scaramucci*, Rodnei Fagundes Dias** e Taiana Fortunato Araújo*****

*Coordenação Geral de Estudos Estratégicos e Informação, da Diretoria de Inovação e Tecnologia (Ditec) do Instituto Nacional de Metrologia, Normalização e Qualidade Industrial (Inmetro) e Núcleo Interdisciplinar de Planejamento Energético (NIPE) – Universidade Estadual de Campinas (Unicamp); jascaramucci@inmetro.gov.br

**Coordenação Geral de Estudos Estratégicos e Informação, da Diretoria de Inovação e Tecnologia (Ditec) do Instituto Nacional de Metrologia, Normalização e Qualidade Industrial (Inmetro); rdias@inmetro.gov.br

***Coordenação Geral de Estudos Estratégicos e Informação, da Diretoria de Inovação e Tecnologia (Ditec) do Instituto Nacional de Metrologia, Normalização e Qualidade Industrial (Inmetro); tfaraujo@inmetro.gov.br

Rua Santa Alexandrina, 416 – Anexo Sesao – Rio Comprido, CEP: 20.261-232 Rio de Janeiro, RJ, Brasil. Tel.: +55 21 2563-5570 / Fax: +55 21 2563-5579

Palavras-chave: Avaliação de impacto; eletricidade, perdas comerciais; medição centralizada

O setor elétrico brasileiro vem se ampliando para assistir o crescimento econômico do país. Entretanto, o suprimento de energia ainda é sujeito a grandes perdas comerciais, que se constitui em um dos fatores de maior importância no cálculo do reajuste das tarifas de energia elétrica. Se comparados com outros países europeus ou mesmo latino-americanos, as perdas comerciais verificadas no setor elétrico brasileiro são significativamente superiores. A medição centralizada vem sendo adotada por algumas

concessionárias de distribuição com o propósito de minimizar as perdas comerciais de energia elétrica, através de um sistema remoto que as possibilita monitorar em tempo real o consumo de eletricidade, efetuar cortes e re-ligações a distância e detectar esquemas de fraude pelos consumidores, como desvios de energia ("gatos") e adulterações de equipamentos. Este artigo pretende investigar como a metodologia de avaliação de impacto pode ser aplicada para avaliar as conseqüências econômicas e sociais da introdução de sistemas de medição centralizada no Brasil.

Key-words: Impact assessment, electricity, commercial loss, automatic meter reading

The electric sector in Brazil is expanding to support its economic growth. However, energy supply is still subject to a great deal of losses, which is an important factor in the scheme used by the government for fixing electricity tariff rates. Commercial losses of electricity are significantly higher in Brazil than in other parts of the world, including Latin America. Automatic meter reading has been adopted by Brazilian power utilities as an attempt to reduce commercial losses by means of a remote system which allows them to monitor electricity use in real time, impose or reverse punitive cutoffs and detect fraud schemes perpetrated by consumers, such as energy stealing and device tampering. This work aims at investigating how impact assessment methods can be applied to evaluate the economic and social consequences of introducing automatic meter reading in Brazil.

## 1.- Introdução

O setor elétrico brasileiro vem se ampliando em virtude da necessidade do aumento da capacidade no fornecimento de energia, fundamental para a continuidade do crescimento econômico do país. A partir da década de 1990, essa ampliação baseou-se no investimento privado com a separação dos segmentos de geração, transmissão, distribuição e comercialização e, sobretudo, com as privatizações do setor.

O programa de privatização foi bem sucedido nos setores de distribuição e comercialização onde, em 2001, 90% das empresas tinham sido vendidas a grandes grupos americanos e europeus; em compensação, à mesma época, 80% da geração e transmissão de energia elétrica permaneciam concentradas em empresas estatais (Mello, 2008), situação que se mantém atualmente.

A partir de 2002, as empresas estatais voltaram a ocupar espaço na realização de investimentos no setor, especialmente com a mudança de postura do governo, interrompendo o processo de privatizações. Assim, o governo passou a priorizar a regulação e o planejamento integrado do setor (*Ibid*, 2008). Prova disso é a licitação de novos projetos para a construção de hidrelétricas na região norte, como a Usina de Santo Antônio que, depois de concluída, terá capacidade de fornecer 2.144 MW por ano, ao custo de R$ 9 bilhões.

Em contraposição a esta expansão, o setor elétrico nacional tem sofrido significativas perdas comerciais[69] nos últimos anos, como foi apontado em recente relatório do Tribunal de Contas da União (TCU, 2008). Tais perdas se constituem como um dos fatores de maior influência no aumento da tarifa de energia para o consumidor.

Embora de extrema importância, a quantificação das perdas comerciais é difícil de ser realizada e, por isso, seu cálculo é obtido de maneira residual, através da diferença entre as perdas globais e as perdas técnicas (Aranha Neto *et. al*., 2008). Dados de 2008 mostram que, no Brasil, a perda total de energia elétrica é da ordem 16% de toda a energia produzida sendo que, em média, 50% dessas perdas podem ser classificadas como perdas comerciais. No entanto, esse percentual é bastante heterogêneo entre as diversas regiões brasileiras, sendo função direta, dentre outros fatores, da complexidade social e urbana[70] e da concentração de carga[71] das diversas áreas (Aranha Neto *et. al*., 2008; Vieiralves, 2005).

Ao contrário do senso comum, furtos e fraudes não estão apenas associados aos consumidores de baixa renda, mas também é verificado, em grande escala, na classe média e alta, no comércio, nas empresas e indústrias.

Com exceção da fraude e do furto, as demais modalidades estão sob o controle das concessionárias e, conforme regulamentação da ANEEL, devem ser alvos de políticas internas de gestão da qualidade e inovação de processos. As fraudes e os furtos são decorrentes de fatores exógenos ao sistema elétrico e fogem ao controle gerencial das empresas distribuidoras. A fraude é a alteração no funcionamento do equipamento de medição provocando a redução no registro do consumo tal como a troca das ligações que faz o disco eletromecânico girar, o tombamento do equipamento, entre outras. As fraudes têm se sofisticado, acompanhando os desenvolvimentos

---

[69] Perdas comerciais ou não-técnicas podem ser definidas como a energia efetivamente entregue à determinada unidade consumidora, mas que, por algum motivo, deixa de ser faturada. Além da energia não medida, as perdas comerciais incluem também outras perdas de receita ocorridas durante o processo de comercialização, como furtos de energia ("gatos"), erros de medição no processo de faturamento, além de unidades consumidoras sem equipamentos de medição.

[70] Um índice de complexidade social foi desenvolvido a partir de um estudo encomendado pela empresa Ampla junto à Fundação Getúlio Vargas (FGV) e a Universidade Federal Fluminense (UFF). Este índice relaciona as perdas observadas nas áreas de concessão com as taxas de urbanização, a quantidade de mortes por agressão, a proporção de residências em "favelas", de residências com rede de água e esgoto para determinar o grau de complexidade social de cada uma das áreas onde a concessionária atua (Araújo, 2007).

[71] Quanto menor a concentração de carga, menor o incentivo das concessionárias ao investimento e fiscalização do sistema de distribuição de energia e maior a facilidade para o furto ou fraude (Aranha Neto *et. al*., 2008).

técnicos dos medidores. Na tecnologia eletrônica, as fraudes são refinadas, de difícil e complexa detecção (*Ibid*, 2008; *Ibid*, 2005).

A terceirização da mão-de-obra para a leitura e manutenção dos medidores de energia, indiretamente acaba por ser um mecanismo propulsor das fraudes, na medida em que, o empregado, muitas vezes mal remunerado ou após sair do emprego, aprende a tecnologia para a manutenção ou o método de leitura e verificação de fraude, utilizando esse conhecimento adversamente aos interesses das empresas distribuidoras Esses indivíduos atuam através da venda de serviços ilícitos de adulteração dos medidores, aceitando subornos para anotar um consumo menor do que o verificado ou para fazerem "vista grossa" às fraudes encontradas, entre outros métodos (*Ibid*, 2005).

O furto é a subtração de energia elétrica das redes das concessionárias sem que haja a medição, com prejuízo para as distribuidoras. O furto é realizado por meio de ligação clandestina, desvio de energia, entre outras maneiras[72] (*Ibid*, 2005). Vale apontar que a fraude e o furto são culturalmente aceitos no Brasil, principalmente nas comunidades de baixa renda que se "sentem" no direito de consumir a energia e não pagar por tal. A cultura da fraude/furto e da impunidade não permite o funcionamento de um controle social eficiente. Existe certa tolerância por parte da vizinhança com as fraudes ou furtos realizados, mesmo que essas atividades possam trazer tanto danos físicos (como incêndios provocados por curtos-circuitos, entre outros) como econômicos, uma vez que o custo das fraudes/furtos acaba recaindo na composição tarifária paga por todos os consumidores, independente da categoria de tensão consumida.

Na comparação com outros países europeus ou mesmo latino-americanos, as perdas comerciais verificadas no setor elétrico brasileiro são significativamente superiores. A tabela a seguir apresenta os resultados das perdas de energia entre alguns países selecionados.

Tabela 2

Tabela 1 - Perdas do setor elétrico de alguns países selecionados

| Empresa | Perdas Técnicas | Perdas Comerciais | Perdas Totais |
|---|---|---|---|
| Chilectra – Chile (2007) | 5,0% | 0,9% | 5,9% |

[72] A Resolução nº 456/2000 da ANEEL dispõe sobre as condições gerais de fornecimento de energia elétrica, define como devem ser as relações comerciais entre as concessionárias e as unidades consumidoras e disciplina a questão das perdas não técnicas, considerando as fraudes e furtos como "procedimentos irregulares". Nesta resolução, são previstas sanções administrativas a serem aplicadas pelas concessionárias no intuito de combater as perdas decorrentes destas irregularidades.

| | | | |
|---|---|---|---|
| Condensa – Colômbia (2007) | 8,1% | 0,6% | 8,7% |
| Eldenor – Peru (2007) | 6,0% | 2,1% | 8,1% |
| Edesur – Argentina (2007) | 6,8% | 3,9% | 10,7% |
| Brasil (2008) | 8,0% | 8,0% | 16,0% |
| União Européia (1996) | - | - | 4,7% |

Fonte: Ampla, TCU (2008) e Aranha Neto (2008). Elaboração própria

Dada à complexidade e os tipos de perdas, na tentativa de reduzir de modo significativo e sustentável as perdas comerciais, as concessionárias têm aliado várias ações como: instalação de máquinas antifurto, medição eletrônica, centralizada ou não, instalação de sentinelas, inspeções técnicas, acompanhamento do histórico de faturamento de cada unidade consumidora na busca de alterações significativas em relação ao histórico, entre outras (Vieiralves, 2005).

As perdas comerciais, além de serem de difícil controle e combate, têm ocasionado uma redução no faturamento das concessionárias do setor elétrico brasileiro, o que incentiva as empresas a buscarem tecnologias de medição de consumo mais eficientes[73]. Uma das alternativas apresentadas pelas próprias empresas para a redução destas perdas, verificadas por fraudes e furtos, tem sido a implantação de um sistema de medição centralizada[74].

A medição eletrônica[75], centralizada ou não, tem como vantagens, vis a vis à medição eletromecânica, uma maior precisão no consumo medido quando comparado com a medição eletromecânica, isto é, uma redução nas perdas técnicas. Ademais, a medição eletrônica centralizada possibilita funções

---

[73] Eficiência diz respeito à capacidade de alcance dos objetivos desejados com um mínimo dispêndio de recursos possível. Isto é, a avaliação da eficiência perpassa a comparação de benefício e custo (Marinho e Façanha, 2001).

[74] A medição eletromecânica é uma tecnologia tradicional, com mais de 120 anos de mercado e socialmente aceita. Ao longo dos anos, a tecnologia de medição de consumo de energia foi sendo aprimorada, até mesmo para atender às necessidades de ser mais robusta a fraudes e furtos. No início dos anos de 1990, surgem as versões híbridas (eletromecânica e eletrônica) de medição e o posterior desenvolvimento do medidor totalmente eletrônico e, em 1992, do medidor eletrônico de dupla tarifa . O medidor eletrônico de dupla tarifa tem dois relógios que contabilizam o consumo com diferenciação de tarifas. Ou seja, permite que em períodos pré-fixados um ou outro relógio (com tarifas diferentes) registre o consumo que é somado posteriormente. Do medidor eletrônico de dupla tarifa, o progresso tecnológico ocorreu no sentido do desenvolvimento da medição eletrônica com telecomando e, posteriormente, centralizada, com patente registrada, em 1992, no Brasil, Canadá, Estados Unidos e países da Europa pelo Centro de Pesquisas de Energia Elétrica – CEPEL, do Grupo Eletrobrás. O CEPEL realiza pesquisa e desenvolvimento, que resultaram em diversas patentes depositadas no Brasil e no exterior, nas áreas de automação de sistemas, otimização energética e meio ambiente, instalações e equipamentos elétricos, sistemas elétricos, eficiência energética e materiais. Conta com cerca de 200 pesquisadores e 90 técnicos, que dispõem de uma estrutura de 30 laboratórios. Maiores informações estão disponíveis no endereço http://www.cepel.br.

[75] O primeiro medidor eletrônico de energia homologado pelo Inmetro é do ano de 1994, referente à portaria Portaria INPM/Nº 150, de 14 de dezembro. O Inmetro é o órgão responsável pela regulamentação da atividade metrológica no Brasil.

adicionais como o corte e religamento à distância, tarifa horo-sazonal[76], leitura remota (sem a necessidade do leiturista entrar na residência ou estabelecimento comercial) e sistemática de pré-pagamento, o que confere maior eficiência ao sistema, ao permitir uma redução de custos diretos e indiretos.

Todavia, o medidor eletrônico tem uma vida útil inferior ao medidor tradicional, há inseguranças quanto ao desempenho em condições climáticas adversas e indefinições na regulamentação quanto ao uso dos recursos adicionais, como a aplicação de tarifas diferenciadas por hora e questões tributárias, que ainda inviabilizam a utilização do pré-pagamento. Ademais, ainda não há um regulamento técnico-metrológico de medição centralizada, embora o Inmetro já tenha aprovado um regulamento provisório em 2008, com o definitivo em fase final de aprovação.

No que concerne à redução das perdas comerciais, a medição eletrônica centralizada tem se mostrado mais eficiente, em comparação com a medição eletromecânica e eletrônica descentralizadas, dado que retira o sistema de medição do interior da propriedade a ser tarifada (residências, indústrias, lojas), o que impossibilita a realização de adulterações no equipamento, permite um maior fiscalização por parte da concessionária, inibe furtos de energia (ligações clandestinas direto na rede), possibilita a realização de um balanço da energia demandada e da consumida efetivamente, além das vantagens da medição eletrônica *per si*, apontadas acima. Isto é, a implantação da medição eletrônica por si só, não se constitui como ferramenta tão eficaz na minoração das perdas não técnicas quando comparado com o sistema eletrônico e centralizado.

Algumas experiências têm revelado que a implantação deste sistema de medição centralizada é realmente capaz de reduzir as perdas e o furto de energia. O surgimento da medição centralizada, capitaneado pelo CEPEL, é caracterizado como um importante avanço tecnológico no combate as perdas comerciais. Além deste, a elevação da rede secundária (baixa tensão) até o nível da rede primária (média tensão), que passa a ficar bem acima do solo, dificulta ligações clandestinas. Com isso, grupos de consumidores passam a estar ligados a um medidor central e, caso haja qualquer tentativa de violação do mesmo, o fornecimento de energia é automaticamente interrompido para todo o grupo (TCU, 2008), como forma de promover uma espécie de controle social do sistema.

As perdas comerciais muitas vezes estão associadas a áreas de grande complexidade social, que carecem de infra-estrutura básica e possuem

---

[76] A tarifação horo-sazonal permite uma discriminação de preços por faixa de horário, o que incentiva uma mudança de hábitos dos consumidores e uma conseqüente redução do consumo nos horários de pico. Portanto, tal tipo de tarifação, se implantado, poderia gerar impactos positivos tanto para as concessionárias quanto para os consumidores, sejam eles domésticos ou não.

elevados níveis de pobreza e criminalidade. No entanto, é cada vez mais comum verificar perdas comerciais entre consumidores localizados fora do perímetro destas áreas, como apontado acima. Isto reflete a falta de investimento, por parte das concessionárias, no combate as perdas comerciais que, por decisão da Agência Nacional de Energia Elétrica (ANEEL), vem sendo integralmente incorporadas às tarifas cobradas aos consumidores, aumentando os custos energéticos para a economia como um todo.

Nas audiências públicas realizadas pela ANEEL é comum que os participantes, especialmente consumidores, levantem questionamentos sobre o repasse das perdas comerciais para as tarifas. Na Audiência Pública nº 47/2004, o representante da Companhia Siderúrgica Nacional (CSN), José Bueno Leppos, indagou que

"quando da privatização das distribuidoras de energia, um dos pontos de maior atratividade para os compradores destas empresas era o nível de perda de energia: quanto maior o nível de perda de energia maior era a possibilidade de ganho dos compradores, caso as distribuidoras investissem na redução destas perdas. O que acontece atualmente é que praticamente toda, ou quase toda, a perda comercial está sendo coberta pelo pagamento dos consumidores, fazendo com que as distribuidoras possam ter este ganho com muito pouco investimentos na redução das perdas. Qual o incentivo que os gestores das distribuidoras têm em aplicar recursos para sua diminuição se todos os consumidores já estão pagando esta conta? Absolutamente nenhum, ou seja, as distribuidoras trabalham como se não tivessem nenhuma, ou quase nenhuma, perda comercial, ou seja, todo o ganho que teriam com a privatização já obtêm hoje sem a aplicação de recursos financeiros para a diminuição destas perdas" (Audiência Pública nº 47, 2005).

Em virtude da relevância do tema e preocupado com os impactos econômicos, ambientais e sociais inerentes ao crescimento da perda de energia no Brasil, este artigo se propõe a abrir uma agenda de pesquisa sobre o tema, com o aporte das diversas metodologias de avaliação de impacto. De forma inicial, objetiva-se investigar se a implantação do sistema de medição centralizada em larga escala é realmente uma medida eficiente na minoração das perdas comerciais. Para tanto, além desta seção introdutória, este artigo contará com mais três seções, a saber: a seção dois discorrerá sobre o atual perfil da regulação brasileira para as perdas comerciais; a seção três discutirá um modelo para avaliação econômico-financeira da mudança de medidores eletromecânicos para o sistema de medição centralizada; e a seção quatro apresentará as considerações finais.

## 2.- A atual regulação sobre as perdas comerciais no Brasil

No período que precedeu às privatizações, o problema das perdas comerciais era sempre negligenciado, em virtude da adoção de um modelo verticalizado[77] e os prejuízos financeiros eram sistematicamente assumidos pelo Tesouro Nacional. Com a privatização do setor e a criação da ANEEL, o enfoque do tratamento das perdas ganhou nova roupagem, sendo fator fundamental na determinação do lucro das concessionárias distribuidoras de energia elétrica (Patrício, 2005).

Desde então, a política energética brasileira vem buscando se adaptar a essa realidade. Atualmente, esta política prevê três mecanismos de reajustes tarifários: a Revisão Tarifária Periódica (RTP) realizada, em média, a cada 04 anos, visando redefinir o equilíbrio econômico-financeiro das empresas; o Reajuste Tarifário (RT) realizado anualmente pelo IGP-M, que tem como objetivo preservar o equilíbrio econômico-financeiro das empresas, definido pelo ajuste tarifário; e a Revisão Extraordinária (RE) que é aplicada quando algo extraordinário (desastres naturais, por exemplo) desequilibra o contrato de concessão (Nota Técnica n.º 262, 2006).

A RTP tem como objetivo equilibrar as tarifas com base na remuneração dos investimentos das empresas voltadas à apresentação dos serviços de distribuição e a cobertura de despesas efetivamente reconhecidas pela ANEEL. Na RTP são consideradas variações dos índices inflacionários, a mudança na estrutura de capital e de custos das empresas, os ganhos de produtividade, além de fatores macroeconômicos, como oscilações de câmbio e juros (*Ibid*, 2006). As perdas comerciais são inseridas, normalmente, na mudança de custos das empresas. Cabe ressaltar ainda que as revisões são feitas pela ANEEL de forma discricionária, considerando as particularidades de cada empresa.

Dado ser as perdas comerciais parte componente da estrutura de custo das distribuidoras de energia, muitas delas têm impetrado uma série de ações para combater tais perdas, como apontado na seção anterior. Contudo, em decorrência de sua onerosidade, os custos podem superar os benefícios, o que tornariam essas ações inviáveis do ponto de vista econômico. Como ressalta o Instituto Acende Brasil

"[o] combate às perdas comerciais é [considerado] economicamente viável até o ponto em que seus custos não superem a receita incremental advinda de sua implementação. A partir deste ponto, as iniciativas de combate se tornam

---

[77] O setor elétrico brasileiro caracterizava-se por sua verticalização, pois, sob o bojo de uma única empresa, estavam concentradas as atividades de geração, transmissão, distribuição e comercialização. Essa estrutura dificultava a identificação de ineficiências na cadeia de produção/fornecimento de energia. O processo de privatização do setor visou conduzir a uma desverticalização deste sistema, fomentando a criação de empresas especializadas em cada uma das atividades supracitadas, com autonomia em suas operações. Entretanto, mesmo com essa tentativa de desverticalização, em muitos casos, foram criadas *holdings* com ativos dos diversos segmentos – geração, transmissão, distribuição e comercialização (Mello, 2008).

impraticáveis pela ótica privada, exigindo do Estado, via regulação das tarifas, a criação de incentivos e recursos para que se atinjam os patamares socialmente desejáveis" (Instituto Acende Brasil, 2007).

Assim, a ANEEL deveria incentivar uma regulação por incentivos eficaz, definindo uma meta para a "perda regulatória" de modo que um operador eficiente possa atingi-la em condições de equilíbrio econômico-financeiro (*Ibid*, 2007). Dessa forma, estabelece-se uma lógica de incentivos, na qual a ocorrência de perdas comerciais maiores do que aquelas previamente definidas tornam-se um ônus para o operador, que não terá as perdas superiores à meta reconhecidas em sua tarifa. Por outro lado, a superação do alvo representa um bônus para o operador, que poderá se apropriar de parte dos ganhos obtidos como recompensa por sua maior eficiência. Em ambos os casos, o regulador poderá estabelecer novas metas regulatórias no ciclo tarifário seguinte, possibilitando o compartilhamento destes ganhos com os consumidores, via redução de tarifas.

A regulação por incentivos tem dois aspectos. Se o regulador não determina uma meta para as perdas comerciais, toda a energia comprada pelo distribuidor acaba sendo repassada à tarifa, onerando indevidamente os clientes, que acabam pagando um maior custo associado à fraude e/ou furto de energia. Além disso, os consumidores, em função da ausência de incentivos, acabam por pagar esse acréscimo *ad infinitum*.

Por outro lado, o estabelecimento de uma meta para as perdas comerciais sem permitir ao distribuidor, ao menos num primeiro momento, repassar tais custos às tarifas como forma de financiar seu combate, simplesmente transfere o ônus das iniciativas de combate às perdas comerciais aos distribuidores, o que pode acarretar num desequilíbrio econômico-financeiro na concessão, podendo até inviabilizar a sustentabilidade dos serviços.

Assim, o ideal é que o regulador estabeleça uma meta para as perdas comerciais, além dos recursos necessários para atingi-la. Estes recursos podem advir da permissão para que as concessionárias incorporem tais perdas ao valor da tarifa por determinado período, situação que a ANEEL, inicialmente, permitiria até o segundo ciclo de revisão tarifária iniciado em 2006, considerando o grau de complexidade social[78] da localidade onde a concessionária se insere. Entretanto, diferentemente do que se esperava, a ANEEL, mesmo após o segundo ciclo, tem permitido a manutenção do nível de

---

[78] O índice de complexidade social foi desenvolvido a partir de um estudo encomendado pela empresa Ampla junto à Fundação Getúlio Vargas (FGV) e a Universidade Federal Fluminense (UFF). Ele relaciona as perdas observadas nas áreas de concessão com as taxas de urbanização, a quantidade de mortes por agressão, a proporção de residências em "favelas", com rede de água e esgoto para determinar o grau de complexidade social de cada uma das áreas onde a concessionária atua (ARAÚJO, 2006).

perdas comerciais anteriormente constatados[79], situação que incentiva as concessionárias em procrastinar maiores investimentos no combate a tais perdas. E isso acaba sendo, como ressaltado por Vieiralves (2005), um ônus para toda a sociedade, pois

"(...) a perda de energia elétrica atualmente registrada não [deve ser encarada como] (...) um problema exclusivo das concessionárias (...), mas de toda a sociedade, haja vista que, de uma forma ou de outra, seus custos são transferidos via tarifas, subsídios (...) além das perdas (...) impactarem diretamente a saúde financeira das empresas e, indiretamente, (...) [n]os preços das tarifas de energia elétrica para toda a sociedade. Somem-se a isso os problemas ambientais advindos dessa demanda adicional de energia elétrica. A sociedade brasileira, uma das mais taxadas do mundo, não pode arcar com essa tributação indireta" (Vieiralves, pp. 34, 2005).

3.- Metodologia para avaliação econômico-financeira da substituição de medidores eletromecânicos pelo sistema de medição centralizada

A agenda de pesquisa sobre uma metodologia para a avaliação econômico-financeira da substituição de medidores eletromecânicos pelo sistema de medição centralizada ainda encontra-se em aberto, carecendo de maior aprofundamento em torno de trabalhos, no Brasil e no mundo, que tratem não apenas do caráter econômico da avaliação, mas que também estejam preocupados com os impactos sociais e ambientais. Desta forma, como exercício preliminar, buscou-se mapear algumas das ferramentas básicas na avaliação econômico-financeira, postergando para um momento posterior, o necessário aprofundamento e definição sobre as demais questões.

Antes de se realizar qualquer investimento é importante avaliar qual a forma mais rentável e adequada de alocar os recursos. Na literatura especializada, existem alguns cálculos importantes que normalmente são considerados para mensurar a viabilidade econômico-financeira de determinado investimento[80].

---

[79] A título de exemplo, as concessionárias Empresa Luz e Força Santa Maria S.A. (ELFSM) e a Companhia Paulista de Energia Elétrica (CPEE), que passaram recentemente pela segunda revisão tarifária junto a ANEEL em janeiro de 2008, obtiveram a permissão de manter o nível de perdas técnicas apurado no ciclo tarifário anterior. Assim, mesmo que essas empresas não realizem nenhuma ação com o objetivo de reduzir esse percentual, fica assegurado seu direito de repassar os percentuais acordados à tarifa cobrada junto ao consumidor. Para maior detalhamento, ver NOTA (2008) e NOTA (2008a).

[80] Os principais índices e suas respectivas definições (Buarque, 1984) são: Rentabilidade simples (RS): procura determinar lucro médio provável em cada ano (L) dividido pelo total investido (I), ou seja, $RS = L/I$. Sua principal vantagem é a facilidade de sua determinação e a possibilidade de comparar diferentes alternativas. Retorno do capital (RC): determina o número de anos necessários para que a empresa recupere seu investimento, ou seja, $RC = I/L$. Lucro líquido total (LLT): total do lucro médio provável (Lt) dividido pelo total investido (I), ou seja, $LLT = L_n/I$. A fim de conferir mais proximidade com a realidade é importante atribuir valor ao tempo, possibilitando diferenciar os lucros recebidos em diferentes anos. Valor atual líquido (VAL): determina o valor atualizado do lucro (receita – custos) subtraindo o investimento necessário, ou seja, $VAL = \sum R_n - C_n/(1 + i)^n - \sum I_n/(1 + i)^j$. Taxa interna de retorno (TIR): é a taxa capaz de igualar, em valores atualizados, todos os custos do projeto com suas receitas. Para tanto, basta considerar o valor líquido atual igual a zero, ou seja, $\sum R_n - C_n/(1 + i)^n = \sum I_n/(1 + i)^j$ e, assim, a taxa interna de retorno será o valor de i. Taxa interna financeira de retorno (TIFR): é a taxa interna de retorno sob o ponto de vista do empresário, ou seja, $VAL = \sum (R_n - C_n - A_n)/(1 + i)^n - E$ onde A = gastos com pagamentos financeiros

Neste artigo, será mensurada a ferramenta mais difundida no meio técnico para análise de viabilidade econômica pela sua facilidade de aplicação (Vieiralves, 2005): o tempo de retorno de capital, ou *payback*. Esse critério indica qual é o tempo necessário para que os benefícios se igualem ao investimento inicial. A taxa de juros adotada é o próprio custo do capital. O tempo de retorno do capital investido pode ser calculado pela seguinte expressão matemática:

$n = \ln(1 - I_r/A)/\ln(1+r)$ (1)

onde:

*n* = tempo de retorno do capital; *I* = valor do investimento inicial; *r* = taxa de juros; e
*A* = benefícios esperados.

Com base em algumas informações coletadas junto a um dos fabricantes do sistema de medição centralizada (Cam Brasil, empresa do grupo espanhol Endesa, responsável pelo fornecimento do equipamento utilizado pela Ampla), o custo médio *per capita* para se implantar uma unidade deste sistema é de R$ 600,00. Como a Ampla possuía 1,880 milhões de clientes do grupo B (baixa tensão) em 2007[81], sendo que 299 mil já são faturados através do sistema de medição centralizada, o custo estimado para substituir os demais medidores eletromecânicos pelo sistema de medição centralizada é estimado em R$ 948,6 milhões.

Além disso, cabe ressaltar que a receita anual da empresa em 2007 foi de R$ 2,13 bilhões e as perdas comerciais registradas neste período foram da ordem de 11,2%. Logo, se a medição centralizada reduzir em, pelo menos, 50% (de 11,2% para 5,6%) o valor das perdas comerciais, os ganhos monetários seriam da ordem de R$ 119,28 milhões/ano. Considerando que o tempo de vida útil estimado do equipamento é de 10 a 15 anos[82]. Vale destacar que, entre 2006 e 2007, o faturamento da Ampla apresentou uma taxa de crescimento de 7,58%. A partir da manutenção dessa taxa de crescimento para os próximos 10 anos é possível realizar a seguinte projeção para os benefícios acumulados advindos com a redução das perdas (Tabela 2).

Tabela 3

---

(juros + amortizações), caso seja necessário financiar o investimento e E = capital próprio. Para o cálculo desses índices é preciso acesso a um maior número de informações, o que não foi possível neste artigo.

[81] O relatório sobre o exame das demonstrações financeiras da Ampla de 2008, referente aos exercícios de 2006 e 2007 (Relatório sobre o exame das demonstrações financeiras, 2008) informa que o número de possíveis clientes do grupo B estão distribuídos em residenciais (2,134 milhões), rurais (58 mil) e iluminação pública (cerca de mil), totalizando 2,193 milhões. Levando em conta que nem todos os clientes residenciais pertencem, necessariamente, ao grupo B, este estudo considerou que 10% destes pertencem a outros grupos. Com isso, a medição centralizada, desenvolvida para ser utilizada para clientes de baixa tensão, não pode ser implantada nestes casos.

[82] Por ser uma tecnologia recente, as estimativas sobre o tempo de vida útil do equipamento ainda não estão plenamente consolidadas. Assim, neste artigo, buscamos a estimativa mais conservadora possível, ou seja, 10 anos.

| Tabela 2 - Benefícios estimados com a redução das perdas no período de 10 anos | |
|---|---|
| Redução das perdas comerciais | Benefícios esperados (R$) |
| 50% | 1.693.871.892,45 |
| 60% | 2.032.646.270,94 |
| 70% | 2.371.420.649,43 |
| 80% | 2.710.195.027,92 |
| 90% | 3.048.969.406,41 |
| 95% | 3.218.356.595,66 |
| Fonte: AMPLA. Elaboração própria | |

A fim de se obter uma primeira estimativa inicial sobre a viabilidade do investimento necessário para a substituição dos medidores eletromecânicos para o sistema de medição centralizada é preciso definir:

n = valor procurado

I = R$ 948,6 milhões

i = 1,25% a.m.[83]

A = De R$ 2,13 bilhões x 0,056 (redução de 50% nas perdas comerciais observadas em 2007) = R$ 119,28 milhões[84]

Com base nestas informações, é possível elaborar a seguinte tabela:

Tabela 4

Tabela 3 - Tempo de retorno do investimento (payback)

| Redução das perdas comerciais | Benefícios (R$) | Investimento Inicial (R$) | (1-Ii/A) | Ln (1- Ii/A) | (1+i) | Ln (1 + i) | n (anos) | n (meses) |
|---|---|---|---|---|---|---|---|---|

[83] Esta taxa de juros baseia-se na taxa de juros básica praticada atualmente pelo Banco Central do Brasil, que é de 13,75% ao ano, definida na última reunião realizada em dezembro de 2008 pelo Comitê de Política Monetária – COPOM. Maiores informações na página do Banco Central na internet: http://www.bacen.gov.br

[84] A receita anual da empresa em 2007 foi de R$ 2,13 bilhões e as perdas comerciais registradas neste período foram da ordem de 11,2% (Guimarães, 2008). Logo, se a medição centralizada reduzir em, pelo menos, 50% (de 11,2% para 5,6%) o valor das perdas comerciais, os ganhos monetários seriam da ordem de R$ 119,28 milhões.

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 50% | 119.280.000 | 948.600.000 | 0,9141 | 0,0898 | 1,0108 | 0,0107 | 8,36 | 100 |
| 60% | 143.136.000 | 948.600.000 | 0,9284 | 0,0743 | 1,0108 | 0,0107 | 6,91 | 83 |
| 70% | 166.992.000 | 948.600.000 | 0,9387 | 0,0633 | 1,0108 | 0,0107 | 5,89 | 71 |
| 80% | 190.848.000 | 948.600.000 | 0,9463 | 0,0552 | 1,0108 | 0,0107 | 5,14 | 62 |
| 90% | 214.704.000 | 948.600.000 | 0,9523 | 0,0489 | 1,0108 | 0,0107 | 4,55 | 55 |
| 95% | 226.632.000 | 948.600.000 | 0,9548 | 0,0463 | 1,0108 | 0,0107 | 4,31 | 52 |

Fonte: AMPLA. Elaboração própria

Assim, conforme os valores anteriormente apresentados, a concessionária utilizada como exemplo, caso consiga ampliar a instalação do sistema de medição centralizada para todos os seus clientes e, pelo menos, melhorar o índice de perdas em 50%, precisaria de 100 meses para recuperar o investimento realizado. Quanto maior a recuperação das perdas, menor será o tempo necessário para recuperar o investimento, como aponta a tabela anterior.

Deste modo, um plano concreto de combate às perdas comerciais, por meio da substituição de medidores eletromecânicos pelo sistema de medição centralizada, mostra-se eficiente no médio prazo. Essa substituição é capaz de trazer benefícios tanto aos consumidores (que deixarão de pagar pela energia "furtada/fraudada" por alguns), quanto às concessionárias (que reduzirão suas perdas comerciais, melhorando sua eficiência e, indiretamente, podendo até reduzir suas equipes técnicas, responsáveis atualmente por efetuarem a leitura, os cortes e as religações *in loco*). Entretanto é importante que a ANEEL estabeleça um período superior à realização das revisões tarifárias, de aproximadamente oito anos, para que tal substituição mostre-se economicamente viável.

4.- Considerações finais

O sistema de medição centralizada tem se mostrado um importante aliado no combate às perdas comerciais observadas no sistema de distribuição de energia elétrica no Brasil. Concessionárias que passaram a utilizar tal sistema vêm atingindo significativos aumentos de receitas, por meio da redução de furtos e fraudes no fornecimento de energia elétrica aos consumidores cativos de baixa tensão. A título de exemplo, a Ampla conseguiu reduzir suas perdas comerciais, entre 2003 e 2007, com a implantação do sistema de medição centralizada em algumas de suas áreas de concessão em aproximadamente

4,2 p.p[85]. Isso trouxe um aumento de receita da ordem de R$ 277,53 milhões entre dezembro de 2003 e julho de 2008, conforme informações disponibilizadas pela empresa no Seminário Internacional sobre Medição Eletrônica, promovido pela ANEEL em 2008.

Tal medida, todavia, é apenas uma das inúmeras possibilidades de se combater as perdas comerciais no setor elétrico, que tem causas diversas, além de fraudes e furtos de energia. Desta forma, outras ações também devem ser consideradas, como a revitalização e reurbanização de áreas de grande risco social e que apresentam elevados índices de perdas comerciais. Um exemplo destas experiências é o Programa Rede Comunidade, desenvolvido pela Eletropaulo para a regularização do sistema de distribuição e medição em áreas de grande complexidade social. Seu principal objetivo é reduzir o consumo ilegal de energia. Entretanto, sua ação se baseia na melhoria das condições de vida da comunidade, em conjunto com o setor público local, conscientizando os indivíduos a respeito da importância da utilização de eletrodomésticos com comprovada eficiência energética e da importância de uma ação cidadã[86].

Assim, vale destacar a dificuldade em se isolar apenas o impacto da instalação do sistema de medição centralizada, ainda que os dados preliminares sinalizem favoravelmente para a realização dos investimentos para a substituição dos medidores eletromecânicos, ao menos no caso da Ampla. No entanto, uma base de dados consolidada é necessária para a realização de uma análise mais consistente e abrangente, permitindo mensurar não apenas os impactos econômicos dessa substituição, mas também as demais medidas de combate às perdas comerciais, suas implicações sociais e ambientais.

Para tanto e sugerindo os próximos passos de uma agenda de pesquisa, os futuros artigos que serão desenvolvidos procurarão aprofundar os resultados obtidos pela Ampla, que adotou em escala razoável o sistema de medição centralizada, através de um estudo de caso sobre a trajetória do desempenho recente desta empresa no combate às perdas comerciais. A partir daí, com base em entendimentos com outros importantes atores do setor, como a ABRADEE e a própria ANEEL, um estudo mais amplo buscará dimensionar os

---

[85] Conforme informações da Associação Brasileira de Distribuidores de Energia Elétrica (ABRADEE), o estado do RJ como um todo apresentava, em 2003, 15,4% de perdas comerciais. A Ampla registrou, em 2007, perdas comerciais da ordem de 11,2%, o que reflete a redução no combate às perdas comerciais promovido pela empresa. Maiores informações, consultar Guimarães (2008) e Rivera (2008).

[86] A própria Ampla tem realizado ação similar, através da doação de novos equipamentos (especialmente geladeiras) a consumidores de baixa renda habitantes de áreas de grande complexidade social e que passaram, recentemente, pela substituição de medidores eletromecânicos pelo sistema de medição centralizada. É importante destacar que a simples substituição da tecnologia de medição pode não se mostrar uma medida eficaz no combate às perdas comerciais, pois, em função da melhoria na qualidade da medição, os consumidores, pelo menos num primeiro momento, passam a conviver com acréscimos em suas contas, o que muitas vezes impossibilita-os de quitá-las. Para evitar o crescimento da inadimplência, ações paralelas de conscientização do consumo, além da substituição de eletrodomésticos obsoletos e que consomem grande quantidade de energia tem sido promovida pelas concessionárias, como a Ampla e a própria Eletropaulo.

impactos desta substituição para a distribuição de energia elétrica no país como um todo.

5.- Referências

Alvarenga, Landulfo Mosqueira. "Sistema de Medição Centralizada: Uma História de Sucesso Brasileira." *Apresentação no Fórum Nacional Combate ao Furto e à Fraude no Consumo de Energia Elétrica*. Rio de Janeiro: 2006.

Aranha Neto, Edison A.C.; Coelho, Jorge; Bettiol, Arlan L.; Barcelos, Sergio M. "Combate às perdas não técnicas no Brasil". *Apresentação no Congreso Latinoamericano de Distribucion Electrica*. Argentina: 2008.

Araújo, Antônio C. M. de. "Perdas e inadimplência na atividade de distribuição de energia elétrica no Brasil". *Tese (doutorado)*, 2006. Rio de Janeiro – UFRJ: Programa de Pós-Graduação de Engenharia em Ciências em Planejamento Energético. Disponível em: http://www.ppe.ufrj.br/ppe/production/tesis/daraujoacm.pdf. Acesso em: 16 Dez. 2008.

Audiência Pública nº 47/2004. *Comentários da Companhia Siderúrgica Nacional (CSN).* Disponível em: http://www.aneel.gov.br/aplicacoes/audiencia/arquivo/2004/047/contribuicao/csn.pdf. Acesso em: 21 Nov. 2008.

Buarque, C. Avaliação econômica de projetos: uma apresentação didática. Rio de Janeiro: Elsevier, 1984.

Guimarães, Luiz C. "Reflexos da inadimplência no setor de energia elétrica". *V Seminário Jurídico. Associação Brasileira de Distribuidores de Energia Elétrica – ABRADEE.* Rio de Janeiro, 2004. Disponível em: http://www.abradee.org.br/Downloads/Juridico. Acesso em: 18 Nov. 2008.

Instituto Acende Brasil. "Perdas e inadimplência no setor elétrico". *Cadernos de Política Tarifária*, Dez. 2007. Disponível em: http://www.institutoacendebrasil.com.br. Acesso em: 29 Dez. 2008.

Marinho, Alexandre; Façanha, Luís Otávio. "Programas Sociais: efetividade, eficiência e eficácia como dimensões operacionais da avaliação". *Texto para discussão nº 787*. Rio de Janeiro: IPEA, 2001.

Mello, Arthur O. P. B. de. "Os investimentos no setor elétrico". *Dissertação (mestrado),* 2008. Rio de Janeiro – COPPE/UFRJ. Disponível em: http://www.ppe.ufrj.br/ppe/production/tesis/mello_arthur.pdf Acesso em: 17 Nov. 2008.

Nota Técnica n.º 262/2006-SER/SFF/SRD/SFE/SRC/ANEEL. "Segundo ciclo de revisão tarifária periódica das concessionárias de distribuição de energia elétrica do Brasil: aprimoramento das metodologias". *Agência Nacional de Energia Elétrica – ANEEL*. Brasília, 2006. Disponível em: www.aneel.gov.br/cedoc/notaren2006234sre.pdf. Acesso em: 05 Jan. 2009.

Nota Técnica nº. 020/2008-SRE/ANEEL. "Segunda revisão tarifária periódica da concessionária de distribuição de energia elétrica – empresa Luz e Força Santa Maria S.A. – ELFSM – ciclo 2007-2010". *Agência Nacional de Energia Elétrica – ANEEL*, Brasília, 2008. Disponível em: http://www.aneel.gov.br/cedoc/reh2008606.pdf. Acesso em: 06 Jan. 2009.

Nota Técnica nº. 024/2008-SRE/ANEEL. "Segunda revisão tarifária periódica da concessionária de distribuição de energia elétrica – Companhia Paulista de Energia Elétrica – CPEE – ciclo 2007-2010". *Agência Nacional de Energia Elétrica – ANEEL*, Brasília, 2008a. Disponível em: http://www.aneel.gov.br/cedoc/reh2008607.pdf. Acesso em: 06 Jan. 2009.

Patrício, Cristina M. M. M. "Detecção de fraude ou erro de medição em grandes consumidores de energia elétrica utilizando rough sets baseado em dados históricos e em dados em tempo real". *Dissertação de Mestrado.* Campo Grande: Universidade Federal do Mato Grosso do Sul, 2005, 138p.

Relatório sobre o exame das demonstrações financeiras. *Ampla Energia e Serviços S.A.* Rio de Janeiro, 2008. Disponível em: http://www.ampla.com/html/if/Demonstrações%20Financeiras-2007.zip. Acesso em: 07 Jan. 2009.

Resolução nº 456/2000 da ANEEL. Disponível em: www.aneel.gov.br/cedoc/res2000456.pdf. Acesso em: 08 Jan. 2009.

Rivera, Caludio. "Experiência da Ampla em Sistemas de Medição Centralizada". *Seminário Internacional sobre Medição Eletrônica. Agência Nacional de Energia Elétrica – ANEEL.* Brasília, 2008. Disponível em: www.aneel.gov.br/arquivos/PDF/medição%20eletrônica.pdf. Acesso em: 18 Nov. 2008.

Tribunal de Contas da União (TCU). *Relatório de auditoria – Agência Nacional de Energia Elétrica – ANEEL.* Disponível em: http://www.tcu.gov.br/Consultas/Juris/Docs/judoc/Acord/20081010/025-619-2007-2.doc Acesso em: 10 Nov. 2008.

Vieiralves, Moacyr T. de O. A. "Proposta de uma metodologia para avaliação das perdas comerciais dos sistemas elétricos: o caso Manaus". *Dissertação (mestrado),* 2005. Campinas – UNICAMP: Programa de Pós-Graduação em Planejamento de Sistemas Energéticos. Disponível em: http://libdigi.unicamp.br/document/?code=vtls000377013. Acesso em: 17 Nov. 2008.

# 22. Energía e Inclusión Social en Brasil y Colombia: principios del acceso y uso (combustibles y electricidad)

**Julieta Puerto[*+], Ildo Luis Sauer[**]**

[++]Programa de Postgraduación en Energía, Instituto de Electrotécnica y Energía, Universidad de São Paulo julietapuerto@iee.usp.br, illsauer@iee.usp.br

En la década de 90, la normatividad creada reflejó la filosofía regulatória para el desarrollo de los mercados energéticos dentro del esquema de la competitividad. Estas medidas afectaron el acceso a la energía y dependiendo del país lograron cubrir un grupo mayoritario de la población o marginar fracciones de la misma. En una sociedad altamente interdependiente como la actual, la falta de energía comercial, sea gas o electricidad, representa un factor limitante para la inclusión social. El presente trabajo objetiva realizar el diagnóstico de programas y mecanismos que determinaron y determinan el acceso a los combustibles y la electricidad en Brasil y Colombia. El análisis está basado en la comparación de criterios de atención de la demanda como estratificación de usuarios, tarifas y programas aplicados para el acceso al GLP, electricidad y gas natural.

Palabras clave: inclusión social, políticas públicas, acceso a energía.

## Introducción

Algunos países reestructuraron la organización de sus industrias energéticas, otros todavía mantienen sus industrias originales, cada caso resultado de sus respectivos procesos históricos. Sin embargo, la problemática del acceso a la energía continúa como una cuestión esencial para los Gobiernos, las empresas de energía, los organismos formuladores de políticas públicas, las entidades reguladoras y para las sociedades. Los gobiernos encaminan acciones sobre las cuestiones económicas, sociales, regulatorias, técnicas y logísticas para proporcionar y viabilizar el acceso para aquellos que fueron excluidos. El ecuacionamiento del acceso en términos técnicos, económicos y sociales con base en la revisión de diversas experiencias de diferentes regiones, va a permitir la reducción de conflictos sociales, de las pérdidas comerciales, y la mejoría en el padrón técnico de servicios. El objetivo de este trabajo es mostrar algunas de las experiencias en Brasil y Colombia, bien sea como procesos anteriores o actuales para facilitar el acceso a la energía comercial y a una canasta energética diversificada en usuarios con características económicas frágiles.

## 1. Principios para el acceso a los servicios públicos

La Constitución Federal de 1988, en Brasil, y la Constitución Nacional de 1991 en Colombia consagran el tema de Servicios Públicos Domiciliarios (SPD).

En Brasil:

Art. 175. Incumbe ao Poder Público, na forma da lei, diretamente ou sob regime de concessão ou permissão, sempre através de licitação, a prestação de serviços públicos.

Parágrafo único. A lei disporá sobre:

I - o regime das empresas concessionárias e permissionárias de serviços públicos, o caráter especial de seu contrato e de sua prorrogação, bem como as condições de caducidade, fiscalização e rescisão da concessão ou permissão;

II - os direitos dos usuários;

III - política tarifária;

IV - a obrigação de manter serviço adequado

En Colombia la constitución establece que podrían ser usados subsidios para lograr la prestación de los servicios públicos en los habitantes con menores ingresos bajo los principios de solidaridad y redistribución, estos últimos bajo la concepción de la Ley 142 de Servicios Públicos.

“Por solidaridad y redistribución se entiende que al poner en práctica el régimen tarifario se adoptarán medidas para asignar recursos a los fondos de solidaridad y redistribución, para que los usuarios de los estratos altos y los usuarios comerciales e industriales ayuden a los usuarios de estratos bajos a pagar las tarifas de los servicios que cubran sus necesidades básicas”. La Ley 142 de 1994, artículo sobre régimen tarifario.

En el caso de la Constitución Colombiana el tema de los servicios públicos es tratado así:

Artículo 365º.- Los servicios públicos son inherentes a la finalidad social del Estado. Es deber del Estado asegurar su prestación eficiente a todos los habitantes del territorio nacional…… el Estado mantendrá la regulación, el control y la vigilancia de dichos servicios. Si por razones de soberanía o de interés social.

Artículo 367º.-La ley fijará las competencias y responsabilidades relativas a la prestación de los servicios públicos domiciliarios, su cobertura, calidad y financiación, y el régimen tarifario que tendrá en cuenta además de los criterios de costos, los de solidaridad y redistribución de ingresos…

Artículo 368º.-La Nación, los departamentos, los distritos, los municipios y las entidades descentralizadas podrán conceder subsidios, en susrespectivos presupuestos, para que las personas de menores ingresos puedan pagar las tarifas de los servicios públicos domiciliarios que cubran sus necesidades básicas.

2. Características y Condiciones para el acceso a los servicios públicos

2.1 Estratificación Social en Colombia

El cobro de los servicios públicos en Colombia es basado en la estratificación social de usuarios. La estratificación socioeconómica colombiana es una clasificación de los domicilios o inmuebles residenciales a partir de sus características físicas y su entorno, urbano o rural, en 6 grupos o estratos que connotan diferentes capacidades económicas de sus moradores, razón por la que principalmente se emplea, desde 1983, para cobrar de manera diferencial los SPD. Específicamente la estratificación fue consagrada por la Ley 142 de 1994, Régimen de los SPD, en el Titulo VI "Régimen tarifario de las empresas de SPD", Capítulo IV *"Estratificación Socioeconómica"*, en cumplimiento del mandato de la Constitución Nacional, que ordena al Estado asegurar la prestación eficiente a todos los habitantes del territorio nacional, en sujeción a la Ley (CN, 1991: Artículo365).

Al analizar el régimen tarifario, y la forma como atiende a la capacidad de pago de los usuarios, el valor a pagar por un SPD residencial es equivalente al producto del consumo (metros cúbicos de agua-gas mensuales, kilovatios hora mensuales, impulsos telefónicos mensuales) por un valor unitario que, a su vez, es el producto de una tarifa (costo de referencia) por un porcentaje de subsidio o contribución según el estrato: Valor a pagar = Consumo * (Tarifa* P% ). El porcentaje del subsidio o de la contribución (P%) consiste en son constantes a nivel nacional para cada estrato socioeconómico. Según la Ley 142 de 1.994, estos son:

Estratos y Factor para subsidio, o contribución:

1: bajo-bajo 0,50 (subsidios hasta 50%)

2: bajo 0,60 (subsidios hasta 40%)

3: medio-bajo 0,85 (subsidios hasta 15%)

4: medio 1,00 (sin subsidio ni contribución)

5: medio-alto 1,20 (contribuciones hasta 20%)

6: alto 1,20 (contribuciones hasta 20%)

En el estrato más bajo el usuario sólo podrá acceder a los SPD si paga 50% de lo que cuesta suministrarlos; así mismo, en el estrato más alto, aunque la tarifa sea muy baja, sólo estará obligado a aportar 20% más de lo que cuesta.

El estrato al que corresponde el porcentaje de subsidio o contribución antes mencionado, , es el resultante de “la clasificación de los inmuebles residenciales de un municipio”, máximo en seis grupos. El valor unitario (costo de referencia o tarifa por porcentajes de subsidio o contribución, por servicio y período de facturación según empresa) es, entonces, el que resulta afectado por el estrato socioeconómico. No es la tarifa propiamente dicha, como comúnmente se ha planteado. De esta manera, a un usuario residencial, dependiendo del estrato en que quede clasificada su vivienda, se le factura el consumo a un porcentaje determinado de la tarifa (no el consumo total sino el consumo básico o mínimo de subsistencia, o consumo subsidiable en el caso de los estratos 1, 2 y 3. ALZATE (2.006)

Para KOZULJ (2.007) la Ley 142 de 1.994 ayudó a organizar la cobertura de los servicios públicos:

[...] En tal sentido se podría afirmar que con la excepción del caso de Colombia donde se establece una Ley de Servicios Públicos por la cual se define un sistema explícito de subsidios entre estratos sociales para el conjunto de dichos servicios públicos (electricidad, gas, agua, alcantarillado, saneamiento y telefonía rural)[...]

La siguiente tabla muestra los valores cobrados por la prestación del servicio de gas natural por ALCANOS DE COLOMBIA S.A para los estratos 1 y 2 para un consumo igual o inferior a 20m$^3$ incluyendo el subsidio. El ejemplo es para un usuario de la parte dentral centro del departamento del Tolima, ubicado en la región sur-oeste de Colombia.

Tabla 1. Tarifa cobrada por Alcanos de Colombia, Diciembre de 2008

| Básico (0-20m3) | | | | |
|---|---|---|---|---|
| Estrato | Valor | Subsidio | Valor a Facturar | Porcentaje del Subsidio |

| | | | | |
|---|---|---|---|---|
| 1 | 694,95 | 354,6 | 339,99 | 51,06% |
| 2 | 701,07 | 288,84 | 412,23 | 41,20% |

Fuente: Alcanos de Colombia 2009

## 2.2 Brasil

El desafío de universalizar el servicio de energía eléctrica en Brasil es proporcional al alto grado de desigualdad social y regional del país, existiendo una gran fracción sin recursos económicos suficientes y con escasas posibilidades de ser atendida.

La tabla 2 muestra las tarifas residenciales vigentes en 2008 cobradas por las principales empresas. Estas están ordenadas desde la empresa con mayor tarifa hasta la empresa con menor tarifa. Actualmente la empresa con menor tarifa residencial (Eletropaulo) cobra 56,74% del valor de la mayor tarifa que en este caso es de la Enersul. Esto significa que un consumidor residencial de Mato Grosso do Sul (área de actuación de la Enersul) gasta con energía eléctrica mucho más que un usuario de la capital paulista, demostrando que las diferencias entre regiones no son llevadas en cuenta a la hora de definir las tarifas. Las ventajas observadas en la área de concesión de la Eletropaulo, que tiene las características de un mercado amplio y concentrado, no son divididas con los consumidores de la área de concesión de la Enersul en donde el mercado es menor y mucho mas disperso.

Tabla 2. Tarifas Residenciales vigentes hasta 2008 – Principales Empresas (R$ por KWh).

| Concessionária | Área de atuação | Valor Tarifa Residencial (R$/KWh) | Índice Tarifa |
|---|---|---|---|
| Enersul | Mato Grosso do Sul | 0,43364 | 100,00 |
| Cemig | Minas Gerais | 0,43315 | 99,89 |
| Celtins | Tocantins | 0,42854 | 98,82 |
| Cataguazes-Leopoldina | Parte de Minas Gerais | 0,41928 | 96,69 |
| Cemar (interligado) | Maranhão | 0,37708 | 86,96 |
| Coelba | Bahia | 0,36964 | 85,24 |
| Cepisa | Piauí | 0,36160 | 83,39 |
| Ampla | Parte do Rio de Janeiro | 0,35973 | 82,96 |
| Saelpa | Paraíba | 0,35072 | 80,88 |
| Ceal | Alagoas | 0,34190 | 78,84 |
| Celpe | Pernambuco | 0,33822 | 78,00 |
| Coelce | Ceará | 0,33338 | 76,88 |
| RGE | Parte do Rio Grande do Sul | 0,32974 | 76,04 |
| Cemat (interligado) | Mato Grosso | 0,32881 | 75,83 |
| Energipe | Sergipe | 0,31018 | 71,53 |
| Boa Vista | Capital de Roraima | 0,30330 | 69,94 |
| Light | Parte do Rio de Janeiro | 0,30180 | 69,60 |
| CEEE | Parte do Rio Grande do Sul | 0,30071 | 69,35 |
| Celesc | Santa Catarina | 0,30017 | 69,22 |
| Elektro | Parte de São Paulo | 0,29865 | 68,87 |
| Celg | Goiás | 0,29353 | 67,69 |
| AES - Sul | Parte do Rio Grande do Sul | 0,29117 | 67,15 |
| Escelsa | Espírito Santo | 0,28916 | 66,68 |
| Cosern | Rio Grande do Norte | 0,28797 | 66,41 |
| CER | Estado de Roraima | 0,28066 | 64,72 |
| Ceam | Amazonas | 0,27847 | 64,22 |
| CPFL - Piratininga | Parte de São Paulo | 0,27464 | 63,33 |
| Manaus - Energia | Manaus - Capital | 0,27322 | 63,01 |
| Celpa (interligado) | Pará | 0,26786 | 61,77 |
| Bandeirante | Parte de São Paulo | 0,26782 | 61,76 |
| Copel | Paraná | 0,25555 | 58,93 |
| CEB | Distrito Federal | 0,25162 | 58,03 |
| Eletropaulo | Parte de São Paulo | 0,24606 | 56,74 |

Fuente: DIESSE (2007)

## 3. Algunos Programas

### 3.1 Tarifa Social en Brasil

Hasta 1995 los usuarios de energía eléctrica en Brasil usufruiron menores tarifas en los primeros kilovatios-hora consumidos. Las tasas de descuento disminuían a medida que aumentaba el consumo, hasta llegar a un límite a partir del cual se cobraba la tarifa plena. Esta fué una de las medidas usadas para dar atención a la demanda de la población carente y se caracterizó como espacio de implementación de políticas de redistribución de renta. La estructura inicial estuvo basada en subsidiar a las clases más pobres a través de las clases más ricas. Existía el criterio de imprimir precios mas altos a medida que el consumo fuera mayor, considerando que riqueza y nivel de consumo son directamente proporcionales. Esta medida terminó favoreciendo segmentos de la población diferentes a las clases mas pobres. Hasta los domicilios de alta renta llegaron a tener descuento en los primeros kWh/mes consumidos. La dificultad estuvo en identificar los domicilios que podrían ser favorecidos con esta medida. (BERMANN, 203)

La portaria 5/11/1.995 del Departamento Nacional de Aguas y Energía Eléctrica (DNAEE) creó la sub-clasificación “Residencial de Baja Renta”. La población clasificada de esta forma seria beneficiada por los descuentos según el consumo y la otra parcela, clasificada como clase “Residencial” tendrían tarifa con descuento. La Tarifa Social de Baja Renta fué creada por el Gobierno Federal con la publicación de la Ley nº 10.438, de 26 de abril de 2002, y reglamentada por las Resoluciones de la Agencia Nacional de Energía Eléctrica (ANEEL) nº 246/02 e nº 485/02. Actualmente la definición de los parámetros para inclusión de los consumidores de baja renta es homologada por la entidad reguladora.

La “Tarifa Social de Baja Renta” es un descuento en la cuenta de energía eléctrica que puede ser concedido para clientes residenciales con un consumo igual o inferior a 220 kWh. El descuento varía de acuerdo con el rango en el consumo de energía y otros criterios. En el caso de la Eletropaulo son explicados en la tabla 3. Estos descuentos fueron definidos por la Resolución Homologatoria N° 675 de 2.008 así:

Tabla 3 : Criterios para la aplicación de la Tarifa de Baja Renta por la Eletropaulo

| kWh | Desconto | Critérios |
|---|---|---|
| Até 30 | 66,13% | Cliente con consumo médio de hasta 79 kWh por mes (últimos 12 meses)<br>- La instalación eléctrica debe estar conectada en un circuito monofásico con tensión nominal de 115/230 V.<br>- En los últimos 12 meses no puede Haber consumos mensuales superiores de 120 kWh.<br>- La instalación debe ser responsabilidad de la persona física. |
| 31 a 80 | 41,95% | |

| | | |
|---|---|---|
| 81 a 100 | 41,69% | Cliente com consumo médio entre 80 e 220 kWh por mês (últimos 12 meses).- La instalación eléctrica debe estar conectada en un circuito monofásico con tensión nominal de 115/230 V.<br>- Los ingresos familiares deben ser de hasta R$ 120,00 por persona.<br>- El responsable por la cuenta de energía debe estar inscrito en el cadastro único (CadUnico) o demostrar que pertenece a la família cadastrada en el CadUnico y ser beneficiario del Programa Bolsa Familia. |
| 101 a 200 | 12,54% | |
| Acima de 201 | 2,82% | |

Fuente: Eletropaulo 2.009.

Según AGUIAR (2.008) entre 1.996 y 2.003 los gastos de los domicilios brasileros con relación a energía eléctrica variaron entre -4% a -15% para las familias cuya renta es hasta 5 salarios mínimos[87]; sin embargo la tarifa aumentó 52%, mientras el consumo en consumo de energía tuvo una reducción media de 46% para el Brasil metropolitano. El aumento de las tarifas en parte fué consecuencia del racionamiento entre 2.001 e 2.002 y la privatización de las empresas de energía.

Los gastos con energía eléctrica representan una parcela mayor en las clases de mas bajos ingresos. Entre mas altos son los ingresos, la canasta energética es más diversificada. Adicionalmente, según la canasta energética básica propuesta por BERMANN (2.003) para satisfacer las necesidades básicas de una familia de 5 personas los requerimientos serían los siguientes:

Electricidad: 220 kWh/mes, GLP: 13 kg/mes, Diesel: 380 litros/ano.

Estos valores para las familias cuyos ingresos alcanzan hasta un salario mínimo[88] representan 34.2% de su presupuesto mensual, 11,4% para las familias con hasta 3 salarios mínimos, e 11.4% hasta 5 salarios mínimos. Como

---

[87] Segundo datos Departamento Intersindical de Estadística y Estudios Socioeconómicos (DIEESEE) un salário mínimo brasilero en enero de 2.009 R$415. El salario mínimo indicado por la misma institución para octubre de 2.008 fué de R$2.014. Este salario atenderia las necesidades vitaes básicas y las de la familia como vivienda, alimentación, salud, placer, educación, vestuario, higiene, transporte y aportes a pensiones y salud.

[88] Según el Departamento Intersindical de Estadística y Estudios Económicos (DIESSE) para febrero de 2009 el salario mínimo fué de 465 reales equivalente a USD 202.

muestra la tabla 4 el número de domicilios que reciben hasta 1 (un) salario mínimo en Brasil es elevado.

Tabla 4 - Domicilios particulares permanentes urbanos, total e respectiva distribución porcentual, por clases de rendimiento mensual domiciliar per-capita, por regiones 2005

| Grandes Regiones | Domicílios particulares permanentes urbanos | | | | | | |
|---|---|---|---|---|---|---|---|
| | Total (1) | Distribución porcentual, por classes de rendimento mensal domiciliar *per capita* (salário mínimo) (%) | | | | | |
| | | Até 1/2 | Mais de 1/2 a 1 | Mais de 1 a 2 | Mais de 2 a 3 | Mais de 3 a 5 | Mais de 5 |
| Brasil | 44 860 739 | 20,7 | 26,7 | 25,2 | 9,5 | 7,7 | 7,3 |
| Norte | 2 798 223 | 31,8 | 30,9 | 20,7 | 6,4 | 5,1 | 3,5 |
| Nordeste | 9 762 476 | 39,7 | 29,6 | 16,1 | 4,8 | 3,9 | 3,7 |
| Sudeste | 21 999 875 | 13,7 | 25,4 | 28,4 | 11,1 | 8,9 | 8,8 |
| Sul | 6 993 357 | 12,5 | 23,8 | 30,2 | 12,7 | 10,2 | 8,7 |
| Centro-Oeste | 3 306 808 | 19,2 | 29,5 | 24,2 | 9,0 | 7,5 | 8,5 |

Fuente: IBGE Pesquisa Nacional por Muestra de Domicílios, 2005.

Para SAUER (2.003), las medidas introducidas a partir de 1.995 en cuestión tarifaria ocasionaron el desestímulo para el desarrollo social y económico, proporcionado por políticas de subsidios regionales, sectoriales y de distribución de renta. Como puede ser observado en la tabla 5.

Tabla 5. Aumentos en la tarifa de usuarios residenciales (Eletropaulo): jun/94 a jul/02

| Franjas de Consumo | Para consumidores que permanecieron en la | Para consumidores que perdieron la condición de |
|---|---|---|

| | clasificación de baja renta % | baja renta % |
|---|---|---|
| Até 30 kWh | 332,6% | 1.171,8% |
| De 31 até 100 kWh | 194,2% | 404,5% |
| De 101 a 200 kWh | 144,7% | 179,8% |

Fuente: SAUER (2.003) apud DNAEE, 1.995, ANEEL 2.001.

4.2 Vale-Gás en Brasil

A partir del Decreto N° 4.102 de 2.002 se instituye el Programa "Auxílio-Gás", destinado a subsidiar el precio del gas liquido de petróleo GLP a las famílias de baja renda. Los recursos necesarios para bancar el Programa son provenientes de la Contribución de Intervención en el Dominio Económico –CIDE-, incidente sobre la importación y la comercialización de petróleo y sus derivados, gas natural y sus derivados, y alcohol combustible, instituida por la Ley N°10.336, de 19 de diciembre de 2001. Las familias cobijadas con este beneficio deberían cumplir con los siguientes requisitos: Tener ingresos mensuales per capita máximos y equivalentes a medio salario mínimo definido por el Gobierno Federal y atender por lo menos una de las siguientes condiciones cadastrales:

- Ser integrante del Cadastramiento Único para Programas Sociales del Gobierno Federal, creado por el Decreto N° 3.877, de 24 de julio de 2001;

- Ser beneficiaria de los programas "Bolsa Escola" o "Bolsa Alimentação", o estar cadastrada como potencial beneficiária de esos programas.

El valor de este beneficio mensual seria de R$ 7,50[89] (siete reales y cincuenta centavos) y serian pagos bimestralmente a la madre o, en su ausencia al responsable por la familia. De la misma forma que la Tarifa de Baja Renta, este programa es financiado por la CIDE que es cobrada sobre los combustibles.

[89] En diciembre de 2.008 um dólar equivalia a R$2,33

**Mediante Decreto N° 6.392 de 12 de marzo de 2.008 se establece que la validad de los beneficios conseguidos en el ámbito del Programa "Auxilio- Gás" finaliza el 31 de diciembre de 2.008.**

4.3 Programa de Masificación del GLP en Colombia

Según el Pan Energético Nacional 2.003-2.020, PEN 2.003-2.020, el mercado de GLP era restringido por 4 factores : oferta restringida; el conflicto armado y la inseguridad en el campo; la informalidad de los agentes del mercado y el deterioro del parque de cilindros. El mercado del GLP, se ha caracterizado por ser un mercado marginalmente deficitario, donde la demanda siempre ha estado supeditada a la oferta.

La informalidad de la industria del GLP fué uno de los puntos a ser mejorados en la visión del PEN de 2.003. Esta era ocasionada en parte por la aparición de intermediarios que hacían las tareas de subdistribución y lugares de venta no apropiados, sin cumplir normas técnicas y de seguridad. En gran medida la razón de la informalidad fué catalogada como consecuencia de la ausencia de marca de los cilindros Entonces fué propuesto el establecimiento de un esquema de marca que ordenaría y formalizaría el mercado, entre otros puntos. A continuación se resaltan los puntos del plan de masificación del GLP, propuesto en el PEN 2.003-2.020:

Cuadro 1. Plan de Masificación del Gas Licuado de Petroleo –GLP-

| |
|---|
| Establecer sistema de marcas y propiedad en los cilindros |
| Liberar las restricciones sobre el tamaño de los cilindros |
| Incrementar la producción de GLP mediante las modificaciones que sean necesarias en el equipamento y operación de las refinerías. |
| Facilitar las importaciones adaptando puertos y sistemas de transporte |
| Relanzar el programa GLP para el campo |
| Mejorar las condiciones de seguridad para la distribución del GLP |
| Sincerar los precios del GLP en las grandes ciudades en concordancia con la política de precios de los energéticos |

Fuente: UPME 2.004

Aún en el PEN 2.003-2.020 con respecto a la oferta, se planteó la posibilidad de incrementar las importaciones de Venezuela por vía terrestre, para abastecer principalmente las zonas de frontera y áreas de influencia. Cuando la oferta de GLP fuese suficiente, se debería relanzar el programa de GLP para el campo, y mejorar las condiciones de seguridad para la distribución del GLP en el mismo, enmarcado en el objetivo gubernamental de seguridad democrática.

La penetración del gas natural en la principales ciudades del interior del País; la tendencia creciente del precio restringiendo las posibilidades de incursionar en nuevos mercados, un marco regulatorio que aún no se define con claridad, una baja gestión empresarial originada en la insuficiencia financiera de algunas empresas y la informalidad, entre otras, fueron algunas de las razones expuestas en el PEN, para explicar el no alcanzar la cobertura esperada con el GLP.

Según el PEN 2.006-2.020 ante estas circunstancias y en consonancia con los planteamientos incluidos en el Plan Nacional de Desarrollo 2.006, es necesario adelantar un programa para consolidar el uso de GLP como energético en la periferia de las ciudades, en las cabeceras municipales que no cuentan con el servicio de gas natural y en las áreas rurales, para lo cual será necesario desarrollar un esquema de mercado que permita alcanzar los mayores niveles de cobertura y calidad del servicio, así como un análisis de la potencialidad de nuevos usos que generen productividad y bienestar socioeconómico.

Las estrategias y acciones planteadas en este sentido son:

-Cuantificar la disponibilidad del GLP para usos energéticos

-Caracterizar la oferta del GLP incluyendo los aportes de los nuevos proyectos de producción.

-Estudiar y definir proyectos de la utilización de GLP de refinería, con orientación hacia el sector petroquímico.

-Desarrollar un programa para consolidar el uso de GLP como energético en la periferia de las ciudades, en las cabeceras municipales que no cuentan con el servicio de gas natural y en las áreas rurales.

-Adelantar un estudio donde se identifique el esquema de mercado y tecnologías de suministro que permita alcanzar los mayores niveles de cobertura y calidad del servicio.

-Definir el marco regulatorio e institucional que haga viable el desarrollo del sector del GLP, para lo cual se deberán tener en cuenta temas institucionales, de comportamiento de los agentes y de las tarifas.

-Por último, el Plan Nacional de Desarrollo 2.019 propone nuevamente un plan de masificación del GLP

Según la UPME la producción de GLP se mantuvo casi constante entre el periodo 2.002-2.007: 22,16; 24,09; 19,89; 20,02; 20,96 e 17,94 (MBPDC) Miles de Barriles por Dia Calendario.

## 4.4 Plan de Masificación de Gas Natural en Colombia

Según el CONPES (2.002), la política energética de comienzos de los 90, tuvo como uno de sus objetivos la masificación del gas en el interior del país. En 1991, mediante documento CONPES No. 2571 se aprobó el "Programa para la Masificación del Consumo de Gas", orientado a impulsar el gas en el interior del país como sustituto de recursos energéticos de alto costo y considerando la existencia de reservas importantes en la época. Dentro de los objetivos generales se planteó: i) promover el consumo masivo de gas natural y gas propano; ii) inducir el ahorro de energía términos de costos y de cantidades; iii) garantizar una oferta de energéticos flexible, suficiente y diversificada; y iv) estimular la inversión privada. Este plan además de tender a mejorar el problema de los subsidios eléctricos y utilizar un recurso abundante, iría sustituir al cocinol en los sectores residenciales mas pobres. En consecuencia las primeras instalaciones en la capital del País comenzaron por los estratos más bajos.

En 1.993 o documento CONPES, No. 2646, aprobó las estrategias de lo que en ese entonces se denominó "El Plan de Gas" y se establecieron acciones tendientes a garantizar la oferta del combustible mediante la continuidad en las actividades de exploración y explotación de nuevos yacimientos, la construcción de una red troncal de gasoductos, la ampliación del sistema de transporte existente y la conformación de un mercado en los sectores industrial, residencial y termoeléctrico.

Después de iniciado el proceso de mercado en el sector energético, el aumento en las tarifas de electricidad han creado un mercado cautivo para el gas, sobre todo, en el uso calórico del sector residencial, sustituyendo la energía eléctrica, e incrementando así la necesidad de expandir la oferta y la cobertura. La sustitución no solamente se dió para la electricidad sino que alcanzó también la leña.

Dada la importancia del gas natural en la canasta energética nacional, el Plan de Masificación de Gas, tanto en su componente de gas natural como de GLP, tiene un tratamiento específico dentro de los objetivos del PEN 2006-2025, esto considerando que la masificación del gas conlleva el establecimiento de políticas específicas de desarrollo de la demanda en todos los segmentos, incluyendo residencial, energía eléctrica, industria y exportaciones.

La política de masificación del gas natural ha dado cobertura en los estratos bajos de la población. Se estima que 85% del sector residencial atendido con gas natural corresponde a los estratos 1, 2 y 3. Como resultado de la política de masificación de gas, actualmente se presta el servicio a 4.175.425 usuarios residenciales en todo el país, 66.929 usuarios del sector comercial y 2.782 usuarios industriales.

Tabla 6: Número de Usuarios Residenciales conectados a la red de Gás natural, por estrato

| Número Total de Usuarios Residenciales Conectados por Estrato | | | | | |
|---|---|---|---|---|---|
| Estrato 1 | Estrato 2 | Estrato 3 | Estrato 4 | Estrato 5 | Estrato 6 |
| 669.381 | 1.536.681 | 1.350.808 | 364.724 | 155.203 | 98.628 |
| Pocentaje por Estrato (E) de Usuarios Residenciales Conectados | | | | | |
| 16% | 37% | 32% | 9% | 4% | 2% |

Fuente: UPME 2.007a.

### 4.4 Luz Para Todos en Brasil

El Gobierno Federal Brasilero, inició en noviembre de 2003 el Programa Nacional de Universalización para el Acceso y Uso de Energía Eléctrica: Luz para Todos, con fin de disminuir la exclusión en el servicio de energía eléctrica. La meta era llevar hasta finales de 2008, el servicio de energía eléctrica a más de 10 millones de personas del medio rural (2 millones de conexiones). Mediante Decreto nº 6.442 o Programa Luz para Todos fué prorrogado hasta el año 2010, con el objetivo de atender nuevas demandas provenientes Del crecimiento vegetativo y La fijación y retorno de las familias en el campo (MME, 2008). Hasta enero de 2009 fueron realizadas atendidas 9.5 millones de personas :2.9 en la región norte, 3.8 en la región nordeste, 1.9 en la región sudeste y 898 mil en la región sur. (MME, 2009)

El Programa es coordinado por el Ministerio de Minas, operado por la Eletrobrás y ejecutado por las empresas prestadoras del servicio de energía eléctrica y por las cooperativas de electrificación rural. Los fondos son provenientes del Gobierno Federal (~58%) a través de recursos de la "Conta de Desenvolvimento Energético"-CDE- de los Gobiernos de cada Estado y Municipio (13%), y a través de recursos propios de la empresa prestadora del servicio a través de la Reserva Global de Reversão –RGR-.

El Programa contempla atender la demanda de energía eléctrica en el medio rural a través de Extensión de la Red, de Sistemas de Generación Descentralizada con Redes aisladas, o con Sistemas de Generación Individuales.

El Programa observa algunas prioridades como proyectos de electrificación rural paralizados por falta de recursos, municipios con índice de atención de domicilios inferior a 85%, municipios con IDH inferior a la media del estado, comunidades damnificadas por construcción de hidroeléctricas, o por obras del sistema eléctrico, escuelas públicas, sentamientos rurales, proyectos para el desarrollo de agricultura familiar, atención a pequeños y medios agricultores, poblaciones dentro de reservas naturales y poblaciones en áreas de uso específico como minorías raciales, quilombolas e comunidades extrativistas.

## 4.5 Programas de Electrificación Rural y zonas no interconectadas en Colombia.

En Colombia existen dos fondos destinados a la construcción de infraestructura para universalizar el servicio: el Fondo de Apoyo para la Energización de las Zonas No Interconectadas - FAZNI el Fondo de Apoyo Financiero para la Energización de las Zonas Rurales Interconectadas – FAER, y un tercer fondo destinado a subsidiar usuarios ubicados en zonas de difícil gestión, áreas rurales de menor desarrollo y zonas subnormales urbanas conocido como Fondo de Energía Social – FOES.

El Fondo de Apoyo para las Zonas no Interconectadas FAZNI, fué creado por la Ley N° 633 de 2000 y regulamentado por el Decreto N°2884 de 2001. Su objetivo es financiar proyectos de generación de energía eléctrica no convencional, distribución eléctrica local e interconexión rural y rehabilitación de infraestructura existente en las zonas no interconectadas ZNI. El FAER fue creado mediante la Ley 788 de 2002 y reglamentado por el Decreto 3652 de 2003, su objeto es aportar recursos para desarrollar proyectos que lleven energía a las Zonas Rurales del Sistema Interconectado Nacional.

Los recursos FAZNI son provenientes de recaudar un peso ($1) por cada kWh despachado en el SIN, el cual es incluido en los precios que cobra el generador a los comercializadores y por lo tanto se traslada al usuario final en la fórmula tarifaria. En este caso son los entes territoriales, las empresas prestadoras del servicio de energía eléctrica y el IPSE los gestores de los proyectos de inversión para mejoramiento y nueva infraestructura eléctrica en las ZNI. El FAER tiene como fundo en el pago de un peso ($1) por cada kWh conducido por el Sistema de Transmisión del SIN, aporte que deben hacer las empresas transportadoras de energía y es trasladado al usuario vía el cargo de transmisión. El FOES se sostiene del 80% de las rentas de congestión producidas por efecto de las exportaciones de energía eléctrica al Ecuador. Los recursos recaudados por estos Fondos son cuantiosos, sin embargo su ejecución no ha tenido un buen ritmo, especialmente en el caso de FAZNI, debido a la escasez de proyectos estructurados que garanticen su sostenibilidad. (UPME, 2007b)

Aunque se han realizados proyectos en las zonas no interconectadas ZNI (regiones aisladas geográficamente) con recursos provenientes del presupuesto nacional, de los fondos de regalías y FAZNI, la cobertura del servicio de energía eléctrica es del 34% y el 96% de la generación proviene de plantas térmicas que utilizan como combustible ACPM y no se han aprovechado los potenciales energéticos de cada región (UPME, 2007b). La tabla 7 muestra el número de usuarios conectados por departamento en el periodo 2003-2007.

Tabla 7. Usuarios Beneficiados por los fondos FAZNI y FAER

por departamento 2003-2007

| Departamento | Usuários FAER | Usuarios FAZNI |
|---|---|---|
| Amazonas | | 12557 |
| Antioquia | 2947 | 729 |
| Arauca | 61 | |
| Bolívar | 139 | |
| Boyacá | 3044 | |
| Caldas | 306 | |
| Caquetá | 346 | 5462 |
| Casanare | 223 | 84 |
| Cauca | 8067 | 3658 |
| Choco | | 4581 |
| César | 176 | |
| Córdoba | 310 | |
| Cundinamarca | 860 | |
| Guania | | 116 |
| Guaviare | | 912 |
| Huila | 1037 | |
| La Guajira | 350 | |
| Magadalena | 406 | |
| Meta | 34 | 5063 |

| | | |
|---|---|---|
| Nariño | 1579 | 6533 |
| Norte de Santander | 2853 | |
| Putumayo | 1016 | 867 |
| San Andrés | | 4282 |
| Santander | 1182 | |
| Tolima | 2149 | |
| Valle | 511 | |
| Vaupés | | 1860 |
| Vichada | | 867 |
| Total | 27596 | 47571 |

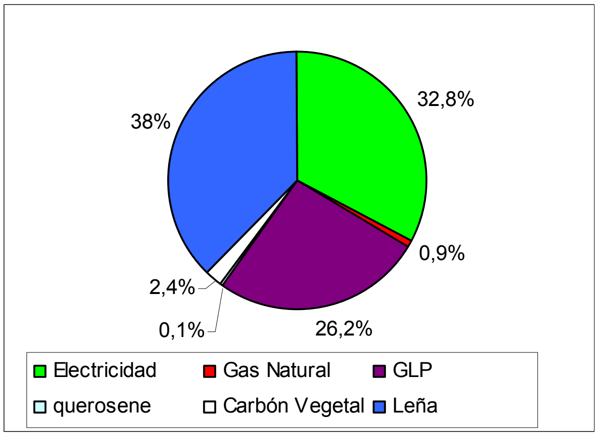
Fuente: UPME 2009

Para tener una idea de lo que significa el número de usuarios cobijado por los fondos FAZNI es relevante tener en cuenta que las zonas no interconectadas en Colombia: ocupan 66 % Territorio Nacional, 89% de su población es de carácter rural, abarcan 14 Departamentos, 4 Capitales departamentales, 12 Grupos territoriales, 44 Cabeceras municipales , 105 Municipios , 1.199 Localidades, 112.052 Usuarios atendidos, 92 Entes prestadores, 116 Plantas Diesel, 2 PCH, 116.00 KW diesel instalados (IPSE,2008).

5. Estructura de Consumo en el sector residencial de los dos países:

Las semejanzas en la estructura de consumo del sector residencial en los dos países muestra que una gran fracción corresponde a electricidad. En Colombia la participación de GLP y leña es semejante, siendo que la leña en los últimos años ha sido desplazada por el uso del GLP en las áreas rurales, definiendo nuevos patrones de consumo. El gas natural se ha posicionado cubriendo gran parte de las necesidades de cocción en las grandes ciudades y periferias urbanas. En Brasil la leña aún ocupa un reglón importante y el uso del GLP tiene cobertura nacional. Este último es distribuido en todo el país y su consumo deberá aumentar conforme el crecimiento demográfico y número de domicilios. Los gráficos siguientes muestran la participación de cada energético en el sector residencial de los dos países.

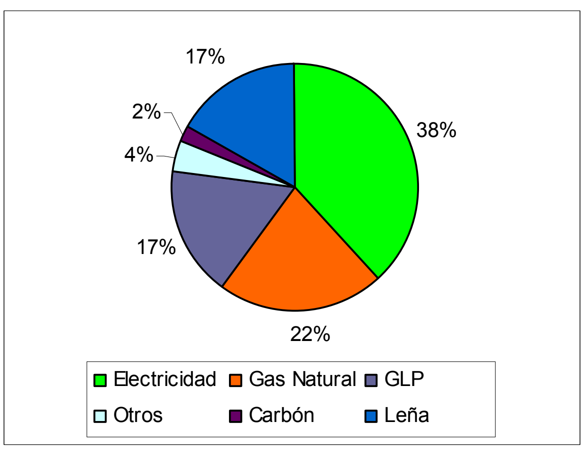
Gráfica 1. Consumo total de energía en el sector residencial, Brasil-2005




Fuente: EPE 2008, p342

Gráfica 2. Consumo Final de Energía Sector Residencial en

Colombia-2005




Fuente: UPME, 2007b, p 61.

Conclusiones

Mientras que en Colombia el cobro de los servicios públicos es basado en la estratificación social de los usuarios, en Brasil las diferencias socio-econômicas no son observadas en el modelo tarifario, prevaleciendo la estructura de costos propuesta por cada empresa. El aumento en las  tarifas de energía eléctrica en Brasil fué diferenciado por empresas y por regiones, regiones menos desenvueltas fueron afectadas por mayores aumentos.

En Brasil los beneficios de Programas como el Vale Gás y la Tarifa Social depende del usuario estar incluido en otros programas sociales que pueden no estar relacionados con la prestación de servicios públicos. En Colombia los subsidios y contribuciones establecidos por el esquema de estratificación social vienen incluidos en la factura.

En Colombia con del Plan de Masificación del Gas Natural se diversificó la canasta energética en sectores de la población con características económicas más frágiles. En Brasil el GLP tiene gran importancia social. Su substitución por el gas natural se puede dar más fácilmente en áreas urbanas dependiendo de la extensión de la infraestructura, la cual todavía es reducida, en número.

En Colombia, a pesar de no estar consolidado el Programa de Masificación del GLP, este energético comparte una fracción semejante a la del gas natural en el consumo del sector residencial. La demanda de GLP depende de la oferta la cual se mantiene constante desde 2002

Ambos países presentan programas de energización rural, mostrando alguna cobertura en el caso colombiano a través de los fondos FAZNI y FAER pero con una gran área de ZNI sin servicio de energía eléctrica. En Brasil el servicio de energía eléctrica en el sector rural viene presentando una tendencia creciente a través del Programa Luz para Todos

Bibliografía:

AGUIAR, Anna Cecília J de Aguiar; et al. Tarifas de Energia Elétrica e o Consumo. Em: XII Congresso Brasileiro de Energia –CBEXII-. Anais 2.008, Rio de Janeiro RJ, p 1.251-1.255.

ALCANOS DE COLOMBIA S.A. Tarifas: Zona Huila y sur del Tolima. Disponible en: http://www.alcanosesp.com/archivos.php?zona=0, acceo en enero de 2009.

ALZATE, Maria Cristina. La estratificación socioeconómica para el cobro de los servicios públicos domiciliarios en Colombia ¿Solidaridad o focalización?. CEPAL. Bogotá, Setembro de 2.006. 101 p.

BERMANN, Célio. Energia no Brasil: para quê, para quem?. Crise e Alternativas para um país sustentável. Ed Livraria da Física: FASE, 2.003. São Paulo. P 53-67.

BRASIL, Presidência da República. Decreto N° 4.102 de 2.002. Brasília D.F.

BRASIL, Presidência da República. Decreto N° 6.392 de 2.008.Brasília D.F.

COLOMBIA, Congreso de la República. Ley 142 de 1.994, Servicios Públicos. Bogotá-D.C.

CONSEJO NACIONAL DE POLITICA ECONOMICA E SOCIAL. CONPES 3190 (2.002). Balances e Estrategias a seguir para impulsar el Plan de Gasificación del Gas Natural. Ministerio de Minas y Energia, Departamento Nacional de Planeación. Bogotá- Colombia.

Departamento Intersindical de Estadística y Estúdios Sócio-Económicos (DIESSE, 2007). As Tarifas de Energia Electrica no Brasil: sistemática de correção e evolução dos valores. Em: Nota Técnica N° 58, dezembro de 2007. 14p.

ELETROPAULO. Tarifa de Baixa Renda. Diponible en: http://www.eletropaulo.com.br/portal/page.cfm?Conteudo_ID=1348&desc=Tarifa%20Social%20Baixa%20Renda&origem_id=640. Acceso em Enero de 2.009.

EMPRESA DE PESQUISA ENERGÉTICA (EPE), 2007. Plano Nacional de Energia 2030, Ministério de Minas e Energia, Rio de Janeiro.

Instituto de Planificación y Promoción de Soluciones Energéticas para zonas no interconectadas. IPSE(2008).Cobertura IPSE en las ZNI. Disponible en: http://asp2.netco.net.co/webipse.nsf/busc/C60D20D455B33264052570760001OEAA.

KOZULJ, Roberto. Contribución de los servicios energéticos a los Objetivos de Desarrollo del Milenio y a la Mitigación de la Pobreza: Análisis para los países de América del Sur. Bariloche, Argentina. Mayo de 2.008. 60 p.

Ministerio de Minas e Energia.(MME, 2008) Informativo Luz Para Todos N°9. Disponible en: http://luzparatodos.mme.gov.br/luzparatodos/downloads/Informativo%2009.pdf, acceso en enero de 2009.

Ministerio de Minas e Energia. (MME,2009). Personas atendidas por region (mapa) http://luzparatodos.mme.gov.br/luzparatodos/downloads/Informativo%2016.pdf acceso ene enero de 2009.

SAUER, Ildo Luis; et al. A Reconstrução do Setor Elétrico Brasileiro. Ed. UFMS: Campo Grande, MS, Ed Paz e Terra: São Pãulo. Abril de 2.003. Brasil. P 19-26.

UNIDAD DE PLANEACION MINERO ENERGÉTICA.(UPME, 2004). Ministerio de Minas y Energia. Plan Energético Nacional 2003-2020: Estrategia Energética Integral. Bogotá, Colombia. 116 pg.

_________.(UPME, 2007a). Ministerio de Minas y Energía, Boletín Estadístico de Minas y Energía. 2.002-2.007. 195 p. Bogotá, Colombia. 132 pg

__________.(UPME, 2007b). Ministerio de Minas y Energía. Plan Energético Nacional 2006-2020: Contexto y Estrategias. Bogotá, Colombia. 240 pg.

UNIDAD DE PLANEACION MINERO-ENERGÉTICA (UPME), 2009. *Boletín Estadístico de Minas y Energía 2003-2008*, Ministerio de Minas y Energía, Bogotá.

# 23. Avaliacao Ex Post do Programa Brasileiro de Electrificao Rural “Luz para todos”

**ALEXANDRE COSME JOSÉ JERONYMO -SINCLAIR MALLET GUY - GUERRA**

Universidade Federal do ABC (UFABC)

Rua Catequese, 242, Bairro Jardim, Santo André/SP, Brasil. CEP: 09090-400

Resumo: Um dos vetores que estruturam o desenvolvimento social e econômico é o acesso à eletricidade. Sabe-se que a exclusão elétrica no meio rural é mais intensa se comparada com o meio urbano. Para enfrentar e implementar a solução deste problema no meio rural brasileiro foi constituído, através do Decreto nº 4.873, de 11 de novembro de 2003, o Programa Nacional de Universalização de Acesso e Uso da Energia Elétrica - “Luz Para Todos”. A proposta inicial do Programa foi conectar 2 milhões de famílias, o que representaria cerca de 10 milhões de pessoas, com renda de até três salários mínimos e em todo território nacional. O objetivo desta pesquisa é desenvolver análise qualitativa através dos resultados do Programa “Luz Para Todos” (2.004-2.008) identificando os sucessos que apontam para a inclusão no sistema de energia elétrica nacional cerca de 10 milhões de pessoas, a fixação do camponês no campo seqüenciada pela reversão de grave quadro de êxodo rural; e as suas insuficiências que indicam a vulnerabilidade do Programa quando se tenta implantá-lo sem o comprometimento em reconhecer as particularidades e características regionais. As ferramentas utilizadas para a confecção deste trabalho são as informações oficiais, Teses e Dissertações, artigos que tratam do tema eletrificação rural. Ademais o período identificado para o desenvolvimento da pesquisa é o mesmo que fora implantado inicialmente para o início e término do Programa “Luz para Todos”.

Palavras - chave: Política Pública, Eletrificação Rural, Acesso e Uso da Eletricidade.

## INTRODUÇÃO

Para o Estado brasileiro existe uma consistente dicotomia envolvendo ilhas de prosperidade e pobreza, elevados Índices de Desenvolvimento Humano acompanhados das suas piores taxas. Essas características recordam o fenômeno designado como dualismo social[90], ou seja, uma sociedade moderna e avançada economicamente contrastando com considerada parcela do

[90] Ver Jaguaribe (2000).

contingente populacional sobrevivendo e/ou subsistindo em condições de miserabilidade urbana e rural.

A construção e o enrijecer deste dualismo social recebeu sementes e cuidados a partir das realidades concretas que envolvem a má distribuição de renda, concentrações de poder econômico e político, desequilíbrios regionais, intensa ondas migratórios seguidas de urbanização acelerada e desenfreada, etc. Ainda encontra-se dentre os fenômenos tributários daquele dualismo social a ineficiência e/ou ausência de acesso ao abastecimento de eletricidade em zonas rurais. Um dos resultados objetivos desta condição foi traçado por Sauer (2003), cirurgicamente. "*A energia elétrica pode ser encarada como fator de promoção da qualidade de vida, de produção, desenvolvimento econômico e geração de emprego e renda. A exclusão social também se dá por falta de acesso a energia*" (Sauer, 2003: 39).

Com o fito em estender a eletricidade até as regiões não abastecidas pela rede de energia elétrica foram desenvolvidos os primeiros projetos de eletrificação rural, ao longo do território brasileiro. Em geral, tais projetos, eram classificados como investimentos pelos seus proponentes. "*Quem pretendesse ter atendimento de energia elétrica no meio rural era obrigado a fazer investimentos, muitas vezes de grande monta, sendo garantidas as concessionárias o retorno breve dos investimentos efetuados*" (Camargo et alli, 2008: 22). Ademais, esteve imersa à própria atividade de conexão, a difusão da prática excludente e pré-concebida da Engenharia de Distribuição. Strazzi (2008) argumenta sobre esta característica.

A tradição da eletrificação rural é farta em programas implementados pelas próprias concessionárias de energia elétrica, praticando Engenharia de Distribuição com alto teor de preciosismo, com critérios de cadastramento fortemente excludentes e com alto custo por ligação, tornado-a proibitiva ao pobre rural" (Strazzi, 2008: 21).

Esses dois elementos, os investimentos e a Engenharia de Distribuição, não consideram a importante função social da eletrificação rural ao desconhecerem a realidade econômica das famílias sem eletricidade. O custo elevado deste acesso também representava a longevidade ou a não continuidade do projeto.

Através do Programa de eletrificação Rural "Luz Para Todos" tornou-se possível o acesso integral à eletricidade para famílias rurais com renda até três salários mínimos mensais. Uma análise "*ex-post*" deste programa constitui-se em ferramenta que contribui para conhecer alguns dos elementos que indicam o seu sucesso e identificar quais são as suas insuficiências.

O objeto deste estudo é o primeiro período para implantação do Programa Nacional de Acesso e do Uso da Energia Elétrica "Luz Para Todos" (2004 – 2008). O objetivo desta pesquisa foi analisar o Programa "Luz Par Todos" a partir dos seguintes elementos: A) comparar quantidade de conexões necessárias no meio rural com o montante de conexões efetivadas no meio rural; B) o Programa "Luz Para Todos" como ferramenta que auxilia a fixação do camponês no campo; C) os elementos que permitem viabilizar e/ou dificultar a difusão da eletrificação rural em cada Estado.

Conclui-se que as particularidades de cada um dos Estados (econômica, social e ambiental) necessitam maior atenção do poder público durante o processo desenho da política de eletrificação e que o Programa cumpre parcialmente com o êxodo rural.

A FUNÇÃO SOCIAL DA ELETRIFICAÇÃO RURAL

Em minuciosa análise sobre a inserção de tecnologias para consumo energético em comunidades rurais, Serpa (2001) considera que é este um processo de intensa mudança cultural. Inserido neste processo está à modificação nos hábitos de consumo destas comunidades, a qual, em geral, passa a utilizar como uso final: a iluminação, o entretenimento, a informação, o acondicionamento de alimentos e ampliação das horas de estudo (Camargo et alli, 2008: 23; Lobão, 2008; Costa et alli, 2003). Ademais, também foram detectadas melhorias na infra-estrutura de material para construção civil e de saneamento (água e esgoto) das residências (Khan e Silva, 2007).

As modificações presentes nos hábitos de consumo das famílias rurais que passam a usufruir das benesses derivadas da transferência de tecnologias são muitas, porém, em geral, ao se destacar o que é consumido pelos seus usuários fica evidente a importante função social da eletrificação rural[91]. Ademais, a própria legislação destaca que a eletricidade é um serviço público e que, portanto, o público, onde quer que esteja, necessita atendimento. Assim roga a Lei n° 7.783, de 28 de junho de 1989. "*Artigo 10 - São considerados serviços ou atividades essenciais: I - tratamento e abastecimento de água; produção e distribuição de energia elétrica, gás e combustíveis*" (Constituição da República Federativa do Brasil, 1989).

Através dos programas de eletrificação rural "o Luz da Terra" e "Luz no Campo" houve repercussão e entrechoque sobre a função social da Eletrificação rural mediante a prática pré-concebida da Engenharia de Distribuição. O primeiro Programa foi publicado através do Decreto Estadual nº 41.187, de 25/09/1996, pelo governo do Estado de São Paulo, para elaboração do Programa de Eletrificação Rural "Luz da Terra" e a "Comissão de Eletrificação Rural do Estado de São Paulo" (CERESP), voltados ao desenvolvimento de um programa de eletrificação rural explicitamente social. O Programa Nacional de Eletrificação Rural "Luz no Campo" foi criado pelo governo federal através do

---

[91] Extravagâncias, excessos, consumos não necessário, produtos eletro-eletrônicos, salvo algumas exceções, em geral não são objetos correntes na "cesta energética" destas famílias.

Decreto Federal de 2/12/1999 para convergir com a prática da eletrificação rural social. Esses Programas balizaram o paradigma da eletrificação rural brasileira ao utilizar conceitos de Engenharia de baixo custo e técnicas simplificadas.

A execução dos Programas “Luz da Terra” e “Luz no Campo”, repassava aos interessados o ônus da conexão, entretanto, este repasse, favorecia para ocorrência da inadimplência entre os seus usuários, marginalizando-os, novamente, da conexão de energia elétrica. Um resultado desta marginalização - adicionado ao montante de famílias nunca conectadas – foi à dificuldade em satisfazer a demanda familiar rural interessada no sistema de eletrificação rural.

Através de pesquisa elaborada pelo Instituto Brasileiro de Geografia e Estatística (IBGE) / Pesquisa Nacional por Amostragem de Domicílios – 1997 (PNAD) foram indicadas as taxas de ausência de eletrificação rural, que se segue.

Tabela 1: Índice de eletrificação dos domicílios

| Situação | N◦ de domicílios | Domicílios sem eletricidade | Domicílios com eletricidade |
|---|---|---|---|
| Rural | 7.980.498 | 1.960.734 | 6.019.764 |

Nota: Não estão considerados os domicílios rurais de Rondônia, Acre, Amazonas, Roraima, Pará e Amapá.

Fonte: IBGE (1997) *apud* Bermann (2001: 51).

Bermann (2001) destaca que (...) “*o problema desta avaliação é que o PNAD apenas identifica a iluminação elétrica no seu levantamento*”. A falha do PNAD é a não consideração com os domicílios que obtêm a iluminação elétrica através de ligações clandestinas, ou através de pequenos geradores que utilizam recursos energéticos típicos para o espaço rural (gordura animal e ceras), mas também derivados do petróleo (gasolina e diesel). Nessas duas situações existe o consumo de eletricidade, porém, tal consumo, poderá vir a significar falta de qualidade, de segurança e de confiabilidade. Ademais, soçobra dúvidas sobre a quantidade conexões necessárias para suprir a demanda pela eletrificação rural no Brasil. A própria tabela 1 evidencia o quão precário são estes dados quando não há menção dos Estados da região Amazônica.

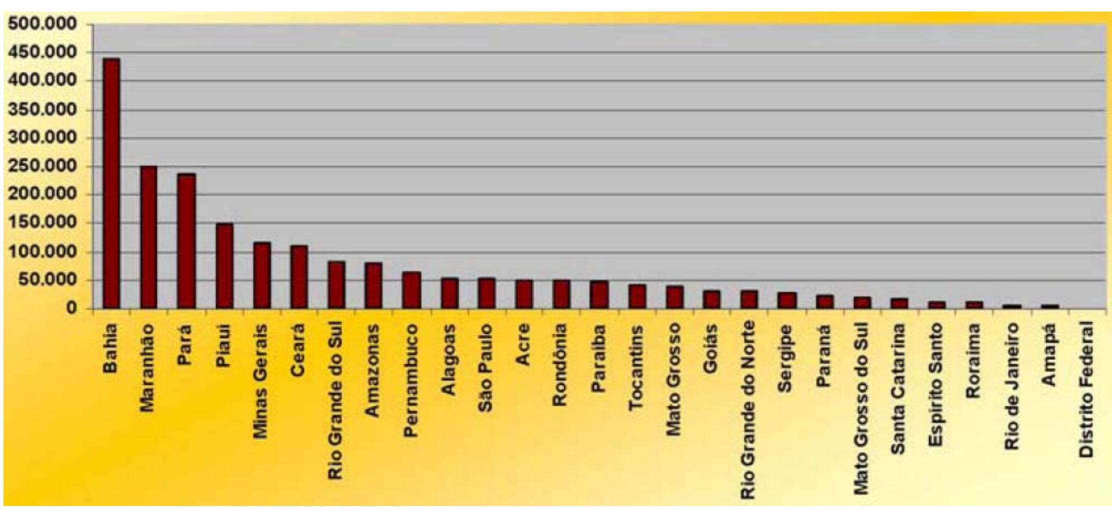
Foi estimada pelo Sistema de Informação Elétrico da Eletrobras (SIESE), através do boletim janeiro/junho de 1999, a demanda por eletricidade no meio rural, o qual acaba por questionar os valores expostos na tabela 1. Para tanto foi considerado os Estados isentos da contabilidade do PNAD (1997).

Segundo os dados do SIESE, o número de consumidores residenciais conectados regularmente às redes de distribuição de energia elétrica, tanto nos sistemas interligados Norte – Nordeste e Sul – Sudeste – Centroeste, como nos sistemas isolados localizados na região Amazônica, era de 38.668 mil domicílios em junho de 1999. Ou seja, dos 40.603 mil domicílios com iluminação elétrica identificados pelo IBGE na PNAD de 1999, cerca de 2.826,1 mil domicílios têm acesso à iluminação elétrica sem qualidade em termos de segurança e confiabilidade. Portanto, aos 2.248,3 mil domicílios sem iluminação elétrica, conforme os dados do PNAD / 1999, devem ser acrescentados estes outros, 2.826,1 mil domicílios, o que perfaz um total de 5.074,4 mil domicílios sem eletrificação no Brasil, ou cerca de 11,8% do total dos domicílios, perfazendo uma população total de cerca de 20,297,6 mil habitantes (Bermann, 2001: 56 - 57).

Os valores expostos na tabela 1 ilustram uma suntuosa diferença. Entretanto, para desenhar políticas públicas de eletrificação rural, o poder público federal utiliza os valores naquela tabela.

O gráfico 1, que se segue, apresenta os indicadores sobre ausência de eletricidade em unidades domiciliares, para cada um dos Estados. Perceba que os valores correspondentes coadunam com as taxas de ausência de eletrificação rural indicadas pelo IBGE / PNAD.

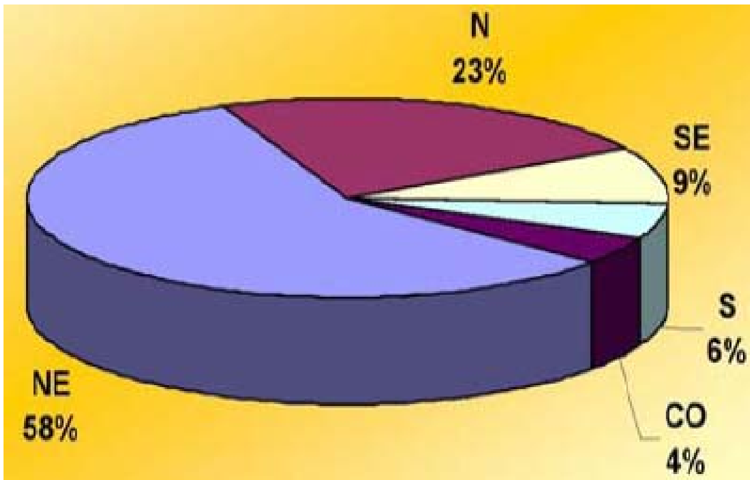
Gráfico 1. Números absolutos da exclusão elétrica rural por Estado da Federação




FONTE: Manual de Operacionalização do Programa "Luz para Todos" (2003: 6).

O gráfico 2, que se segue, apresenta o índice de exclusão de eletrificação rural para cada um dos Estados da federação.

Gráfico 2. Índice percentual de exclusão elétrica dos domicílios rurais, por Região




FONTE: Manual de Operacionalização do Programa "Luz para Todos" (2003: 7).

Com este cenário foi desenhada a Lei de Universalização do Atendimento, nº 10.438/2002, que implantou a não obrigatoriedade do interessado pelo acesso à eletricidade em arcar com os custos dos serviços de conexão.

Através do Decreto Federal n◦ 4.873/2003 passa a vigorar o Programa Nacional de Acesso e do Uso da Energia Elétrica "Luz Para Todos" orientado fundamentalmente para a eletrificação do espaço rural e para determinada parcela da sociedade brasileira.

A seguir, o Decreto n◦ 4.873/2003 e indicadores sobre ausência de eletrificação rural no País são considerados para a redação desta política pública.

O Decreto no 4.873, de 11 de novembro de 2003, instituiu o Programa "Luz Para Todos", destinado a propiciar, até o ano de 2008, o atendimento em energia elétrica à parcela da população do meio rural brasileiro que ainda não tem acesso a esse serviço público (MME, 2003: 4).

Existem atualmente cerca de 2 milhões de domicílios rurais não atendidos, correspondendo a 80% do total nacional da exclusão elétrica, ou seja, 10 milhões de brasileiros vivem no meio rural sem acesso a esse serviço público. Cerca de 90% dessas famílias possuem renda inferior a 3 salários mínimos (MME, 2003: 5).

O Programa “Luz Para Todos” é coordenado pelo Ministério de Minas e Energia (MME). A operação é feita pelas Centrais Elétricas Brasileiras (ELETROBRAS) e as empresas que compõem o sistema ELETROBRAS. O Programa oferece financiamentos e créditos para as empresas Concessionárias de eletricidade e as Cooperativas de Eletrificação Rural visando viabilizar economicamente as conexões e efetivar a universalização.

Para o atendimento da meta inicial, serão investidos R$ 12,7 bilhões. O Governo Federal destinará R$ 9,1 bilhões e o restante será partilhado entre governos estaduais e as empresas de energia elétrica. Os recursos federais são provenientes de fundos setoriais de energia - a Conta de Desenvolvimento Energético (CDE) e a Reserva Global de Reversão (RGR) (MME, 2003).

Existem três modalidades para conexão: “Extensão de Rede, Sistemas de Geração Descentralizada com Redes Isoladas e Sistemas de Geração Individuais” (MME 2003: 20). Ademais, existem critérios para definição das obras prioritárias. As obras que satisfizerem os maiores números de itens, os quais se seguem, serão contempladas.

● “Projetos de eletrificação rural paralisados, por falta de recursos, que atendam comunidades e povoados rurais;

● Municípios com Índice de Atendimento a Domicílios inferior a 85%, calculado com base no Censo 2000;

● Municípios com Índice de Desenvolvimento Humano inferior à média estadual;

● Comunidades atingidas por barragens de usinas hidrelétricas ou por obras do sistema elétrico;

● Projetos que enfoquem o uso produtivo da energia elétrica e que fomentem o desenvolvimento local integrado;

● Escolas públicas, postos de saúde e poços de abastecimento d’água;

● Assentamentos rurais;

● Projetos para o desenvolvimento da agricultura familiar ou de atividades de artesanato de base familiar;

● Atendimento de pequenos e médios agricultores;

● Populações do entorno de Unidades de Conservação da Natureza; e

● Populações em áreas de uso específico de comunidades especiais, tais como minorias raciais, comunidades remanescentes de quilombos e comunidades extrativistas" (MME, 2003: 20).

POLÍTICA MULTISSETORIAL DO PROGRAMA "LUZ PARA TODOS"

A elaboração de política pública que contemple os instrumentos para a sua aplicação e não considere os instrumentos para o seu desenvolvimento e estruturação poderá gerar uma política pública pouco efetiva. O Programa "Luz Para Todos" apresenta estrutura transversal (permite interação com diferentes Ministérios, o sistema ELETROBRAS, Cooperativas de Eletrificação Rural, Programas sociais), a qual favorece a sua própria implantação e fixação da família camponesa. O "Luz Para Todos" atua como política pública que dispõem de financiamentos e créditos para as famílias beneficiadas desenvolverem atividades que permitam a fixação no campo e ofereçam condições para geração de renda e redução da pobreza rural.

Barbosa (2002) argumenta sobre a importância da multissetorialidade no ato da formulação das políticas públicas e no planejamento dos processos de transformação social.

A abordagem multissetorial integrada pretende considerar o conhecimento da complexidade de uma dada realidade e não somente a intuição dos atores responsáveis pela sua modificação. Pretende encontrar soluções coordenadas, levando o planejamento estratégico para o plano social, desenhando ações apropriadas e articuladas para os problemas detectados, considerando-se a promoção de processos indutores de transformação social (Barbosa, 2002: 3).

Na acepção de Lobão (2008) o Programa "Luz Para Todos" (...) *é um instrumento de integração social e melhoria econômica das comunidades atingidas* (Lobão, 2008), ou seja, o próprio Programa não visualiza apenas atuação no processo de eletrificação em si, mas articula ações de desenvolvimento rural integrado que possibilitem o uso social e produtivo da energia elétrica.

O Programa LUZ PARA TODOS se integra aos diversos programas sociais e de desenvolvimento rural implementados pelo Governo Federal e pelos Estados, para assegurar que o esforço de eletrificação do campo resulte em incremento da produção agrícola, proporcionando o crescimento da demanda por energia elétrica, o aumento de renda e a inclusão social da população beneficiada (MME, 2003).

Neto et alli (2008) ao pesquisar a inserção de eletrificação rural através do Programa "Luz Para Todos", em assentamento rural no Estado do Ceará, enfatiza a importância da eletrificação vir acompanhada de Programas que possam servir como apoio para quem recentemente foi conectado ao sistema elétrico. "*Deve ser associado a outros vetores como infra-estrutura de transporte, e saneamento e políticas que possam aperfeiçoar seu uso trazendo além da saúde, lazer e educação a possibilidade de proporcionar geração de renda e permanência no campo*" (Neto et alli, 2008). Ao pesquisar indicadores para o desenvolvimento rural com a meta de universalização do acesso à eletricidade Gianinni et alli (2008) aponta para alguns outros elementos com atuação decisiva neste processo. [...] "*os resultados são influenciados por questões de políticas públicas transversais, além da eletrificação, como por exemplo: acesso a crédito, apoio técnico, associativismo, logística disponível, acesso ao mercado consumidor, entre outros* (Gianinni et alli, 2008).

## A PRESENÇA DO PRONAF

Atua em conjunto ao Programa "Luz Para Todos" o Programa Nacional Para Agricultura Familiar (PRONAF), o qual foi desenhado pelo governo federal em 1995. Este Programa está direcionado para o financiamento da agricultura familiar em todo território nacional e, através deste grupo social, promover o desenvolvimento rural e a geração de renda. A importância do PRONAF é identificada em muitas pesquisas (IPEA, 2006: 12). São os agentes financeiros Banco do Brasil e Banco do Nordeste quem concentram a quase totalidade das operações de crédito do PRONAF (PRONAF, 2006).

Dentre os itens financiáveis do PRONAF está a eletrificação rural. Certamente, os recursos oriundos deste Programa para o Programa "Luz Para Todos" afetaram positivamente a produção agrícola familiar beneficiada com a eletrificação. O desenho da política multissetorial se demonstra eficaz. A eficiência do Programa "Luz Para Todos" é destacada quando se coloca sob questionamento o montante de famílias beneficiadas ao longo dos primeiros quatro anos do Programa.

## A REVERSÃO DO QUADRO DE ÊXODO RURAL E ALGUNS REFLEXOS

Os efeitos da política multissetorial do Programa "Luz Para Todos" são velozes. Através do ínterim 2004 até maio de 2008 é possível identificar a quantidade de famílias beneficiadas pelo Programa.

A Tabela 2 indica a quantidade de unidades domiciliares conectadas e a quantidade de unidades domiciliares ainda sem conexão. O montante de conexões efetivadas aponta para o sucesso do Programa.

Tabela 2. Unidades Domiciliares (UD) rurais atendidades e não atendidas pelo Programa “Luz Par Todos” – até 05/2008

| Região / Estado | | UDs sem eletrificação rural | UDs atendidas com ER | UDs não atendidas com ER | Excedente de UDs atendidas |
|---|---|---|---|---|---|
| Norte | Amapá | 4.783 | 1.017 | 3.766 | ---------- |
| | Amazonas | 79.309 | 19.759 | 59.550 | ---------- |
| | Acre | 49.586 | 20.590 | 28.996 | ---------- |
| | Rondônia | 48.265 | 17.931 | 30.334 | ---------- |
| | Roraima | 9.815 | 3.202 | 6.613 | ---------- |
| | Tocantins | 39.963 | 26.035 | 13.928 | ---------- |
| | Pará | 236.050 | 155.747 | 80.303 | ---------- |
| Nordeste | Piauí | 149.638 | 29.984 | 119.654 | ---------- |
| | Bahia | 439.316 | 249.875 | 189.441 | ---------- |
| | Maranhão | 248.716 | 157.171 | 91.545 | ---------- |
| | Paraíba | 47.584 | 35.141 | 12.443 | ---------- |
| | Alagoas | 53.488 | 47.202 | 6.286 | ---------- |
| | Ceará | 110.825 | 98.793 | 12.032 | ---------- |
| | Pernambuco | 63.139 | 76.195 | ---------- | 13.056 |
| | Sergipe | 28.716 | 41.384 | ---------- | 12.668 |
| | RN[1] | 30.095 | 35.486 | ---------- | 5.391 |
| Sudeste | Minas Gerais | 115.314 | 208.231 | ---------- | 92.917 |
| | Espírito Santo | 10.162 | 38.481 | ---------- | 28.319 |
| | RJ[1] | 5.314 | 15.425 | ---------- | 10.111 |
| | São Paulo | 53.119 | 59.084 | ---------- | 5.965 |
| Centro- | Goiás | 30.845 | 27.288 | 3.557 | |

| | | | | | |
|---|---|---|---|---|---|
| Oeste | Mato Grosso | 38.758 | 57.169 | ---------- | 18.411 |
| | MS[1] | 20.350 | 24.409 | ---------- | 4.059 |
| | RS[1] | 81.476 | 59.636 | 21.840 | |
| Sul | Paraná | 22.791 | 36.094 | ---------- | 13.303 |
| | SC[1] | 17.377 | 33.720 | ---------- | 16.343 |
| Total | ---------- | 2.034.794 | 1.575.049 | 680.288 | 220.543 |

[1]RN (Rio Grande do Norte), RJ (Rio de Janeiro), MS (Mato Grosso do Sul) e RS (Rio Grande do Sul) e SC (Santa Catarina).

Fonte: Tabela elaborada pelo autor a partir do IBGE / PNAD (2000) e MME (2008).

As informações contidas na tabela 3 se apresentam próximas do montante de conexões identificadas como necessária, quando se considera os propósitos iniciais do Programa. Ao adicionar o total de unidades domiciliares beneficiadas ao total excedente de unidades domiciliares será encontrada 1.795.592 de conexões, a qual representa 88,24% do valor planejado inicialmente. Ainda na tabela 3 existem alguns destaques. A coluna vermelha, a qual representa as unidades domiciliares sem atendimento e informa sobre a taxa de eletrificação necessária, e a coluna verde, que sinaliza o atendimento pleno para alguns Estados e desvela o excedente de conexões já efetivadas (não planejadas inicialmente).

O excedente de unidades domiciliares aqui é destacado como um dos pontos positivos do Programa. Segundo experiência da Cooperativa de Eletrificação do Estado de São Paulo, a CERESP, [...] "para cada 2 ligações elétricas realizadas no meio rural gera-se uma terceira (Strazzi, 2008: 66) e isto representa um excedente de conexões. O MME (2008) destaca a existência deste excedente no caso do Luz Para Todos. "*Durante a execução do Programa, novas famílias sem energia elétrica em casa foram localizadas* [...] (MME, 2008) e passaram a provocar o processo de [...] "*ocupação humana*" (Strazzi, 2008: 19), gerando aumento na demanda pela eletrificação rural. Camargo et alli (2008: 3) elucida sobre o tema demanda excedente. "*Não se considerou um fenômeno que acabou por ser verificado quando da implantação do Programa, que foi o aumento de demanda em decorrência da notícia da chegada da energia elétrica à determinada região, ou seja, devido ao próprio avanço do Programa nas áreas rurais*" (Camargo et alli, 2008: 3). Para Lobão (2008) as famílias beneficiadas servem como exemplo para outras famílias retornar para o meio rural, requisitar o benefício e aliviar [...] "*o impacto que o êxodo rural descontrolado causava nos centros urbanos*" (Lobão, 2008). Camargo (et alli, 2008), desta vez, argumenta sobre eletrificação rural e o êxodo rural.

A boa nova se espalhou. Alguns que estavam fora da área rural, em condições sofríveis de vida, retornaram ao campo. A chegada da energia ajudou a reter no campo, no meio rural, jovens casais, famílias inteiras que, em outras condições, teriam buscado outras oportunidades, fora de sua realidade, de sua cultura, no meio urbano. Assim, a energia elétrica, ao manter o homem em seu meio, respeitando sua cultura, ao mesmo tempo em que integra esse homem ao restante do mundo pelo acesso à informação global e imediata da televisão, realiza dupla função, tanto de inclusão quanto de tornar real o contato com a vida fora do campo, melhorando a vida de maneira geral pela possibilidade de acesso aos itens de conforto tecnológico (Camargo et alli, 2008).

Outro ponto importante derivado das conexões envolve a cadeia produtiva do Luz Para Todos. A implantação do Programa atua diretamente em determinado setor da economia, no caso: *materiais elétricos, na fabricação de postes de sustentação das linhas de transporte de eletricidade, cabos de alumínio e transformadores de tensão da energia conduzida* (Lobão, 2008). Os resultados desta importante transformação são também encontrados nos [...] "*empregos diretos e indiretos criados para a execução das obras são estimados em 268 mil, para instalar 4,1 milhões de postes e 790 km de cabos, além de 634 mil transformadores*" (Lobão, 2008). Ademais, em pesquisa realizada pelo Instituto de Pesquisas Econômicas e Aplicadas - IPEA (2006), ao longo da vigência do Programa, foi detectado que os benefícios ofertados pela eletrificação atingem maior consumo de aparelhos eletrodomésticos, interesses em continuar consumindo e melhorias na qualidade da água encanada (Menezes, 2008 *apud* IPEA, 2006).

Outro aspecto positivo do Programa é a sua própria continuidade. O final previsto para 2008 foi estendido por conta das demandas pela eletrificação rural não aguardadas. *"O governo está trabalhando duro para acabar com a exclusão de energia no País. O sucesso do Programa fez parecer novas demandas e prorrogamos o Luz Para Todos até 2010*" (Schuck, 2008).

ALGUMAS INSUFICIÊNCIAS

As insuficiências do Programa "Luz Para Todos" não são poucas, mas também não são exageradas. O gráfico 2 indica que as regiões Nordeste e Norte, respectivamente, apresentam as maiores parcelas de exclusão de energia elétrica por unidades domiciliares. A tabela 2 destaca a região Norte do país e a maior parcela dos Estados Nordestinos não demonstrando que atingirá as metas de eletrificação rural iniciais no tempo previsto (2004 – 2008). Esta tabela coloca sob questionamentos os próprios Estados quando se considera a existência de excedentes de eletrificação rural, para alguns, mediante a quantidade de unidades domiciliares ainda sem atendimento desde o início do Programa, para outros.

Dessa breve reflexão são extraídas algumas considerações:

Não houve interesse familiar pelas conexões;

houve alguma situação inesperada;

houve algum problema com relação ao relevo (corriqueiramente e equivocadamente classificado como obstáculo), e/ou problemas com agente executor.

Essas considerações são utilizadas com intuito em compreender pontos referentes às insuficiências do Programa "Luz Para Todos".

Por conta dos estudos e pesquisas já produzidos se elimina a consideração A (Não houve interesse familiar pelas conexões). Esta consideração contradiz o histórico de pesquisas sobre a eletrificação rural, ou seja, este benefício é bastante interessante para a família rural, presente no espaço rural, mas também como pólo de atração às familias rurais distantes do meio rural (muito possivelmente no meio urbano ou mesmo nos limites urbanos das cidades do interior).

A consideração B (houve alguma situação inesperada) poderá ter retido algumas conexões. Uma situação bastante representativa para este ponto envolve a dificuldade de cadastrar famílias em territórios [...] "*residências localizadas em Áreas de Preservação Ambiental, Parques protegidos, Ilhas; alde*ias *indígenas situadas em Áreas de Preservação Ambiental e residências remanescentes quilombolas*" (Strazzi, 2008: 45). Para dar conta deste problema as Centrais Elétricas do Brasil (FURNAS - integrante do Comitê Gestor Nacional) desenvolveu o Sub-comitê de Eletrificação do Grupo Diferenciado do Estado de São Paulo.

Além das APA existem às APP, as duas são protegidas pelo poder público. A inserção da eletrificação rural nessas áreas, mesmo com a existência de um pedido formal da família interessada, requer ação diferenciada e integrada ao aparato legal que cria cada uma das áreas.

A consideração C se desdobra em duas. A primeira diz respeito ao relevo. A região Norte não conseguiu atingir os propósitos iniciais do Programa "Luz Para Todos", em nenhum dos seus Estados, diferente da região Nordeste, onde apenas os Estados do Pernambuco, de Sergipe e do Rio Grande do Norte atingiram o desejado e atenderam unidades domiciliares excedentes. Parcela dos problemas detectados pelas próprias concessionárias envolve o relevo regional.

No caso do Estado do Amazonas A Companhia Energética do Amazonas (CEAM) ao apresentar relatório sobre o processo de eletrificação rural no Estado do Amazonas responsabiliza o clima e o relevo regional pela demora generalizada.

As constantes chuvas ocorridas de novembro a abril impedem o deslocamento rápido tanto do material quanto da equipe técnica, dificultando a instalação dos equipamentos e atrasando o cronograma das obras. Isto, se levado em consideração, deixa evidente a inviabilidade de se cumprir à programação das metas do modo como foi traçada (CEAM, 2007).

Os obstáculos apontados pela empresa não reduzidos apenas às chuvas e relevo, também existem problemas referentes a custo para acessar as comunidades distantes dos centros urbanos.

Para a concessionária, os obstáculos se concentram na questão do transporte para o deslocamento de material de trabalho e dos técnicos. Por ser realizado via fluvial através de balsas, o custo financeiro envolvido é elevado, levando também muito tempo para chegar ao local de destino. Há comunidades no interior do Amazonas que esse tempo varia em torno de 20 a 30 dias (CEAM, 2007).

Cavalcante e Cartaxo (2008) tecem severas críticas aos objetivos do Programa ao não considerarem as particularidades regionais e a diversidade de interesse do público consumidor. Para as pesquisadoras a percepção desses detalhes poderá auxiliar a prática do próprio Programa.

Nota-se que os objetivos e as metas estabelecidas pelo Programa Luz para Todos não levou em consideração o mercado consumidor e a diversidade de atores envolvidos, com demandas diferenciadas a serem supridas. Se tivesse atentado para esses detalhes, teria percebido que a Região não era propícia a metas de universalização de energia em um curto espaço de tempo, igual às outras regiões da federação brasileira [...] as metas não atingidas foram transferidas para os anos posteriores, não se buscando uma solução que pudesse superar as dificuldades encontradas, e estas por si só não desapareceram, comprometendo a sustentabilidade do Programa (Cavalcante e Cartaxo, 2008).

A crítica referente às metas de universalização no Estado do Amazonas pode ser estendida aos outros Estados da região Norte. Isto é possível porque as dificuldades apontadas pela CEAM (2007), em geral, se referem ao relevo e ao clima amazônicos dificultando o acesso às comunidades rurais. Este fato atua junto aos outros Estados da região Norte do país por que: A) são Estados amazônicos, B) se os limites territoriais estaduais não interferem na extensão da selva amazônica, isto significa dizer que as particularidades amazônicas transcendem estes limites e, por fim, C) nenhum Estado da região Norte cumpriu com as metas iniciais.

O outro desdobramento da consideração “C” diz respeito ao recurso público. O Estado nordestino do Piauí não realizou 80% do montante de eletrificação rural identificado como necessária ao iniciar ao Programa “Luz Para Todos”, porque existem indícios de corrupção no processo de licitação para contratar agente executor responsável pelas conexões. A Construtora Gautama, vencedora da licitação e suspeita de corrupção, teve o contrato rescindido. Este ficou mais caótico com a Operação Navalha na Carne.

O quadro foi agravado com as revelações da Operação Navalha, uma delas envolvendo recursos do governo destinados ao “Luz para Todos”, para cuja liberação a Gautama estaria pagando propinas a autoridades governamentais. Diante das irregularidades, a Advocacia Geral da União declarou a inidoneidade da construtora e a Cepisa[92] rescindiu unilateralmente o contrato com a empreiteira em setembro de 2007 (Menezes, 2008).

Somente ao iniciar 2008, o MME viabilizou a participação da Companhia Hidrelétrica do São Francisco (CHESF) como mais uma executora no Piauí.

Os Estados do Amapá e Roraima, integrantes da região Norte, também tiveram problemas com o agente executor. Os dois casos envolvem inadimplência do agente executor, condição que não permite o repasse de recursos públicos para execução do Programa. A solução para o problema foi encontrada com a Centrais Elétricas do Norte do Brasil (ELETRONORTE), a qual passou a se responsabilizar pelas obras. Embora o caso de Roraima seja semelhante, a resposta para o problema está sendo estudada pela ELETRONORTE.

## COMENTÁRIOS FINAIS E QUESTÕES

Através da Lei de Universalização de Atendimento da Energia Elétrica, n◦ 10.438/2002, foi possível estender, sem custo algum, a eletricidade para as famílias rurais. Entretanto a eficácia do Programa “Luz Para Todos” não pode ser pensada sem a sua política multissetorial. A articulação ministerial oferece ao processo de eletrificação rural mecanismos que auxiliam e estruturam a execução das políticas públicas. Aproximar os Programas de políticas públicas ministeriais produz instrumentos com potencial para dar cabo deles satisfatoriamente. Ademais, a participação integral da sociedade civil durante o processo de eletrificação, a condiciona como sujeito ativo do projeto.

---

[92] Cepisa (Centrais Elétricas do Piauí S.A).

O reflexo da política multissetorial pode ser detectado através da quantidade de conexões efetivadas desde 2003 (ver tabela 2) e nas conexões classificadas como excedentes. Assim sendo, um dos objetivos do "Luz Para Todos", que é a fixação da família rural no campo, fora atingida parcialmente. Onze Estados cumpriram as metas iniciais com eletrificação rural, e contrapondo com outros 16 Estados que não conseguiram atingir esta meta. A porcentagem de conexões efetivadas, até maio de 2008, assume o montante de 77,4 %[93].

Os Estados que concentram as piores taxas de eletrificação estão na região Norte e Nordeste. A concentração destas taxas ocorre porque historicamente esta população foi desconsiderada do acesso a diferentes tipos de infra-estrutura, entre elas, a eletricidade. "*A priorização do Norte e Nordeste é uma orientação de governo para corrigir a dívida histórica com os povos do semi-árido e das florestas*" (Kovalski, 2006). Pelo o que foi apresentado ao longo deste estudo o cumprir das metas estabelecidas pelo Programa para a região amazônica não foi possível por conta da não consideração dos interesses e demandas do público consumidor e do relevo regional. Porém houve o interesse pela extensão, a qualquer custo, do Programa e/ou o interesse em utilizar as famílias rurais sem eletricidade como mecanismo para capitalização das empresas contratadas para efetuar as conexões.

A região Sudeste, a única que cumpriu integralmente as metas iniciais do Programa "Luz Para Todos", apresenta as menores taxas de eletrificação. O Sudeste é economicamente mais importante, quando se compara às regiões Norte e Nordeste. A impressão deixada destaca que a família rural no Norte e Nordeste, mais distante dos centros comerciais e industriais tem dificuldades para receber a conexão, por outro lado, as famílias rurais próximas aos centros comerciais e industriais foram integralmente atendidas antes de finaliza o final do Programa.

Aí surgem as seguintes reflexões:

Será que as famílias rurais que menos necessitam do Programa "Luz Para Todos" são as mais beneficiadas?

Será que as famílias rurais que mais necessitam do Programa "Luz Para Todos" estão sendo preteridas?

BIBLIOGRAFIA

Barbosa, Ana Cristina Moreno Maia; Bustillos, Catarina, Setúbla de Rezende, Soeiro, José Roberto Correia. Projetos Multissetoriais Integrados: Uma Abordagem para as Questões Sociais. Revista do Banco Nacional de Desenvolvimento Econômico Nacional (BNDES), 2002.

---

[93] Consultar tabela 2 para chegar ao valor exposto.

BERMANN, Célio. Energia no Brasil: Para quê? Para quem? Crise e alternativas para um país sustentável. São Paulo/SP: Ed. Livraria da Física, Federação dos Órgãos para Assistência Social e Educacional, 2001. p. 139.

Camargo, Ednaldo; Selles, Fernando; Guerra, Sinclair Mallet – Guy. O Programa Luz Para Todos": metas e resultados. Revista Espaço Energia, n◦ 9, outubro de 2008.

Cavalcante, Andréia; Cartaxo, Eizabeth Ferreira. A (In)sustentabilidade da implementação do programa "Luz Para Todos"no Estado do Amazonas. Congresso Brasileiro de Planejamento Energético. Salvador/BA, 2008.

Companhia Energética do Amazonas - CEAM. Relatório de Ligações de Consumidores. Manaus/AM. 2008.

______ . Relatório da Administração – Exercício 2006. Disponível em: [http://www.ceam-am.com.br]. Acesso em: dezembro de 2008.

Decreto Federal 4.873/2003. Programa nacional de Acesso e Uso da Energia Elétrica "Luz Para Todos". Brasília/DF.

Decreto 41.187 / 1996. Institui o Programa de Eletrificação Rural "Luz da Terra", a Comissão de Eletrificação Rural do Estado de São Paulo - CERESP e dá providências correlatas.

Comissão de Eletrificação Rural do Estado de São Paulo - CERESP, instituída pelo Decreto nº 41.187, de 25 de setembro de 1996, o respectivo gerenciamento e fiscalização.

Costa, Heitor; Eck, Myria; Silva, Gérson; Silva, Quézia; Pimentel, Ricardo; Guido, Rosangela; Pereira, Cristiane; Araújo, Kássia. Capacitação e assistência técnica: componentes críticos na sustentabilidade de sistemas fotovoltaicos autônomos. Anais. Encontro Energia no Meio Rural, 2003

Giannini, Marcio; Camacho, Cristiane; Paz, Luciana; Rodrigues Alexi; Mello, Cyro; Sousa, Danielle; batista, Norma. Indicador de Desenvolvimento Rural: Uma Contribuição Para o Planejamento da Universalização do Acesso à Energia Elétrica. Congresso Brasileiro de Planejamento Energético. Salvado/BA, 2008.

Instituto de Pesquisas Econômicas e Aplicadas – IPEA. Políticas sociais – acompanhamento e análise. Edição especial, 22. Brasília/DF, 2006.

Jaguaribe, Hélio. O sistema interimperial. In.: Desenvolvimento político. Editora Perspectiva. São Paulo/SP, 1982.

Khan, Ahmad Saeed; Silva, Lucia Maria Ramos. Eficácia e evolução dos indicadores socioeconômicos de famílias beneficiadas pelo programa de combate à pobreza rural /Projeto São José no Estado do Ceará. Revista de Economia e Sociologia rural. Volume 45, no 4. Outubro / Dezembro de 2007.

Kovalski, Carlos Henrique. Luz para Todos já atendeu mais de 100 mil famílias de assentados. Disponível em: [www.portaldoagronegocio.com.br], 2006. Acesso em dezembro de 2008.

Lei n◦ 7.783, de 28 de junho de 1.989. Artigo 10.

Lei da Universalização, n◦ 10.438, de 26 de abril de 2.003

Lei n◦ 10.762. Dispõe sobre a criação do Programa Emergencial e Excepcional de Apoio às Concessionárias de Serviços Públicos de Distribuição de Energia Elétrica

Lobão, Edison. Uma revolução no campo. Folha de São Paulo, 26/12/2008.

Ministério de Minas Energia – MME. Manual de Operacionalização do Programa Luz Para Todos - n◦ 5. Brasília/DF. 2003.

Ministério de Minas Energia – MME. Disponível em: [www.mme.gov.br]. Acesso em dezembro de 2008.

Menezes, Lizete Teles. **Valor Econômico (SP): Luz para Todos possibilita a experiência do consumo. Disponível em : [www.ipea.gov.br]. Acesso em 05/05/2008.**

Neto, Manuel Rangel Borges; Carvalho, Paulo Cesar Marques de Carvalho; Lopes, Luiz Carlos Nascimento, Lima, Aureo; Ribeiro, João. O Programa Luz Para Todos: avaliação em um assentamento rural. Congresso Brasileiro de Planejamento Energético. Salvado/BA, 2008.

Programa nacional para Agricultura familiar – PRONAF. Acesso em: [www.pronaf.gov.br]. 2006.

Sauer, Ildo Luís; Sonia Serger P. Mercedes; Kirchner, Carlos; Vieira, Paulo; Juhas, José. Um Novo modelo para setor elétrico brasileiro (13 – 202). In.: A reconstrução do Setor elétrico Brasileiro. Universidade Federal do Mato Grosso do Sul, Editora Paz e Terra. Campo Grande/MS, 2003.

Schuck, Ronaldo. Luz Para Todos é tem a de audiência na Câmara dos Deputados. Disponível em: [www.mme.gov.br], em 18/07/2008. Acesso em dezembro de 2008.

Serpa, Paulo Marcos Noronha. A eletrificação fotovoltaica em comunidades caiçaras e seus impactos socioculturais. Doutorado. Programa Interunidades de Pós Graduação em Energia, Instituto de Eletrotécnica e Energia / Universidade de São Paulo. São Paulo/SP, 2001.

Strazzi, Paulo Ernesto. Desenvolvimento social e programas de eletrificação de não atendidos. Texto para qualificação de Doutorado. Programa Interunidades de Pós Graduação em Energia, Instituto de Eletrotécnica e Energia / Universidade de São Paulo. São Paulo/SP, 2008.

## 24. “La Energía y la Economía ante el Incremento de la Población Mundial”

**Mtro. Juan José Cárdenas Grajeda- Dr. José Antonio Gómez Reyna, Dra. Lioudmila Oleinikova, - Dr. Boris Voronin,**

Cuerpo Académico de Energías Renovables

División de Ingenierías

Centro Universitario de Ciencias Exactas e Ingenierías

Universidad de Guadalajara, México.

Av. Revolución 1500 Guadalajara, Jalisco, México

cardenasgrajeda@yahoo.com.mx

gomezrey@yahoo.com, <loleinik_l@bk.ru>,

boris.voronine@cucei.udg.mx,

INTRODUCCIÓN

La humanidad está creciendo en cantidad y los avances tecnológicos en los diversos órdenes, están cambiando nuestro entorno a una velocidad asombrosa, no bien nos adaptamos a un cambio tecnológico, cuando otro avance está en puerta. Definitivamente las legislaciones de los Estados están siempre atrasadas con respecto a la tecnología.

El incremento en número de la humanidad en la mayoría de los países del orbe, está poniendo en aprietos a los gobiernos, no importa de cual ideología sean; los gobiernos de todos los países del mundo, no tienen experiencia en manejar la cantidad de personas que somos actualmente; los problemas que se presentan son inéditos y algunos países-tratando de conservar su soberanía por un lado y otros tratando de conservar su supremacía- entran en conflictos, tanto internos como con otras naciones.

El respeto a los derechos humanos, en frecuentes ocasiones se contrapone con los intereses nacionales e internacionales y suceden las disputas que en ocasiones terminan en conflictos bélicos.

Dentro del marco del tema “Energía, Desarrollo Económico y Pobreza” tocaremos algunos puntos nodales como:

Los problemas demográficos tanto locales como mundiales.

El crecimiento no simétrico, entre los países industrializados y los no industrializados.

El gasto de energía y medio ambiente.

El desempleo.

a) Los problemas demográficos locales y mundiales.

Definida la demografía, como la ciencia que se encarga del estudio estadístico de los conglomerados humanos, de sus relaciones y sus condiciones en ciertos lapsos temporales, así como de sus cambios y evoluciones, podemos estudiarla en ocasiones de una manera estática y en otras de una manera dinámica y estando íntimamente relacionada con otras ramas del saber humano, nos da pauta para externar lo siguiente:

La humanidad en las últimas tres centurias, ha venido creciendo de una forma casi descontrolada; debido a la revolución industrial, por los años de 1800 en delante más o menos, se provocó un aumento exponencial de la población mundial, es decir hubo un Boom, dado que los avances en la agricultura y en todo tipo de industrias, proveyeron de más satisfactores a la humanidad, como consecuencia sucedió, lo que sucedería con cualquier población animal, cuando se encuentra en un hábitat bonancible, crece y crece hasta donde se lo permite el propio hábitat y comienza a decaer en cuanto llega un deterioro del hábitat tal que ya no le permita seguir creciendo al ritmo que llevaba.

Hubo dos grandes guerras que en su momento causaron una baja perceptible, en la cantidad de habitantes en el mundo, pero estos fueron recuperados de una manera más o menos rápida.

Aunado a lo anterior, en cuanto a la cantidad de más satisfactores disponibles en el mundo, los avances en la ciencia de la medicina, provocaron que las personas fueran más longevas; los sistemas de salud en el mundo, -cuando menos en los países desarrollados- evolucionaron a la alza, permitiendo el aumento de la población.

Los sistemas de comunicación, primero los grandes barcos, pero sobre todo el avión, permitieron el desplazamiento de cantidades importantes de turistas y emigrantes hacia los polos de atracción económica, cultural y turística en todo el mundo.

Debido a lo anterior en estos momentos el mundo está en el umbral de lo permisible en cuanto a la cantidad de seres humanos que puede admitir. Sin embargo muchas personas, la mayoría, no lo comprenden, no lo quieren creer, les parece irreal, el pensar que el mundo no puede contener si no tan sólo una cierta cantidad limitada de personas, las cuales merecerían llevar una vida con comodidades. .

En estos momentos (enero 9 de 2009) somos un poco más de 6,722´000,000 (seis mil setecientos veintidós) millones de habitantes en el mundo oficialmente y recalco oficialmente, porque el World Population Information Source: U.S. Census Bureau, Population Division/International Programs Center lleva el registro oficial, pero existen muchos pueblos y aldeas que no registran en este servicio su población, sin embargo millón más o millón menos no es importante para el caso y podemos aceptar una diferencia de varios millones sin que cambie la realidad del mundo.

Si la población se duplicara en cincuenta años, que es lo que ha estado más o menos sucediendo en los últimos tiempos, dentro de ese periodo seríamos 13,444´000,000 (trece mil cuatrocientos cuarenta y cuatro millones) de habitantes en el mundo. Decenas de Millones más decenas de millones menos, esta es la cantidad de habitantes que los científicos dedicados a estos estudios, creen que la tierra podría aceptar de una manera sustentable, de acuerdo a su “carryng capacity” es decir a su “capacidad de carga”, queriendo con esta frase significar que la tierra está claramente limitada.

Esta absolutamente comprobado que ningún hábitat natural puede soportar un crecimiento exponencial de sus individuos, de manera permanente; en algún momento habrá de colapsar, si la situación no se corrige. Una sencilla ecuación nos puede modelar el fenómeno y permitirá que vislumbremos el futuro:

(cp) * (r) ^ (np) = cf ;

En donde:

cp, es cantidad presente.

r, es razón de crecimiento;

np , es número de periodos;

cf, es cantidad futura.

Si nos preguntamos la cantidad de habitantes que habrá de tener el planeta tierra en 200 años a partir de ahora, duplicando su población cada 50 años, sería:

6,722´000,000 * 2 ^ 4, (dado que 200años/50años = 4)

6,722´000,000 * 16 = 107,552' 000,000

Un ciento siete mil quinientos cincuenta y dos millones.

Esta cantidad de población, la tierra no habría de soportarla, de hecho la mayor cantidad de personas -considerando la más alta estimación- que soportaría el mundo es 40,000'000,000 (cuarenta mil millones); con las tasas de crecimiento actuales esa cantidad habríamos de alcanzarla dentro de los siguientes 150 años[1]

.

"La población del mundo era más o menos de 6.1 miles de millones en 2000 y se incremento en 1.4% por año. Asumiendo que cada persona ocupa un promedio de 4 pies cuadrados sobre la superficie de la tierra, el modelo exponencial para el crecimiento poblacional, proyecta que por el año 2801 ¡habrá espacio sólo para estar de pie![2] "

Ni siquiera un crecimiento verde es sostenible. Hay un límite en cuanto a la población de árboles que puede soportar la tierra, como hay un límite a la población de seres humanos y de Automóviles. Engañarnos a nosotros mismos creyendo que el crecimiento sigue siendo posible y deseable tanto si lo etiquetamos como "sostenible" o lo coloreamos como "verde" tan sólo retrasará la transición inevitable y la hará más dolorosa.[3]

Todo ser viviente, necesita de un espacio mínimo para vivir, esto nos debe de dejar claro que no toda la tierra es habitable para el ser humano, los desiertos no lo son, aunque por ahí vivan algunas personas, como no lo son los casquetes polares, las selvas tampoco son habitables en su totalidad para los seres humanos dado que los animales también exigen su espacio vital. Y eso reduce todavía las posibilidades de crecimiento poblacional.

La siguiente gráfica nos muestran el crecimiento en forma exponencial de la población mundial y otras que nos dan una idea de lo que podría ser la solución, si es que las reflexionamos.

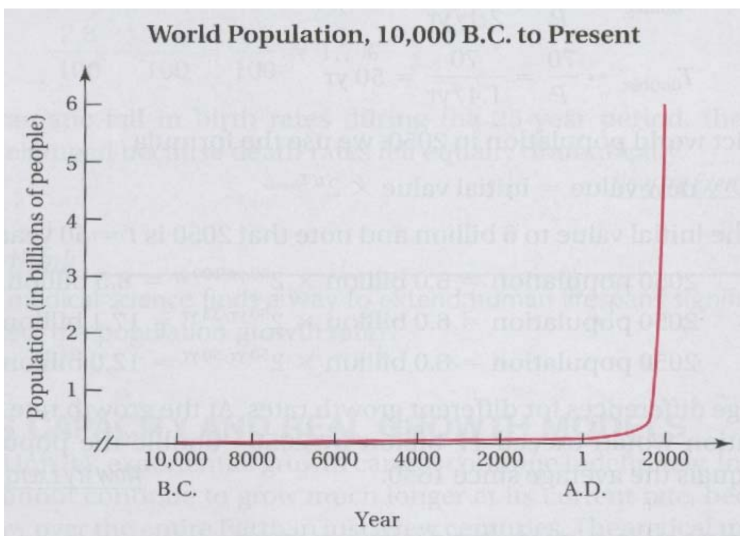


**FIGURE 8.3** World population.

En la figura[4], (figure 8.3), se nuestra un crecimiento lento de la población y luego un crecimiento acelerado, un Boom, allá por los años de 1800, cuando principiaba la revolución industrial.

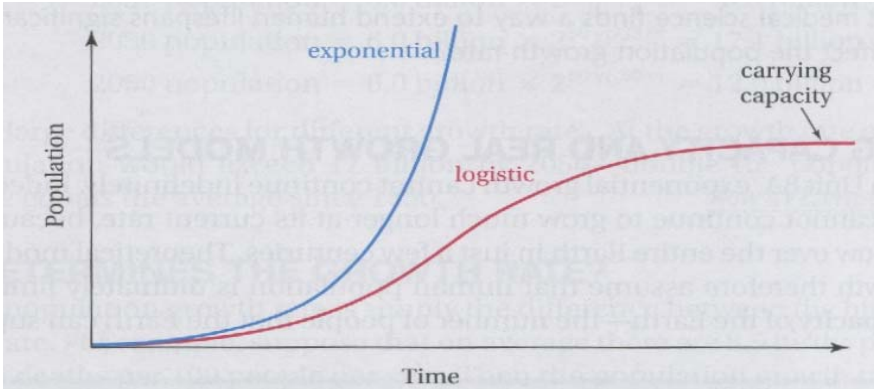



**FIGURE 8.4** This graph contrasts exponential growth with logistic growth. Note that logistic growth looks like exponential growth at early times, but then gradually levels off.

Esta gráfica[5], (figure 8.4), contrasta el crecimiento exponencial, con el crecimiento logístico, Note que el crecimiento logístico se parece al crecimiento exponencial en un principio, pero gradualmente toma su nivel.

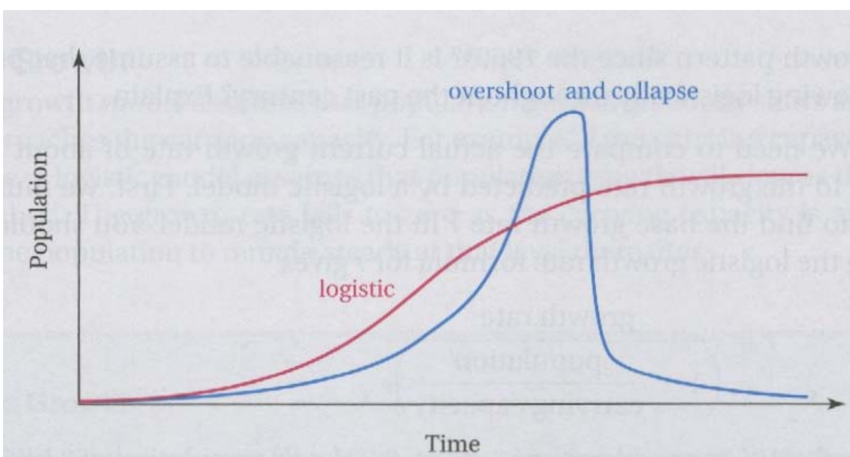



**FIGURE 8.5** This graph contrasts logistic growth with overshoot and collapse.

Esta gráfica[6] (figure 8.5), contrasta el crecimiento logístico con la gráfica de un sobre disparo y un colapso.

Por lo que respecta a México ... en estos momentos somos un poco más de 106 millones de habitantes, si se conserva el ritmo de crecimiento de la población y escribimos el sencillo modelo matemático visto anteriormente seremos en doscientos años, tantos como:

(106)*2^4= 1696; de otra forma (106)*16 = 1696 millones de habitantes.

El siguiente cuadro[7] nos muestra hasta 1996 datos de la población mundial; comparémosla con la calculada anteriormente.

**Cuadro 10.1.** Estimaciones de la población mundial por regiones (en millones de habitantes)

| Años | Población mundial | África | América del Norte | América Latina | Asia | Europa (incluida URSS) | Oceanía |
|---|---|---|---|---|---|---|---|
| **1650** | 553 | 60 | 1 | 10 | 380 | 100 | 2 |
| **1750** | 726 | 68 | 1 | 15 | 500 | 140 | 2 |
| **1850** | 1.325 | 88 | 26 | 35 | 900 | 274 | 2 |
| **1900** | 1.663 | 110 | 81 | 63 | 980 | 423 | 6 |
| **1950** | 2.520 | 224 | 166 | 166 | 1.403 | 549 | 12,6 |
| **1960** | 3.021 | 282 | 199 | 217 | 1.703 | 605 | 15,7 |
| **1970** | 3.697 | 364 | 226 | 283 | 2.147 | 656 | 19,3 |
| **1980** | 4.444 | 476 | 252 | 358 | 2.642 | 693 | 22,7 |
| **1990** | 5.285 | 633 | 278 | 440 | 3.186 | 722 | 26,4 |
| **1996** | 5.804,1 | 748,1 | 295,7 | 490,4 | 3.513,2 | 727,7 | 29 |

*Fuente*: Gora Ohlin. «Historical Outlines of World Population Growth». Comunicación en el Congreso Mundial de la Población, Belgrado, 1965. Statistical Yearbook. NN.UU. y Word Population Prospects. The 1994 Revision NN.UU. N.Y. 1998

La siguiente página de Internet nos muestra datos detallados de la población mundial, región por región y país por país:

Population Reference Bureau.

2007 WORLD POPULATION Data Sheet.

Es de fácil acceso.

b) EL CRECIMIENTO NO SIMÉTRICO ENTRE PAÍSES DESARROLLADOS Y SUBDESARROLLADOS.

Aunque suene molesto utilizar estos términos, es una realidad que en el mundo, el crecimiento es dispar; para los países en vías de desarrollo, su mayor riqueza que lo constituye su población, se convierte en su mayor factor de pobreza, cuando esta población no está alfabetizada, capacitada, y no tiene los recursos necesarios para unirse al tren del desarrollo industrial. Es una verdad que la diferencia de los niveles de vida entre países como Estados Unidos y la India puede ser en una relación de 20 a 1. Nos encontramos con paradojas como en la República Mexicana, que siendo un país en vías de desarrollo con muchos polos de pobreza extrema (se calcula que existirán unos 40 millones de pobres en México), tenemos a varios millonarios y entre ellos tal vez a uno, cuyas posiciones oscilan en los primeros lugares de la riqueza personal mundial.

La propiedad de la riqueza, se está polarizando; el Producto Interno Bruto (PIB) de la mayoría de los países en el mundo crece y sin embargo en algunos decrece.

Existe un fenómeno muy fuera de serie en México: Aunque la cartera vencida de las tarjetas de crédito sigue creciendo, los bancos y las instituciones comerciales de todo tipo siguen emitiendo plásticos, aun cuando se dan cuenta que la capacidad de pago de las personas no es suficiente para cubrir los créditos ofrecidos. Esto da liquidez de más a las personas, pero tenemos las tasas de interés más altas del mundo, que en algunos casos llegan a ser mayores al 100% anual.

La brecha entre los individuos ricos y pobres, así como entre los países industrializados y no industrializados, se ensancha cada día más. Dinero llama a dinero, reza el refrán popular y la pobreza se ensancha en un círculo vicioso, se es pobre porque no se tiene educación y capacitación y no se tiene capacitación ni educación porque se es pobre. En México el gobierno hace un esfuerzo sin par, por llevar educación y capacitación en diferentes niveles a todo lo largo y ancho del país para romper con ese círculo vicioso.

La siguiente grafica nos muestra el ingreso desigualmente distribuido al interior de los países individuales.

El índice GINI es la medida más común de la desigualdad del ingreso. Se construyo de forma tal que cero, significa igualdad perfecta del ingreso (todos tienen ingresos iguales) y 100 corresponde a la desigualdad perfecta (Una persona acapara toda la riqueza).

Índice Gini de la distribución del ingreso

| | | | |
|---|---|---|---|
| 1 | Sweden | (2000) | 25 |
| 2 | Ukraine | 2003 | 28 |
| 3 | India | 2004 | 37 |
| 4 | Israel | 2001 | 39 |
| 5 | Burkina Faso | 2003 | 40 |
| 6 | United States | 2000 | 41 |
| 7 | México | 2004 | 46 |
| 8 | China | 2004 | 47 |
| 9 | Zambia | 2004 | 51 |
| 10 | Bolivia | 2002 | 60 |

c) EL GASTO DE ENERGÍA Y MEDIO AMBIENTE.

El mundo para desarrollarse, necesita energía y las personas e industrias en general, la obtienen de diversas formas; dependiendo del desarrollo de los países.

Al mismo tiempo que existen los avances en que el crecimiento industrial nos presenta inventos que se antojan increíbles, como lo es el Internet y la telefonía celular , las cámaras móviles y los aviones fantásticos, existe el mismo tiempo un submundo de pobreza. Aún en los países que están experimentando en estos tiempos un desarrollo acelerado como lo son la India y China, el crecimiento no se da en toda la sociedad, es solamente en algunas regiones donde este avance se hace evidente.

El tipo de energía consumida, por estos sectores de las sociedades es diferente, en el campo se hace uso de la leña y de otros tipos de deshecho vegetal y animal y en las ciudades el uso de la energía en más limpia en teoría.

Si bien las energías usadas en las ciudades son más limpias, esto no significa que no contaminan.

En el campo y ciertas zonas en los cinturones de las periferias de las ciudades, se utiliza leña y carbón y cualquier tipo de deshecho vegetal o animal para producir energía, en las ciudades, la contaminación que provocamos por los automóviles, las estufas, los calentadores, está creciendo a un ritmo acelerado. No hablo de la contaminación producida por las basuras, que en la ciudad de Guadalajara Jalisco en México, es de más o menos 4,000 toneladas diarias algunas de las cuales quedan rodando por las calles impulsadas por los vientos y la cual en su mayoría se confina en depósitos y vertederos que luego provocaran problemas a los mantos freáticos. Aunque los gobiernos Municipal, Estatal y Federal están haciendo esfuerzos sustantivos para resolver el problema de las basuras, es de reconocer que la escasa preparación de muchos ciudadanos hace más difícil la solución del problema, porque simplemente tiran la basura a las calles.

No hablemos de los automóviles en la zona metropolitana de Guadalajara Jalisco en México; la ciudad está colapsando poco a poco merced a la cantidad de automotores que se incorporan para incrementar el parque vehicular.

Y lo que sucede en Guadalajara parece que sucede en gran parte del mundo, con el problema provocado por los automóviles. Existen en el mundo alrededor de mil millones de automóviles, a grosso modo, ¿cuantos automóviles habrá dentro de 200 años, si se calcula un crecimiento de 65 millones de automóviles anuales?, en realidad será una cifra abrumadora, pero los automóviles se mueven con gasolina que se extrae del petróleo. El consumo diario de barriles de petróleo es de 84.5 millones, si los multiplicamos por 365 días del año nos dará algo así como 30,842 millones de barriles anuales, los cuales obviamente al ser consumidos provocarán contaminación ambiental.

Más como el crecimiento de la cantidad de automóviles va a la alza, la contaminación también habrá de ir de la mano. Terrible dilema en el que se encuentra la humanidad.

Actualmente la cuarta parte de la humanidad se encuentra carente de electricidad y de otros servicios como el gas, si tratáramos de proveerlos de esos servicios indispensables para nosotros, deberemos de considerar una cantidad adicional de contaminación al planeta.[8]

d) EL DESEMPLEO

El asunto del desempleo en el mundo es un tanto cuanto complejo, porque no disponemos de datos en países subdesarrollados. Solamente en ciertos países en vías de desarrollo y en los plenamente desarrollados tenemos información. El pleno empleo no se logra en alguna parte del mundo y un desempleo natural por diversas causas existe.

Las técnicas para las medidas del desempleo, no son aceptadas de igual manera por todas las instituciones u organismos a lo largo y ancho del planeta. Los gobiernos, para consumo interno de sus gobernados, en ocasiones consideran la mínima actividad de alguna persona, para decir que está empleado, por ejemplo tener unas cuantas horas de trabajo a la semana, ya lo considera como empleo, aún cuando no sean suficientes esas horas de trabajo, para producir los necesarios ingresos para subsistir.

El crecimiento poblacional presiona a los países de todo el orbe y unos con mayor desarrollo, se convierten en verdaderos imanes que atraen avalanchas de seres humanos con documentos legales o no, pero con el fin común de encontrar un empleo mejor remunerado que el que lograrían en sus países, si es que lograran conseguir alguno.

Algunos países como México, se convierten en verdaderos exportadores de mano de obra barata y esta exportación trae aparejadas multitud de problemas. Abandono de familias completas, abandono de parcelas de cultivo que a su vez conllevan más problemas para el país exportador de mano de obra.

El problema del desempleo es pues considerado en la actualidad como un problema internacional de primer orden.

Los derechos humanos se ven conculcados, por ser violados cuando se trata de castigar a las personas que cruzan las fronteras de manera ilegal, con el único fin de ejercer su derecho a tener un empleo digno y bien remunerado. Esta es una cuestión que presenta ángulos humanos difíciles de conciliar.

Dependiendo de la institución de que se trate, el desempleo se clasifica de varias formas.

Desempleo por condiciones de mercado del trabajo.

Desempleo por desajustes temporales momentáneos.

Desempleo por la estructura del sistema económico de un país en especial.

Desempleo por cuestiones del sexo.

Desempleo por cuestiones de edad.

Desempleo por la duración.

Desempleo por el tipo de actividad.

La Organización para el Comercio y Desarrollo Económico (OCDE), es la institución a nivel mundial que puede ser la más fiable, en cuanto a las estadísticas para conocer el desempleo, con la salvedad de que sólo reúne a algunos países, y son los agrupados los más desarrollados del planeta. ¿Y los demás países del mundo? No disponemos de datos fiables de algunos.

Las edades de trabajo, varían entre los 16 y 65 años para la mayoría de los países, en los que el promedio de vida es mayor, dado que existen algunos países cuya esperanza de vida de los habitantes llega a ser de 33, 40 y 45 años. La expectativa de vida en los países desarrollados alcanza los 70 y 80 años[9].

En México gracias a los incrementos en los servicios de salud, la expectativa de vida se va haciendo mayor, aunque grandes segmentos de la población carecen de los servicios totalmente adecuados; sin embargo el gobierno en todos sus ordenes, continúa trabajando para dotar a su población de servicios médicos suficientes.

El desempleo es mayor entre el sector joven y el sector anciano de las sociedades desarrolladas.

Los porcentajes de desempleo oscilan según los países y las décadas, y son verdaderos toboganes de sube y baja las gráficas de desempleo que oscilan desde el 1 por ciento para países como Alemania hasta el 12 por ciento para otros países Europeos.

Existen Estados en los cuales no hay empleos y mucho menos estadísticas.

En términos absolutos cada día se crean más y mejores empleos, pero cada día hay más población que desea incorporarse al trabajo remunerado y con todas las garantías de ley - donde existen- y por lo tanto se conservan las tasas de desempleo.

Así como se necesitan más y mejores empleados cualificados, no es menos cierto que se necesitan más y mejores empresarios, audaces, que vean al futuro, que tomen riesgos, que inviertan. Sin embargo estos empresarios por lo general, requieren de más flexibilidad de las condiciones de contratación y es ahí donde intervienen los gobiernos para facilitar la creación de empleos que a la vez que salvaguarden los derechos de los empleados, le brinde condiciones de seguridad a los empleadores para ver fructificar sus inversiones.

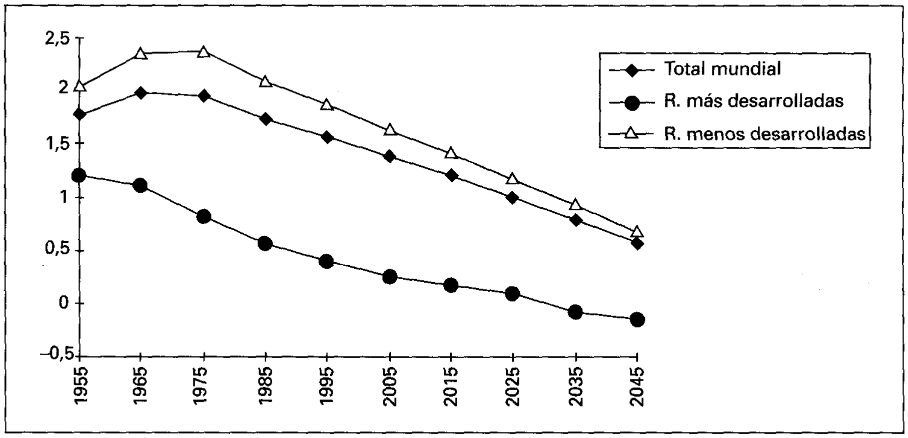
La expansión de las industrias de alta tecnología hace que por ejemplo, las industrias establezcan plantas maquiladoras, pero no en cualquier país. Se necesitan ciertas condiciones para establecer una industria maquiladora de automóviles para armar diferentes a una planta maquiladora de maletas para viajeros por ejemplo. Esto nos dice que si un país desea tener industria maquiladora de nivel, el país debe estar preparado para recibirla.

Los siguientes cuadros nos muestran diferentes aspectos y proyecciones de las poblaciones del mundo[10].

**Cuadro 10.4.** Distribución de la población por edad (porcentajes)

| | Años | Menos de 15 | 15 a 65 | 65 y más | 80 y más |
|---|---|---|---|---|---|
| Mundo | 1955 | 35,6 | 59,2 | 5,2 | 0,6 |
| | 1990 | 32,3 | 61,5 | 6,2 | 1,0 |
| | 2025 | 24,9 | 65,3 | 9,7 | 1,6 |
| Países desarrollados | 1955 | 27,7 | 64,2 | 8,1 | 1,1 |
| | 1990 | 21,5 | 66,5 | 12,0 | 2,6 |
| | 2025 | 18,2 | 63,5 | 18,3 | 4,1 |
| Países en desarrollo | 1955 | 39,4 | 56,7 | 3,8 | 0,3 |
| | 1990 | 35,5 | 60,0 | 4,5 | 0,3 |
| | 2025 | 26,3 | 65,7 | 8,0 | 1,1 |

*Fuente*: World Population Prospects: The 1992 Revision. NN.UU.




*Fuente*: World Population Prospects: The 1992 Revision. NN.UU.

**Figura 10.3.** Aumentos anuales medios de población 1950-1955 a 2040-2045 (porcentajes).

BIBLIOGRAFÍA

1, 2,4, 5, 6,- Mathematics, third edition, Jeffrey Bennet, William Briggs, Editorial Pearson.

8 - National Geographic en español, El Pulso de la tierra, edición especial 2008

7, 10 .- Estructura Económica Mundial; Joaquín Guzmán et al; Mc. Graw Hill 1998.

9.- 2007 World Population Data Sheet.

3.-Modelando la Sociedad; capítulo II

www.tesisenxarxa.net/tesis_UPC/available/tdx-0930102-081930/03

capítuloII.pdf-

# 25. Seasonality in the cost of firewood and sugarcane bagasse from Northwestern and Center-West Paraná State, Brazil

**Alexandre Florindo Alves, Sueli Sato Martins, Thomas Oehninger Ramos**

Department of Economics and Department of Agronomy, Universidade Estadual de Maringá, Paraná, Brazil

Leading Author Address: Departamento de Economia - Universidade Estadual de Maringá. Avenida Colombo, 5790. CEP: 87020-900. Maringá, PR, Brazil, Phone + 55 44 3261 4925, Fax + 55 44 3261 4938, Email: afalves@uem.br

Key words: Seasonality, sugarcane bagasse, firewood.

Abstract: Firewood is an important energy source for the main agroindustrial chains in the state of Paraná and in Brazil as a whole. Brazil, due to the rapid increase in eucalyptus plantations – which gives it competitive advantages in the market for forest products – has exported more and more of this source, reaching the top rankings among world exporters in the case of cellulose. The main results of the growth in this market have been observed in price increases for wood and planted areas. Firewood is used, especially in developing countries, as raw material for heating and energy generation. In the case of Brazil, currently 30% of its energy needs are obtained from biomass through firewood, charcoal, sugarcane bagasse, and other fuel residues. Brazil accounts for 57% of all forest areas in South America and 12% in the world. Even as the world's third largest producer of firewood, international trade is not significant due of the low added value and the manner in which this fuel is used.

This study intended to estimate the seasonal variation behavior of firewood and sugarcane bagasse in the period from 1997 to 2007. To that end, the study used historical price series obtained from agroindustrial sector companies in northwestern and center-west Paraná State. In order to isolate the seasonal component of the price series, the centered moving average method was applied. Results point to a change in the seasonal variation pattern of firewood prices in the period from 1997 to 2001, compared to the more recent 2002-2007 period. Regarding seasonal variation patterns, sugarcane bagasse showed higher price fluctuations than firewood. From the historic analysis of firewood

real prices, a rising trend was detected starting in 2001, due to strong demand resulting from an energy shortage in the country. Starting in March 2007, a reduction in the real prices growth rate was verified. It was also possible to detect, through the comparison between the prices of the studied biomasses, that sugarcane bagasse had a lower cost per unit of convertible energy during the period of the study.

## I.- INTRODUCTION

The search for alternative energies to replace petroleum is on the rise. Petroleum is the world's most consumed energy matrix and the one that's being pointed out as the main cause for the increase in the concentration of greenhouse effect gases in the atmosphere, resulting in climatic changes. Another reason is based on economic issues: the elevation on the price of petroleum on the last decades and the fact that the petroleum market is controlled by monopoly as the locations of the known reserves are concentrated in a few countries. These reasons, among others, add to and highlight the necessity to reduce the dependence from petroleum. Thus, the renewable energy sources are getting more attention from the society and the government of many countries, especially from the Kyoto protocol signatories. Among the renewable energies, it is important to differentiate traditional, hydraulic and biomass, which require new technologies, from solar and wind power, available in almost every country.

The use of renewable energy on the world's energy matrix corresponds, according to Hall (1993), only to 20%, being the largest participation from biomass (14%) and hydraulic (6%). The participation and the use of renewable energy from biomass differ between developed countries and least developed countries – the use of biomass corresponds to 35% on the average energetic participation of the latter.

One of the essential factors for development is the energy. Leite (2007) even points out the energy consumption *per capita* as one of the development indicators. In great part of the countries in which the *per capita* consumption is below one ton of oil equivalent (TOE) per year, according to Goldemberg (1998), the illiteracy, child mortality and total fertility rates are high and the life expectancy is low. In industrialized countries of the European Union, the average consumption is 3.22 TOE *per capita*, being the world average of 1.66 TOE *per capita*. According to Leite (2007), 70% of the world population lives in least developed countries and it is estimated that, according to Hall (1993), 90% of the world population will live in least developed countries until 2050. This will implicate in a greater demand for biomass, as there is a greater participation of biomass as energy matrix in those countries when comparing to developed countries.

Leite (2007) believes that Brazil is in a peculiar situation, comparing to other countries, as it has a wide participation of renewable matrix in its energy matrix, hydroelectric power plants standing out. The *per capita* consumption in Brazil is 1.3 TOE. It is a reasonable value, therefore, comparing to the world average. However, according to Goldemberg (1998), the energy consumption has grown 4.6% per year since 1970, following the GDP growth, as the consumption from 1970 to 1996 tripled. Thus, the author estimates that the consumption will come to reach 2.5 or 3.0 TOE *per capita* in 10 years, what can be considered satisfactory, as the energy in Brazil is not needful for heating during winter.

On the other hand, a tendency to stabilization in consumption in industrialized countries is noticed. This can be explained, according to Leite (2007), by the high level of income already reached by the population of these countries, which leads to the full meeting of their needs as well as it allows the capacity to foster development that is necessary to reach more efficiency in energy production and use. In least developed countries, on the contrary, this does not occur. The energetic resources do not meet the basic needs of most of the population and the increase in energy demand tends to remain high in relation to the income.

It is noticeable that there is a series of factors that promote Brazil to be the leader in both energy agriculture and on the bioenergy market world wide, among which we can point out favorable edafoclimatic conditions and the possibility to make use of new lands to energy agriculture in a way that it is not necessary to reduce the area utilized by annual cultures nor to deforest native forests. All these summed up factors grant competitive advantages in the bioenergy products market.

In order to develop, the economy needs more energy which, on the other hand, requires heavy long-term investments. These, according to Leite (2007), are based on demand perspective analysis and supply possibilities as well as its economic viability which, to Oliveira and Ramalho (2006), necessarily implies in the evaluation of its cost in relation to the oil price.

*The Brazilian Ministry* of *Agriculture, Livestock* and Supply in Brazil develops some strategic actions in bioenergy aiming at fostering its production in Brazil. These actions have the following goals:

To support the change in the energy matrix, aiming at its sustainability; to enable conditions to increase participation of agroenergy sources in the energy matrix composition; to generate conditions to allow the development to be interiorized and regionalized, through expansion of the energy agriculture and adding value to the productive chain; to create opportunities to expand job offers in agribusiness; to allow the expansion in income opportunities, with a more equitative distribution; to contribute to the reduction of greenhouse effect gases emission; to cooperate to the reduction of oil importation and to increment biofuel exportation. (OLIVEIRA; RAMALHO, 2006, p.15)

Biomasses can strongly vary; each type differs in production cycle, improvement technique, physical status and so on. The production cost, according to Oliveira et al. (2003), considerably differs depending on the biomass type and geographic limitations, especially considering the distances to be traveled which affect transportation costs.

The use of technology is one of the keys to successfully transform biomass in energy and few countries have developed and invested in alternatives for its use. Brazil uses sugarcane bagasse as the national production has reached 475.1 millions of tons, expecting 500 millions of tons in 2010 (BALEOTTI, 2007). Sugarcane production would allow electricity energy production by co-generation which, according to Alves (2008), could supply 15% of Brazil's total demand, once it would correspond to twice the total production generated by Itaipu hydroelectric power plant besides supplying the decline of energy production by hydroelectric power plants in less rainy months. Another successful system in Brazil is the one which utilizes eucalyptus to produce charcoal for the steel industry. According to Buinain; Batalha (2007), in most of the least developed countries there is not an extensive exploitation of native forests for firewood and charcoal production yet, as it happens in China, India and Ethiopia.

Firewood is probably the oldest energy matrix used by man and it still is greatly important in the Brazilian energy matrix, representing about 10% of primary energy production (BUAINAIN; BATALHA, 2007). According to the Brazilian Silviculture Society (2007, apud TETTO et al., 2008, p.3), the production of firewood in 2006 was of 91.9 million tons[94], as "the consumption of all this production is domestic, especially for charcoal production (41.7%), home cooking (29%) and industries (20%)". The production of firewood in the Paraná State is of 2.5 million $m^3$, generating a R$ 43.86 million income (EMBRAPA, 2007).

Firewood and sugarcane bagasse are widely used in the Northwestern and Center-west regions of Paraná State as energy matrices in agroindustries in which, according to Leite (2007), the energetic utilization of sugarcane products

[94] A 31.5 % growth in the last decade.

and silviculture share a favorable condition regarding the emission of $CO_2$ and atmosphere pollutants while comparing to fossil fuels.

Giving that firewood and sugarcane bagasse are two very important sources and potential replacers, and that the possibilities of replacing are affected by prices, the present article aims at studying the evolution and the seasonal behavior of these sources prices in Center-west and Northwestern regions of Paraná State from 1997 to 2007.

It is reinforced that the identification of the seasonal variation of prices have two basic advantages: it allows that resources be allocated in such time and in quantity so that its products will get to the market in the higher price season and it helps in the rational selection of achievements, in estimating sales dimension and in stock planning (MELO, 1995). Obviously, from the consumers' point of view, it allows the improvement of using conditions of different energy sources.

## II.- MATERIALS AND METHODS

The information about seasonal series of average monthly prices were collected at sector related companies located in the Center-west and Northwestern regions of Paraná State, covering the period from 1997 to 2007. The data was corrected by the general price index (IGP-DI), calculated by Getulio Vargas Foundation, having December 2007 as a reference.

To determine the seasonal indices of prices, the following procedure was observed (HOFFMANN, 2006):

(I) The prices collected at the companies were considered;

(II) Prices that were missing were added – the addition was done by the monthly average;

(III) Prices collected through the General Price Index (IGP-DI) from Getúlio Vargas Foundation were deflated, having December 2007 as reference.

(IV) There were prices missing on the sugarcane bagasse price series. These were obtained through the weighted average of the previous months. The series of the following months were obtained by weighted average: January, February and March 2003, May 2004, January 2005 and February 2006.

(V) It is known that the monthly price series of the product refers to the periods of January to December, during 10 years to firewood and 5 to sugarcane bagasse. Be $P_t$ the t-esim observation in these monthly price series. The price in a certain month can also be represented by $P_{ij}$, in which $i = 1, \dots, 12$ indicates the month. The t, i and j index obey the following relation:

$$t = 12(i-1) + j$$

Considering the price as the result of the sum of the three components:

The series tendency is linear, where a+bt, in wich a and b are parameters;

One seasonal component $e_j$, in which $\sum_{j=1}^{12} ej = 0$

One aleatory term $u_t$, with $E(u_t) = 0$, in wich: $P_t = P_{ij} = a + bt + e_j + u_t$

On this expression, all the terms have the same measure unit as the price, which is Real (Brazilian currency) per biomass ton.

(VI) To isolate the seasonality of deflated prices, the centered moving average was applied using twelve (12) months. The analysis based on centered moving averages in a period consists in softening the variations of series by means of successive averages. The larger the number of terms used to calculate the moving average, the softener the resulting series will be. Due to its characteristics, the moving average excludes the sporadic variations and the systematic movements that present n size duration. Thus, to eliminate the seasonality from the price, it's only necessary to calculate a 12-month centered moving arithmetic, where n=12. The calculation of the moving average related to $P_t$ is expressed as follows:

$$M_t = \frac{1}{12}(0{,}5P_{t-6} + \cdots + P_{t-2} + P_{t-1} + P_t + P_{t+1} + \cdots + 0{,}5P_{t+6})$$

From $P_t = P_{ij} = a + bt + e_j + u_t$ and from the moving average equation we get:

$$M_t = \frac{1}{12}\left(12a + 12bt + \sum_{j=1}^{12} ej + 0{,}5u_{t-6} + u_{t-5} + \cdots + u_{t+5} + \cdots + 0{,}5u_{t+6}\right)$$

Where:

$$M_t = \left(a + bt + \frac{1}{12}(0{,}5u_{t-6} + u_{t-5} + \cdots + u_{t+5} + \cdots + 0{,}5u_{t+6}\right)$$

Be $d_{ij}$ the differences between the prices and their respective centered moving averages, that is, $d_{ij} = d_t = P_{ij} - M_{ij} = P_t - M_t$..

We get to:

$$d_t = dij = ej + ut\frac{1}{12}(0{,}5u_{t-6} + u_{t-5} + \cdots + u_{t+5} + \cdots + 0{,}5u_{t+6})$$

If $E(u_t) = 0$ for every t, we have:

$E(d_{ij}) = e_j$

Thus, $d_{ij} = P_{ij} - M_{ij}$ is a non-tendentious estimation of the seasonal component $e_j$.

On the series, we have the monthly prices of biomass for 10 and 5 years respectively. In other words, we have 12n values from the price series, obtaining 12(n-1) values for the centered moving average, once is not possible to calculate the moving average values that correspond to the first 6 and last 6 months. Then, for each month, we can obtain n-1 estimates of $e_j$, given by por $d_{ijj} = d_t$. The arithmetic average of these estimates for the j month is:

$$d_j = \frac{1}{n-1}\sum_{i=1}^{n-1} dij$$

If $7 \leq j \leq 12$, and if

$$d_j = \frac{1}{n-1}\sum_{i=2}^{n} dij$$

If $1 \leq j \leq 6$

These averages are estimators of the more effective seasonal components (smaller variance) than each one of the $d_{ij}$.

(V) An analysis on the variation of the seasonal indices was carried out.

## III.- RESULTS AND DISCUSSION

Due to insufficient data for different levels of production, as in Tetto *et al.* (2008), the estimates of price variations were carried out in the producer level.

### III.1- Firewood

In Figure 1, it is possible to observe that there was an increase on the firewood prices, especially from 2002 on, with a reduction in 2006. Even so, the prices in 2007 are significantly higher than those from the beginning of the period.

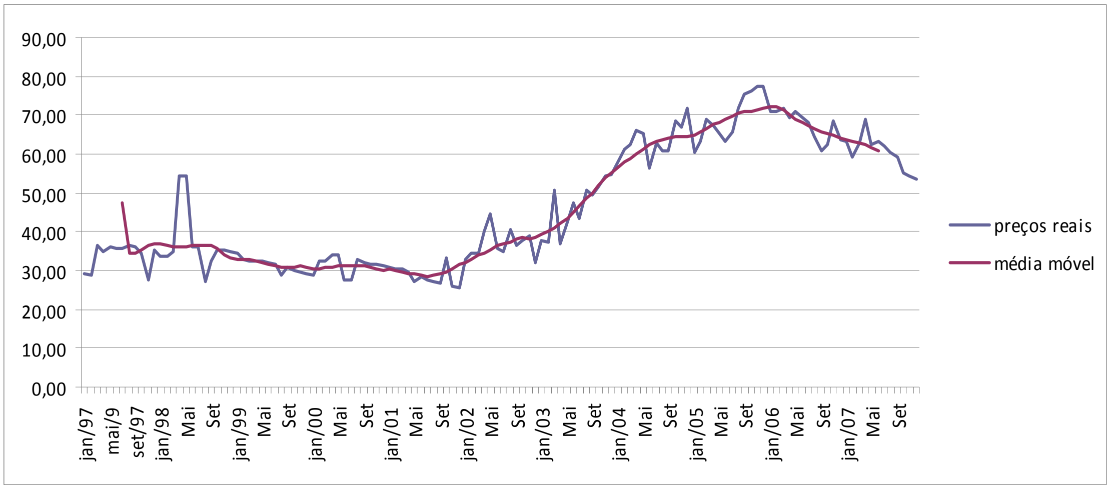



Figure 1 – Historic Series of Real Prices R$/ton of Firewood payed to the producer from January 1997 to December 2007.

Source: Research data. Elaborated by the authors.

The analysis on the behavior of the seasonal pattern of firewood prices paid to the producer between 1997 and 2007 showed a well defined fluctuation of prices, attesting seasonal price indices over the average price indices during the first semester. The elevation on prices coincides with the harvest period of the main grain cultures in the state. Therefore, there is a higher consumption of firewood for it is used in the drying of those grains. This leads to excess of demand in relation to supply, forcing an increase on the prices. We still point out based on the buyers' affirmations that the harvest periods last from February to April, when the price begins to decrease. This conclusion is confirmed by the seasonal index calculated for the Firewood.

The minimum seasonal index is verified in the month of November (88.24) and the maximum seasonal index occurs in April (127.72), which determines an amplitude of 29.1% between the higher and the lower value (Table 01 and Figure 3).

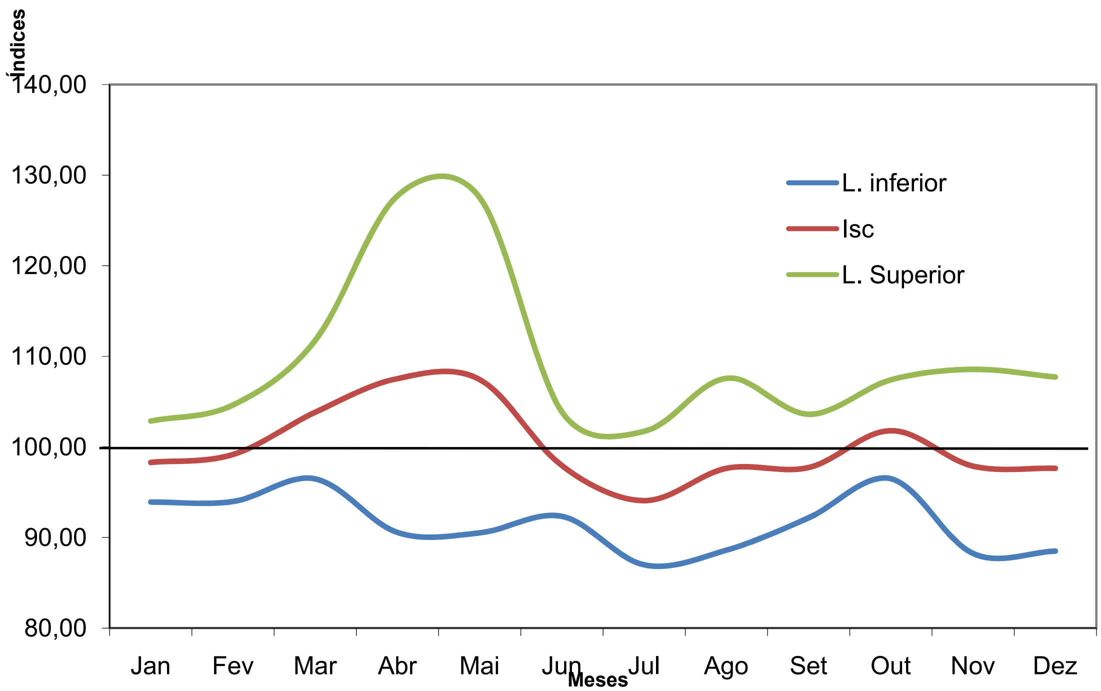



Figure 2 – Seasonal index of Firewood price paid to the producer: Period: 1997 to 2007.

Source: Research data. Elaborated by the authors.

Table 01 – Seasonal indices (Isc), Superior and Inferior limits of seasonal variations of firewood prices R$/ton received by the producer: Period: 1997 to 2007.

| Months | Isc | Superior L. | Inferior L. |
|---|---|---|---|
| Jan | 98.29 | 102.86 | 93.91 |
| Feb | 99.16 | 104.64 | 93.97 |
| Mar | 103.83 | 111.76 | 96.47 |
| Apr | 107.55 | 127.72 | 90.56 |
| May | 107.44 | 127.52 | 90.52 |
| Jun | 97.94 | 103.87 | 92.34 |
| Jul | 94.07 | 101.73 | 86.99 |
| Aug | 97.64 | 107.59 | 88.61 |

| | | | |
|---|---|---|---|
| Sep | 97.72 | 103.61 | 92.17 |
| Oct | 101.80 | 107.41 | 96.48 |
| Nov | 97.88 | 108.57 | 88.24 |
| Dec | 97.64 | 107.72 | 88.50 |

Source: Research data. Elaborated by the authors.

Though there might be certain stability, the greater amplitudes on variation occur in March and April, while the smaller variations are spotted in the months of January and June. The amplitudes of maximum variation above and below the average seasonal index are, respectively, of 19.97 and 9.64, indicating that the increases on firewood prices were of greater amplitude than the decreases.

The possibility of the producer to take advantage of the harvest periods of annual cultures in March and April is noticeable due to the higher demand for energy, aiming at increasing its profitability.

To compare the values from the seasonal index calculated for two periods with the same number of years is a way to verify if there were modifications in the seasonal variation pattern of the price (HOFFMANN, 2006). Table 2 and Figure 4 present the values of the seasonal index for firewood prices received by the producers in the period from January 1997 to December 2001 (Period I) and from January 2002 to December 2007 (Period II).

Table 02 – Seasonal indices of firewood prices R$/ton received by the producer: Periods: I (1997 to 2001) and II (2002 to 2007).

| Months | Period: 1997 to 2001 | Period: 2002 to 2007 |
|---|---|---|
| Jan | 98.21 | 97.58 |
| Feb | 100.53 | 97.06 |
| Mar | 101.45 | 106.30 |
| Apr | 114.48 | 100.82 |
| May | 112.08 | 100.62 |
| Jun | 97.41 | 98.30 |
| Jul | 90.70 | 96.34 |

| | | |
|---|---|---|
| Aug | 94.32 | 101.13 |
| Sep | 99.42 | 97.57 |
| Oct | 99.87 | 101.35 |
| Nov | 94.19 | 103.94 |
| Dec | 99.85 | 99.46 |

Source: Research data.

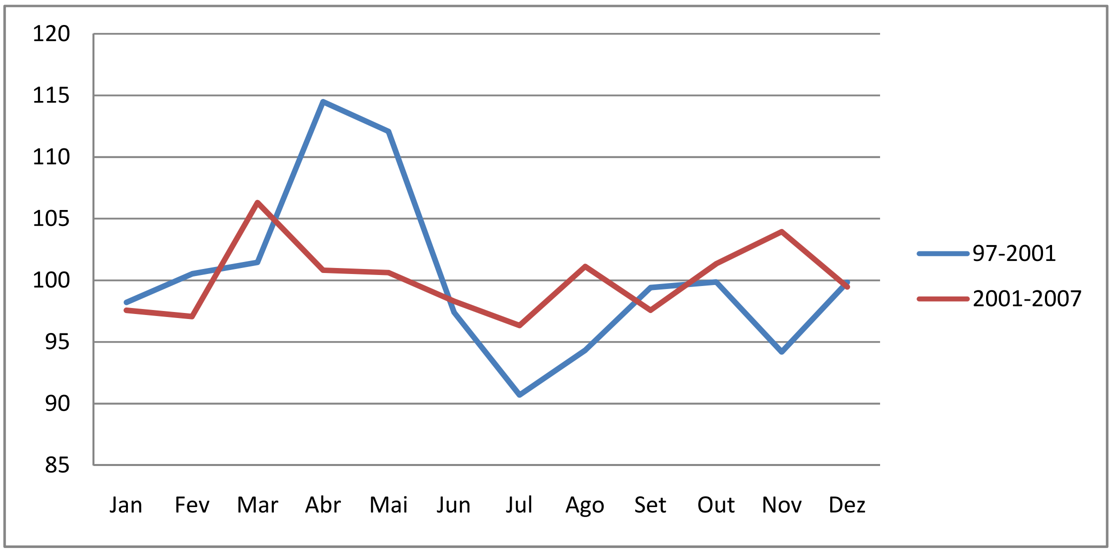



Figure 3 – Comparison of seasonal variation patterns of firewood price received by the producers of the center-west region in Paraná state from January 1997 to December 2001 and from January 2002 to December 2007.

Source: Research data. Elaborated by the authors.

Comparing the seasonal indices from both periods, we notice that the intensity in the seasonal variation of the price of firewood diminished. The amplitude of the seasonal index diminished from 23.78 in the period of January 1997 to December 2001 to 9.96 in the period of January 2002 to December 2007. The variation in seasonal intensity of the price of firewood is due, possibly, to the fact that one growing part of the buyers consist of cooperatives, freezer warehouses and industries that increased their stock and started to better control their demand of firewood in higher consumption seasons.

III.2- Sugarcane bagasse

Analyzing the behavior of the seasonal pattern of sugarcane bagasse paid to the producer between 2003 and 2007, a rising trend of the seasonal indices was detected from April to June, from November to December and a falling trend between January and March. This points out that in periods of high seasonal indices there is a smaller volume of bagasse being offered by the producers, while in the months of low indices there is a greater supply, resulting on price reduction. On the other hand, the period comprising July to October, when the seasonal indices are below the average, characterizes the harvest period.

Though somewhat stable, the greater amplitudes on variation occur in March and April, while the smaller variations are spotted in the months of January and June. The amplitudes of maximum variation above and below the average seasonal index are, respectively, of 19.97 and 9.64, verifying that the increases on firewood prices were of greater amplitude than the reductions.

Table 03 – Seasonal indices, Superior and Inferior limits of seasonal variations of sugarcane bagasse prices R$/ton received by the producer: Period: (2003 to 2007).

| Months | Isc | Superior L. | Inferior L. |
|---|---|---|---|
| Jan | 91.11 | 120.96 | 68.63 |
| Feb | 82.30 | 98.67 | 68.65 |
| Mar | 85.21 | 110.56 | 65.67 |
| Apr | 107.14 | 129.29 | 88.78 |
| May | 130.42 | 272.72 | 62.37 |
| Jun | 108.81 | 131.93 | 89.74 |
| Jul | 104.76 | 128.07 | 85.69 |
| Aug | 101.29 | 108.89 | 94.23 |
| Sep | 92.81 | 106.68 | 80.74 |
| Oct | 88.29 | 108.65 | 71.75 |
| Nov | 107.12 | 157.29 | 72.95 |
| Dec | 110.50 | 190.56 | |

64.07

Source: Research data. Elaborated by the authors.

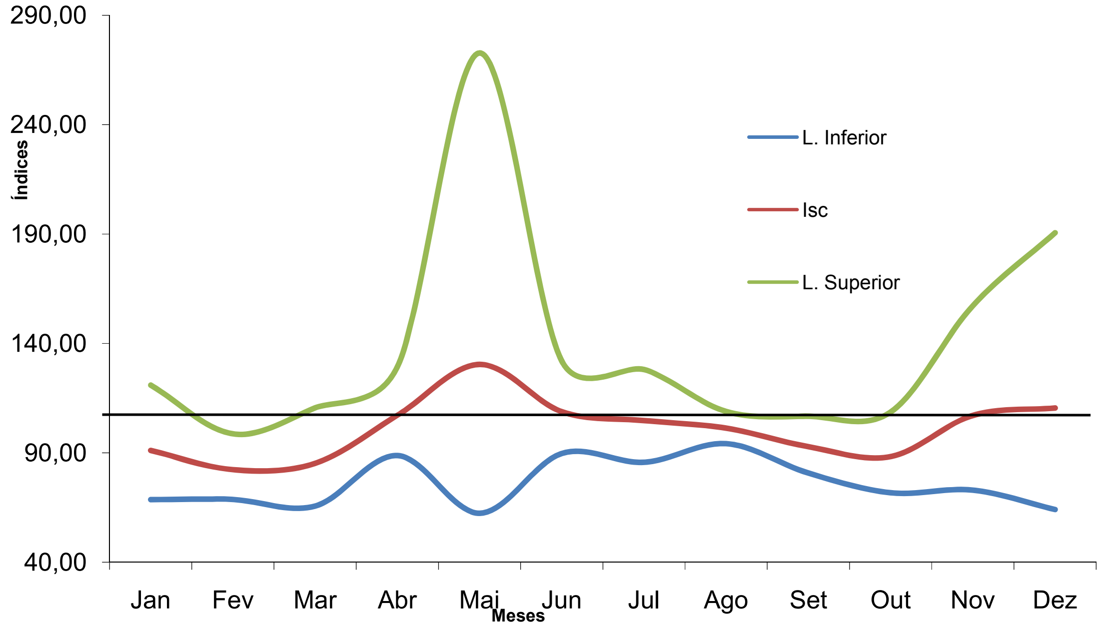



Figure 4 – Seasonal index of sugarcane bagasse price: Period: 2003 to 2007.

Source: Research data. Elaborated by the authors.

III.3 – Results from the comparison between the energy matrices

It is noticeable in Figure 3 that the historical price of opportunity in the production of 1 million kcal of energy in bagasse had some fluctuation but was always lower than the price of opportunity of firewood.

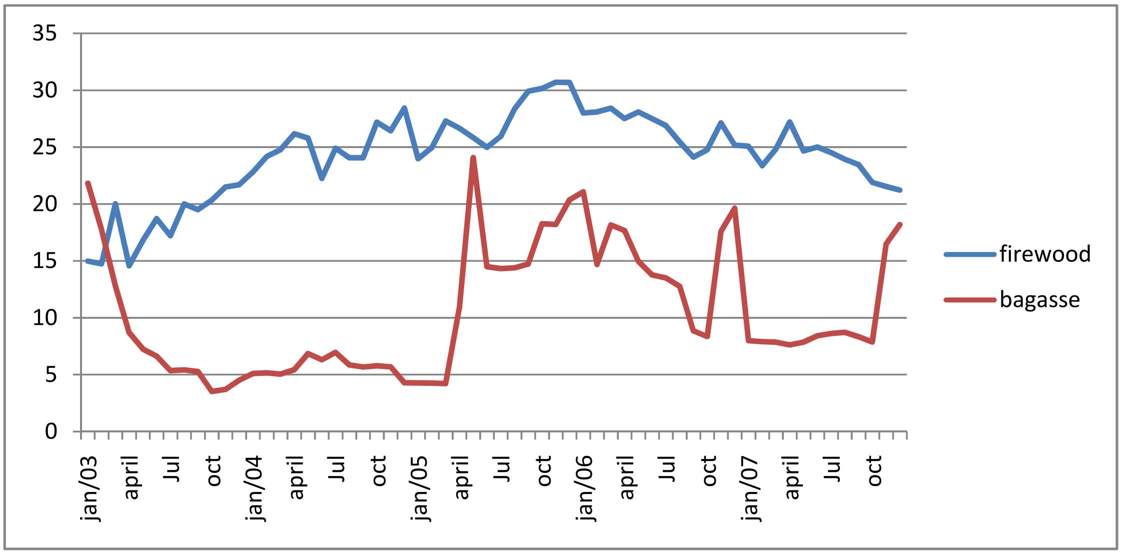



Figure 5 – Comparison 1 million kcal real prices in firewood from center-west Paraná state and sugarcane bagasse from January 2003 to December 2007.

Source: CTGAS (2008).Research data. Elaborated by the authors.

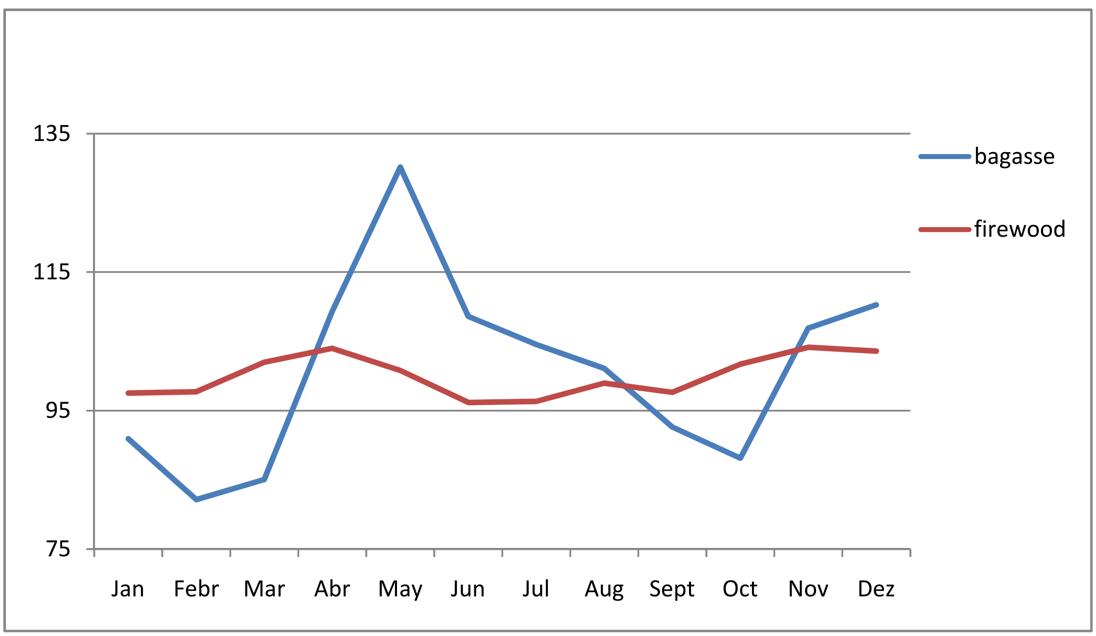



Figure 6 – Comparison between seasonal indices of real prices payed to the producer of firewood in center-west Paraná state and sugarcane bagasse from January 2003 to December 2007.

Source: Research data. Elaborated by the authors.

III.4 - Analysis of the seasonal indices variation

Observing Table 4, one can verify that calculated F=2.04 is a significant value at 10% (tabled F=1.60), as well as at 5% (tabled F=1.91). However, it did not present itself as significant at 1%, showing the importance of seasonality in price variation of firewood payed to center-west Paraná state producers in the analyzed period.

Table 04 – Variance analysis of seasonal indices values related to the price of firewood payed to center-west Paraná state producers from January 1997 to December 2007.

| SV | DF | SS | MS | F |
|---|---|---|---|---|
| MONTHS | 11 | 0.21 | 0.019 | 2.05 |
| RESIDUE | 108 | 1.03 | 0.009 | |
| TOTAL | 119 | 1.25 | | |

Source: Research data. Elaborated by the authors.

The intensity of seasonal variance is given by the dispersion of seasonal indices values. This dispersion can be measured by the amplitude of the seasonal index. For Table 1 data, the amplitude is 107.55-94.07=13.48. (HOFFMANN *et. al.* , 2006).

In Table 5, it is noticeable that calculated F =0.892 is not a significant value at 10%, 5% and 1%.

Table 05 – Variance analysis of seasonal indices values related to the price of sugarcane bagasse in the northwestern region of Paraná from January 2003 to December 2007.

| SV | DF | SS | MS | F |
|---|---|---|---|---|
| MONTHS | 11 | 1.10 | 0.10 | 0.89 |
| RESIDUE | 36 | 4.05 | 0.11 | |
| TOTAL | 47 | 5.15 | | |

Source: Research data. Elaborated by the authors.

## IV.- Concluding Remarks

Analyzing the seasonality in firewood prices, clear oscillations in prices were identified, verifying an oscillation in seasonal indices above average during March and April and close to the average in the other months. There is no monthly alternation of the trend, putting in evidence the strong influence of grains harvest and off-season periods. On the other hand, the seasonal indices of bagasse prices did not present clear oscillations in prices, as it is a sugarcane sub-product and there is no possibility to stock it for long periods. In addition to that, being a semi-perennial culture, sugarcane is subjected to the weather, leading to a greater variation in supply if compared to firewood biomass. This knowledge about seasonal variation is very important for all participants in this market as well as for the formulation of the government policy on agriculture.  The knowledge of seasonal index is also essential to anticipate prices in a certain time of the year.

## REFERENCES

ALVES, M. V. G; OLIVEIRA, R. A; KOEHLER, H. S; MELLO, B. Diagnóstico do setor florestal no estado do Paraná, 2007. **Disponível em:** <http://www.scribd.com/doc/2030586/DIAGNOSTICS-OF-THE-FORESTRY-SECTOR-IN-PARANA-STATE-BRAZIL>. **Acesso em: 23 out. 2007.**

ALVES. F; DIAS, M. O; CASTRO; F. F; MURTA, R. M. **Utilização do bagaço de cana-de-açúcar para a produção de energia. PUBVET, v.2, n.29, 2008. Disponível em: <http://www.pubvet.com.br/texto.php?id=286>. Acesso em: 19 dez. 2008.**

BALEOTTI, L. O Lixo que vira luz. Alcoolbrás, São Paulo, n. 113, p. 34-41, nov./dez. 2007.

BOLLIGER, F. P (Coord.). Produção da Extração,Vegetal e da Silvicultura. Brasília: IBGE, 2007. 20p (v. 22).

BUAINAIN, A.M.; BATALHA, M.O. (Coord.) Cadeia Produtiva de Madeira. Brasília: IICA/MAPA/SPA, 2007. 82p. (Série Agronegócios, v. 6)

GOLDEMBERG, J. Energia e desenvolvimento. Estudos Avançados, v. 12, n. 33, 1998.

HOFMMANN, R. Estatística para Economistas. 4 Ed. São Paulo: Thomson, 2006. 446p.

LEITE, A. D. A energia do Brasil. 2.Ed. Rio de Janeiro. Elsevier. 2007.

OLIVEIRA, A. M. K; LIMA, L. M; CARLETTI, P. T.; FERRARI, R. C; CAIXETA FILHO, J. V. Avaliação da viabilidade técnica e econômica da utilização de biomassas como fonte energética alternativa em fornos industriais. In: In: Congresso Brasileiro de Economia e Sociologia Rural, 42., 2004, Cuiabá. Anais... Cuiabá: SOBER, 2004. CD ROM

OLIVEIRA, A.J.; RAMALHO, J. (Coord.) Plano Nacional de Agroenergia 2006-2011. 2. ed. rev. Brasília: Embrapa Informação Tecnológica, 2006. 110 p.

TETTO, A.F.; HOEFLICH, V.A; RUCKER, N.G.A.; SILVA, D.A.T.; BORGES, J.L. Histórico dos preços e da produção de lenha e de carvão vegetal, no estado do Paraná, entre 1997 e 2007. In: Congresso Brasileiro de Economia, Administração e Sociologia Rural, 46., 2008, Rio Branco. Anais... Rio Branco: SOBER, 2008. CD ROM.

MICROSOFT. Microsoft Office 2007. São Paulo, 2008. 1 CD-ROM.

CENTRO DE TECNOLOGIA DO GÁS (CTGÁS). Dados de unidade de conversão. Disponível em: <http://www.ctgas.com.br>.Acesso em: 10 maio 2008.

# 26. The Role of Family Farmers in the Brazilian Biodiesel Program

**Gisele Ferreira Tiryaki[1], Júlia Tais Ribeiro de Oliveira[2] e Rommel Cavalcanti Silva Araújo[2]**

[1] Universidade Salvador (UNIFACS)

[2] Universidade Federal da Bahia (UFBA).

Endereço: Rua Ponciano de Oliveira, no. 126, Rio Vermelho – Salvador – Bahia, Cep: 41.950-275. E-mail: gisele_fsilva@unifacs.br.

ABSTRACT

The Brazilian government biodiesel policy has as one of its main goals the promotion of an active participation of family farmers in the biodiesel production chain as suppliers of oilseeds. Since 2008, all diesel sold in the country contains 2% of biodiesel, and, despite the government incentives, the national biodiesel production has been largely obtained from soy beans supplied by agribusiness, instead of relying on family farms' production. Analyzing case studies of family farmers' cooperatives successfully involved in the cultivation of oilseeds and the management of oil press facilities associated with biodiesel production, the present work identifies the hurdles and indicates the path to a greater engagement of family farming in the Brazilian biodiesel market.

The analysis of initiatives underway in the south and southeast regions of the country identified several factors that have guaranteed the successful integration of family farmers into the biodiesel production chain, such as: the presence of institutional mechanisms to reduce information asymmetry problems pervasive in cooperative interactions; the level of training, professional skills and leadership of those managing the cooperatives; the existence of governmental or non-governmental financial and non-financial support for the initiatives; the design of strategic planning; and cultural background. In the biodiesel market, particularly, identifying the elements that promote the setting of self-sustainable cooperatives is essential to promote the participation of family farmers in the supply chain, since operational efficiency is key to allowing biodiesel to be competitive against fossil fuels.

O PROGRAMA BRASILEIRO DE BIODIESEL E AS ESTRATÉGIAS DE INSERÇÃO DA AGRICULTURA FAMILIAR*

Gisele Ferreira Tiryaki[1], Júlia Tais Ribeiro de Oliveira[2] e Rommel Cavalcanti Silva Araújo[2]

[1] Universidade Salvador (UNIFACS)

[2] Universidade Federal da Bahia (UFBA).

Endereço: Rua Ponciano de Oliveira, no. 126, Rio Vermelho – Salvador – Bahia, Cep: 41.950-275. E-mail: gisele_fsilva@unifacs.br.

RESUMO

O Programa Nacional de Produção e Uso do Biodiesel (PNPB) tem como um de seus objetivos a inserção da agricultura familiar na cadeia de produção do biodiesel como produtora de grãos oleaginosos. Observa-se, contudo, tal objetivo não vem sendo alcançado e a produção de nacional de biodiesel vem sendo obtida, principalmente, a partir da soja originária do agronegócio. O presente trabalho identifica os entraves e aponta os caminhos para inserção da agricultura familiar no mercado de biodiesel, através da avaliação de experiências de sucesso no cultivo de oleaginosas para produção de biodiesel e na implantação de unidades de esmagamento, em iniciativas lideradas por associações/cooperativas de agricultores familiares.

Os estudos de casos realizados permitiram identificar uma série de fatores como relevantes para o sucesso da integração da agricultura familiar na cadeia produtiva do biodiesel, tais como questões culturais; presença de mecanismos institucionais e organizacionais que minimizem a assimetria de informação nas interações associativas/cooperativas; existência de apoio externo de entidades governamentais e não-governamentais; nível de capacitação, profissionalização e liderança dos gestores das associações/cooperativas; e existência de planejamento estratégico. No mercado de biodiesel, em particular, a identificação de elementos que permitam a estruturação de cooperativas auto-sustentáveis é fundamental para a viabilização da agricultura familiar, já que a eficiência operacional garante a inserção competitiva do biodiesel frente a combustíveis fósseis.

---

* Os autores agradecem ao suporte financeiro concedido pela Fundação de Amparo à Pesquisa do Estado da Bahia (FAPESB) e Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq).

## INTRODUÇÃO

O biodiesel tem sido apontado como uma das alternativas viáveis em curto prazo para a diversificação da matriz energética, em virtude dos vários benefícios associados ao seu uso como combustível (ver, entre outros, International Energy Agency, 2004; Kojima e Johnson, 2005; Tyson e McCormick, 2006). Em comparação com o diesel fóssil, a utilização do biodiesel implica em menor emissão de gases de efeito estufa, como o dióxido de carbono, o dióxido de enxofre e o óxido de carbono, e de matéria particulada. Estudos empíricos indicam que a emissão de gases de efeito estufa no ciclo de vida do biodiesel produzido a partir da canola ou da soja, por exemplo, situa-se em níveis entre 44% e 66% menores que o diesel fóssil (ver International Energy Agency, 2004).

Observa-se, também, um melhor desempenho dos veículos, face à maior lubricidade e maior qualidade de ignição do biocombustível. A adição do biodiesel ao óleo diesel em proporção de até 30% requer poucas modificações nos motores e na infra-estrutura de distribuição de combustíveis e seu menor nível de toxidez e baixo risco de explosão implicam em maior segurança no manuseio, transporte e armazenamento.

O uso do biodiesel é ainda associado com algumas vantagens econômicas. Primeiro, a necessidade de se estimular a produção de insumos a serem utilizados na obtenção de biodiesel tende a promover um maior desenvolvimento rural, com o uso mais eficiente do solo, a geração de postos de trabalho e renda, e, conseqüentemente, a diminuição na pressão demográfica nas periferias das grandes cidades. Finalmente, a substituição do óleo diesel por biodiesel também pode viabilizar uma menor dependência externa, auferindo ganhos na balança comercial através da redução nas importações de petróleo.

De uma forma geral, o principal entrave à produção e utilização do biodiesel são os seus elevados custos de produção, estimados em até duas vezes mais que o diesel fóssil. O principal fator na composição do custo do produto é o óleo vegetal, chegando a representar 70% do custo total, a depender do insumo agrícola utilizado. Espera-se que os custos declinem com a produção em larga escala, com ganhos de produtividade à medida que se avança na curva de aprendizado da produção do biocombustível. Portanto, a competitividade do biocombustível, depende, essencialmente, da produtividade na produção agrícola e do preço da matéria-prima sendo utilizada, além de aumentos significativos nos preços do petróleo (ver International Energy Agency, 2004; e Babwal e Sharma, 2005).

Como forma de estimular o cultivo de oleaginosas para produção de biodiesel no Brasil, o governo federal lançou o Programa Nacional de Produção de Biodiesel (PNPB). A introdução do biodiesel na matriz energética nacional foi oficializada através da Lei

11.097 (Brasil, 2005), que estabeleceu o patamar mínimo de adição de biodiesel ao diesel fóssil comercializado no país em 2%, a partir de 2008, e 5%, a partir de 2013[95]. Considerando que, somente no setor de transportes, o diesel fóssil representou 50,9% do total de combustíveis consumidos no Brasil em 2006 (Ministério das Minas e Energia, 2007), o atendimento dessas diretrizes representará uma economia significativa para a balança comercial do país. Rathmann et al (2006) estimam uma redução da importação do diesel fóssil em torno de US$ 160 milhões por ano a partir de 2008 e de US$ 400 milhões a partir de 2015.

O Brasil dispõe de uma grande variedade de espécies vegetais que podem ser utilizadas para a produção de biodiesel. Dentre elas, destacam-se a mamona, soja, algodão e dendê, por já serem cultivadas de forma intensiva, e, em especial, a mamona e o dendê, por terem elevado rendimento de óleo por hectare. Existem outras espécies que estão em estágio preliminar de avaliação, ou são caracterizadas pelo extrativismo, não sendo possível, por isso, concluir sobre sua viabilidade de forma mais definitiva.

O PNPB foi delineado tendo como objetivo primordial o estímulo à produção de biodiesel utilizando oleaginosas produzidas a partir da agricultura familiar. Neste sentido, ainda em 2005, o Ministério de Desenvolvimento Agrário (MDA) publicou a Instrução Normativa No. 1 instituindo o Selo Combustível Social (MDA, 2005). Os produtores de biodiesel, que comprovem a aquisição de matéria-prima da agricultura familiar em pelo menos 50% na região Nordeste do país, 30% nas regiões Sudeste e Sul e 10% na região Norte, têm o direito de obter a concessão ao uso do referido Selo, por um período de cinco anos.

A obtenção do Selo Combustível Social garante redução de alíquotas de impostos federais, acesso a condições favoráveis de financiamento em bancos governamentais e participação nos leilões de comercialização do biocombustível realizados pela Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (ANP). Além do subsídio do governo federal, os governos estaduais estão impondo uma carga tributária para a comercialização do biodiesel no território nacional em 12% (a alíquota do diesel fóssil, por sua vez, varia a depender do estado, sendo igual ou superior a 12%).

Os leilões de comercialização vêm ocorrendo desde 2005, como forma de acelerar os investimentos e a produção de biodiesel do país, além de garantir que a matéria-prima utilizada seja, em sua maior parte, da agricultura familiar. Nestes leilões, que têm atraído o interesse dos produtores de biodiesel do país e têm como compradores apenas a PETROBRAS e a Repsol YPF, a ANP estabelece o preço-teto e quota de

[95] Ainda em 2008, o Conselho Nacional de Política Energética elevou esse percentual inicial de mistura para 3%.

comercialização do produto[96]. As quotas comercializadas no leilão são divididas em dois lotes: uma fração expressiva da quota é destinada às empresas que possuem o Selo, enquanto o restante, em torno de 20% do volume leiloado, pode ser adquirido por qualquer empresa autorizada pela ANP. Procura-se, assim, garantir a participação da produção de oleaginosas pela agricultura familiar na produção de biodiesel do país.

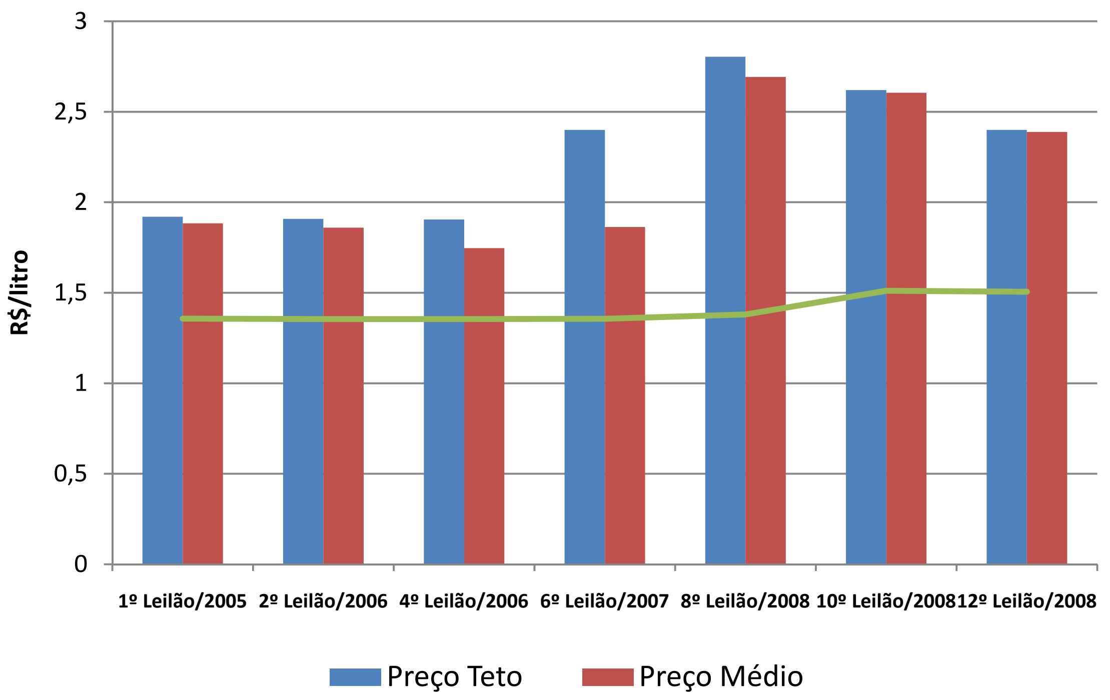
De uma forma geral, os preços médios finais não têm apresentado grandes deságios em relação ao preço de referência estipulado pela ANP e se situam em patamares consideravelmente elevados em relação ao diesel fóssil, dificultando a inserção do biodiesel no mercado de combustíveis (ver Figura 1).

O mercado atual do biodiesel ainda é incipiente. O principal entrave tem sido a dificuldade dos produtores em adquirir a matéria-prima da agricultura familiar, o que tem levado à produção de biodiesel a ser feita em sua grande parte com a utilização da soja[97]. O governo, ao delinear o PNPB, subestimou a necessidade de apoio técnico a ser dado à agricultura familiar que possibilitasse maior produtividade e viabilidade econômica para a sua inserção no mercado de biodiesel. Além disso, as matérias-primas selecionadas para a concessão do benefício fiscal possuem usos alternativos com maior valor agregado que aquele associado à utilização como insumos na produção de biodiesel.

Figura 1 – Resultados dos Leilões para Empresas Detentoras do Selo Combustível Social

[96] Os produtores de biodiesel enfrentam o risco de que, com o fim dos leilões, não seja possível conseguir a venda de biodiesel a preços viáveis economicamente, principalmente quando se considera o caráter monopsônico do mercado, em face do domínio exercido pela Petrobras.

[97] Algumas empresas ganhadoras dos leilões não têm conseguido atender o volume de biodiesel contratado em função da falta de matéria-prima, muito embora a capacidade instalada no país exceda o necessário para atender a meta de 3% de mistura de biodiesel estabelecida pelo PNPB.




Nota: os preços indicados acima não incluem os tributos PIS-COFINS ou ICMS
Fonte: ANP (2009a) e ANP (2009b)

Este trabalho tem por objetivo identificar os entraves e apontar os caminhos para inserção da agricultura familiar no mercado de biodiesel, através da avaliação de experiências de sucesso no cultivo de oleaginosas para produção de biodiesel e na implantação de unidades de esmagamento, em iniciativas lideradas por associações/cooperativas de agricultores familiares. A atuação de cooperativas é de fundamental importância para a inserção da agricultura familiar no PNPB, pois viabiliza a obtenção de ganhos de escala e agregação de valor à produção agrícola, particularmente quando a verticalização da produção com a implementação do esmagamento mostra-se viável.

O artigo está organizado da seguinte forma. A segunda seção apresenta as formas de estruturação de cooperativas, identificando as vantagens e dificuldades associadas à esta estrutura de organização da produção. A terceira seção, por sua vez, avalia algumas experiências de sucesso no cultivo de oleaginosas para produção de biodiesel e na implantação de unidades de esmagamento no Brasil. A quarta seção apresenta as conclusões.

Cooperativismo

O cooperativismo surgiu em meados do século XIX na Inglaterra. A primeira cooperativa denominava-se “Sociedade dos Probos Pioneiros de Rochdale”. Fundada em 21 de dezembro de 1844 em Rochdale, nos arredores da cidade de Manchester, era formada por vinte e oito tecelões – dentre os quais uma mulher. Trabalhando em ambientes fabris insalubres, com jornadas de trabalho de até dezesseis horas por dia e salários miseráveis, estes trabalhadores decidiram se unir para, em conjunto, adquirir bens de primeira necessidade, como roupas e alimentos, adquirir e construir casas para os cooperados, formar algum capital social viabilizado pela poupança resultante da compra comum de alimentos e promover educação, campanhas contra o alcoolismo e a cooperação integral através da criação de núcleos de comunidade piloto que viessem a se transformar em novas cooperativas.

A iniciativa logrou muito êxito. Cada um dos vinte e oito tecelões entrou para a organização contribuindo com uma libra. Ao final do primeiro ano, o capital social chegou a cento e oitenta libras. Em dez anos, a cooperativa contava com mil e quatrocentos cooperados. A experiência se difundiu pela Europa, destacando-se a França com diversas cooperativas de trabalho e a Alemanha e a Itália com a fundação de cooperativas de crédito. Menos de quarenta anos após a criação da primeira associação, mais precisamente em 1881, o continente europeu já contava com mais de mil cooperativas que totalizavam em torno de quinhentos e cinquenta mil associados.

No Brasil, os rudimentos do cooperativismo estão ligados à prática do mutirão. Pode-se dizer que a primeira iniciativa que contava com melhor estruturação remonta ao ano de 1847, quando o médico francês Jean Maurice Faivre inaugurou a colônia teresa Cristina, juntamente com outros colonos europeus no Paraná. Ainda no século XIX, surgiu em Minas Gerais a primeira cooperativa agropecuária. Em São Paulo, n cidade de Campinas, os trabalhadores da Companhia Paulista de Estrada de Ferro criaram a primeira cooperativa de consumo. Já no século XX, mais precisamente em 1902, o padre suíço T. Amstead fundou uma cooperativa de crédito agrícola em Nova Petrópolis, Rio Grande do Sul, a qual foi denominada Caixa Rural Raiffaiser.

A primeira legislação nacional sobre cooperativas foi a lei n° 1.637, de 05/01/1907. Baseada numa lei belga, ela obrigava as cooperativas a se constituirem na forma de sociedades comerciais correntes – anônimas, em comandita simples ou em nome coletivo. Mas somente em 21/11/1966, com a entrada em vigor do decreto-lei n° 59, foi criado o Conselho Nacional de Cooperativismo, definindo-se uma política nacional de cooperativismo.

Para Noronha (1976, p. 15), “cooperativismo é um processo associativo pelo qual homens livres aglutinam suas forças de produção, sua capacidade de consumo e suas poupanças, a fim de se desenvolverem econômica e socialmente, elevando seu padrão de vida, ao mesmo tempo em que, por aí, beneficia-se a sociedade geral, pelo aumento e barateamento da produção, do consumo e do crédito".

Crúzio (2002, p. 13), por sua vez, define cooperativa como "a união de trabalhadores ou profissionais diversos, que se associam por iniciativa própria, sendo livre o ingresso de pessoas, desde que os interesses individuais em produzir, comercializar ou prestar um serviço não sejam conflitantes com os objetivos gerais da cooperativa".

O cooperativismo, portanto, é uma das formas associativas de organização humana. A fim de diferençá-la das demais, a Aliança Cooperativa Internacional – ACI demarcou as suas fronteiras conceituais através de princípios que norteiam os seus processos constitutivos, decisórios e finalísticos. São eles:

Adesão voluntária e livre: as cooperativas devem ser abertas a todas as pessoas aptas a utilizarem seus serviços e assumirem suas responsabilidades como membros.

Gestão democrática pelos membros: os membros devem participar ativamente da formulação de políticas e tomadas de decisões e da escolha dos seus representantes.

Participação econômica dos membros: os cooperados devem contribuir eqüitativamente para o capital da sociedade.

Autonomia e independência da cooperativa: as cooperativas devem atuar com total independência, sem qualquer interferência em sua autonomia e administração pelos seus membros.

Educação, formação e informação: as cooperativas devem promover a formação e educação dos seus membros, representantes eleitos e trabalhadores para que eles possam contribuir de forma cada vez mais eficaz no desenvolvimento das respectivas organizações.

Intercooperação: as cooperativas devem trabalhar em conjunto, através das estruturas locais, regionais, nacionais e internacionais.

Interesse pela comunidade: as cooperativas devem trabalhar para o desenvolvimento sustentado de suas comunidades.

Dentre os princípios acima apresentados, há três que representam diferenciais marcantes da constituição e atuação das cooperativas. Em primeiro lugar, a participação dos membros no processo decisório (gestão democrática), o que confere um traço político à administração organizacional. Em segundo lugar, a necessidade de capacitar os cooperados para tornar sua contribuição mais efetiva aos objetivos da cooperativa, o que é essencial à gestão democrática e participativa proposta para estas organizações. E, por fim, a idéia de desenvolvimento sustentável que está necessariamente atrelada à atuação e aos objetivos das cooperativas desde o momento em que elas se constituem legalmente.

Dadas as características bastante particulares das cooperativas apresentadas acima, é importante destacar alguns fatores supervenientes que interferem decisivamente na constituição e, sobretudo, na forma de atuação e gestão destas entidades. Tais fatores são fundamentais para que sejam atingidos os objetivos organizacionais, para garantir um relacionamento harmônico entre os cooperados e para a estabilidade e a solidez da instituição.

Pode-se dizer que a cultura é um aspecto extremamente relevante para a constituição e o sucesso de cooperativas. Nas sociedades em que o associativismo faz parte da forma como os indivíduos se relacionam, integrando a cultura do grupo e definindo modelos comportamentais, as nuances do cooperativismo tendem a ser melhor compreendidas e aplicadas pelos cooperados. Em consequência, as chances de sucesso das iniciativas nessas comunidades também tendem a ser maiores.

É importante também delinear mecanismos que permitam minimizar os problemas associados à informação assimétrica entre a gestão das cooperativas e os cooperados. Transparência no gerenciamento das atividades e na administração dos recursos da cooperativa é de fundamental importância para que os cooperados tenham segurança que os interesses da coletividade estão sendo privilegiados em detrimento dos interesses dos gestores. Dessa forma, estabelece-se laços de confiança robustos entre cooperados e gestores, o que garante que os compromissos assumidos pela cooperativa serão honrados e que o bem estar coletivo estará sendo maximizado, ceteris paribus.

Outro fator relevante para o sucesso das cooperativas é a atuação do Estado no sentido de fomentar a constituição e criar condições para a sustentabilidade econômica destas associações através de benefícios fiscais e facilidades de crédito. Vale lembrar que tais instituições são constituídas normalmente com parcos recursos tendo em vista a limitação de capacidade contributiva dos seus membros. Ademais, nas comunidades em que o associativismo não faz parte da cultura de grupo, o papel de fomentador do Estado é ainda mais fundamental para a constituição e estabilidade de funcionamento das cooperativas.

Por fim, o nível de capacitação, profissionalização e liderança dos cooperados encarregados da gestão das cooperativas é extremamente relevante. Como estas organizações aplicam por princípio a gestão democrática e participativa, o processo de tomada de decisões é muito mais complexo e delicado do que aquele que se observa nas atividades empresariais. Assim, a habilidade e a representatividade dos gestores são cruciais para o sucesso da organização. Além, obviamente, da utilização de instrumentos e métodos de gestão, tais como o planejamento estratégico, que tem se apresentado como poderosa ferramenta para gestores de cooperativas bem sucedidas no Brasil.

A Inserção de Cooperativas de Agricultores Familiares no Mercado Brasileiro de Biodiesel

As experiências de produção de biocombustíveis pela agricultura familiar são recentes. Para a presente análise, foram selecionados dois casos de cooperativas de pequenos e médios agricultores formadas a partir de 2005 com essa finalidade. São elas:

Cooperativa Mista de Produção, Industrialização e Comercialização de Biocombustíveis do Brasil (Cooperbio), localizada no município de Palmeira das Missões no estado do Rio Grande do Sul; e

Cooperativa Central Agroindustrial Noroeste (Coceagro), com sede em Horizontina e atuante em vários municípios do estado do Rio Grande do Sul.

A Cooperbio é gerida pelo Movimento dos Pequenos Agricultores (MPA) e conta com cerca de 30 mil pequenos e médios agricultores, em 63 municípios da região Noroeste do RS. Foi criada em 2005 com a finalidade de conciliar a produção de energia e alimento, garantindo a participação do agricultor em todas as etapas da cadeia produtiva e da comercialização. Em maio de 2007, inaugurou a primeira microdestilaria de produção de álcool no município de Redentora, em parceria com a Petrobras. Foram investidos cerca de R$ 2,3 milhões, pela empresa estatal. A capacidade de produção no primeiro momento era de 500 litros de álcool/dia. Em seguida, foram inauguradas outras oito microdestilarias e uma unidade central de retificação, em Frederico Westphalen, com a capacidade de processar conco mil litros/dia de álcool. Ressalta-se que a cooperativa produz, de maneira sustentável, a própria da energia elétrica necessária para produção do álcool.

As matérias-primas utilizadas são a cana-de-acúcar e a mandioca. Em relação à produtividade agrícola, atinge cerca de 70 toneladas de cana-de-açúcar por hectare e produtividade industrial de 70 litros de etanol por tonelada. A produtividade agrícola da mandioca é de 19 toneladas por hectare e uma produtividade industrial de 160 litros de etanol por tonelada. São usados, no máximo, dois hectares por família para produção destinada ao etanol.

Em Palmeira das Missões (RS), no ano de 2008, foi instalado um complexo de biodiesel, compreendendo uma usina de biodiesel e uma unidade de esmagamento, em uma área de 35 hectares. O investimento da Petrobras foi da ordem de R$ 35 milhões, enquanto a Cooperbio direcionou R$ 45 milhões para estruturação da unidade de esmagamento. A capacidade de produção de óleo vegetal é calculada em 600 toneladas ao dia e a estimativa de produção da usina, que tem o início das suas atividades previsto para o primeiro semestre de 2009, é de 50 mil toneladas ao ano. Está planejada a implantação de outras quatro estruturas menores de esmagamento nos municípios de Frederico Westphalen, Novo Barreiro, Sarandi e Coronel Bicaco, o que geraria mais R$ 3 milhões de investimento para cada esmagadora.

O girassol, mamona, canola e especialmente a soja, entre outras, são utilizadas como matéria-prima. A produção agrícola de 12 mil famílias agricultoras conta com 53 milhões de sacas de soja e sete teneladas de sementes de pinhão manso por hectare.

A Coceagro, por sua vez, foi fundada em 2001 no município de Três de Maio, surgindo a partir da união de outras três cooperativas: a Cotrimaio[98], do município de Três de Maio, fundada em 1968; a Coopermil[99], de Santa Rosa, fundada em 1955; e, a Comtul[100], de Tucunduva, cujo início das atividades foi em 1957. O objetivo era operar na industrialização, na aquisição de insumos e fornecimento de produtos para seus associados no segmento de cereais. Contava, então, com uma estrutura de moinho de trigo e milho com capacidade de 1,5 mil toneladas por mês de moagem, além do moinho da Cerealista com capacidade de 200 toneladas por mês.

Com a aquisição do patrimônio da fábrica da Empresa Coinbra, estabelecida em Cruz Alta, produtora de óleo vegetal, em 2006, a cooperativa passou a operar também nesse segmento, com o esmagamento de soja e a produção de óleo de soja bruto degomado e farelo de soja. Atualmente, processa mil toneladas de soja in natura por dia, oferecendo um rendimento de 76% de farelo de soja e 18% de óleo de soja. A introdução da nova atividade levou a Coceagro a modificar seu processo de tomada de decisões. Antes organizada por segmentos de atuação, passou a contar com apenas um corpo diretivo para os diversos segmentos.

[98] Cotrimaio - Cooperativa Agro-pecuária Alto Uruguai Ltda - Em 2002, teve início uma nova etapa na cooperativa; com base num projeto de Recursos Humanos avaliou-se a gestão de pessoas e assuntos que tratavam da administração da organização, e passou-se à Gestão por Negócios, sendo esta positiva e cumpridora de metas, tornando a COTRIMAIO mais competitiva. Os objetivos foram ampliados para: foco no desenvolvimento das pessoas, pela própria gestão; foco na organização como um todo e suas atividades; foco nos resultados; foco no mercado; e ampliação da visão dos processos existentes. Informações disponíveis em http://www.cotrimaio.com.br/, consultadas em 5 de Janeiro de 2009.

[99] Coopermil - Cooperativa Mista São Luiz Ltda.

[100] Comtul - Cooperativa Mista Tucunduva Ltda.

Em 2008, a Comtul passou a participar com 35,34% do patrimônio da Coceagro, a Cotimaio, 35,34%, a Coopermil, 16% e a Coasa[101], 13,32%. No total, são 18.792 pequenos agricultores associados, em 40 municípios do Estado.

O aspecto marcante das cooperativas estudadas é a gestão dos pequenos agricultores desde a produção de matéria-prima à parte industrial, precedida por estudos de viabilidade, inúmeros seminários e oficinas para debate e formação de seus associados, ao longo de alguns anos, e capacitação para gestão. Além disso, embora estejam atuando há pouco tempo no segmento de biocombustíveis, em ambas observa-se a existência de um histórico de cooperação e sucesso em relação à mobilização de agricultores e prestação dos serviços propostos em seus objetivos. Algumas chegam a contar com cerca de 30 mil cooperados, como é o caso da Cooperbio, que gerencia oito micro-destilarias e uma refinaria central. Marcelo Leal, Engenheiro Agrônomo, coordenador técnico da cooperativa, afirma que

A questão da cooperação tem nos mostrado que os grupos se formam por necessidades reais. Podemos citar a formação de núcleos pela conquista da terra, do crédito e outros. Supridas tais necessidades, os grupos se dissolvem e isto é um fato. Nossos Movimentos possuem como estratégia política a formação de grupos de base e este é o cerne da organicidade e da participação das massas nos debates e tomadas de decisões. (Leal, 2007)

A produção de biocombustível emerge como possibilidade de agregar valor ao papel elementar da agricultura familiar, qual seja, da produção de matéria-prima, mas, também estabelece condições de produzir seus próprios insumos a partir dos co-produtos gerados no processo de esmagamento das oleaginosas ou da cana-de-açúcar, destinados à alimentação animal e adubação. Segundo o técnico da Cooperbio, a cada 1000 kg de girassol são produzidos 450 litros de óleo vegetal destinados à alimentação humana e à produção de biodiesel e 300 kg de farelo para alimentação animal (incluindo carne, leite, ovos). Adicionalmente, são produzidos 250 kg de cascas que podem ser utilizados como combustível para co-geração de energia elétrica, reduzindo os custos de produção, melhorando o retorno econômico às famílias, ou podem ser usado como adubo orgânico. (Leal, 2007)

A apicultura também pode ser impulsionada. A prática revela que, com um hectare de girassol, são produzidos 100 kg de mel de alta qualidade e as abelhas, com o processo de polinização, provocam o aumento de até 30% da produtividade do girassol. Finalmente, atuando na renovação do canavial, o girassol pode aumentar em até 40% a produtividade cana de em relação ao primeiro ano. Os consórcios com cana e

---

[101] Coasa - Cooperativa Agrícola Água Santa Ltda.

mandioca também vêm se mostrando viáveis aumentando as sinergias entre os projetos biodiesel e álcool e suas respectivas combinações. (Leal, 2007)

A produtividade da terra é, portanto, potencializada com os consórcios, pois a produção de tortas/farelos de fins não-comestíveis fomenta uma nova rota de insumos para a agricultura, ao mesmo tempo em que reduz a ocupação de área necessária para a mesma quantidade de óleo. Um exemplo significativo pode ser o tungue. Para a produção de 30 milhões de litros de óleo vegetal com base no cultivo do tungue, são necessários em torno de 23 mil ha capazes de gerar cerca de 138 mil toneladas de adubo orgânico, rico em Fósforo, Potássio e fibras. (Leal, 2007)

Nesse sentido, os consórcios de oleaginosas ou cana-de-açúcar com os cultivares para consumo da família e comercialização desempenham um papel primordial na superação do temor de que os biocombustíveis coloquem em risco a produção de alimentos e um papel não menos importante para diversificação do plantio, a fim de evitar a prática de degradação do solo associada à prática da monocultura. Esse aspecto parece ser central para a manutenção da agricultura familiar, pois a unidade de produção não deve ser considerada apenas economicamente, mas como espaço de reprodução social, onde a produção voltada para auto-consumo (produção de subsistência) garante a estabilidade do produtor frente à oscilação dos mercados e dificuldades de comercialização (NOGUEIRA, 2007).

Todos esses fatores propulsores das experiências analisadas revelam existência de um projeto designado por auto-suficiência energética ou auto-desenvolvimento de comunidades da agricultura familiar, pelos Movimentos Sociais do campo, seja auto-suficiência dos cooperados, da própria comunidade ou região, o que demonstra uma profunda consonância com as buscas de soluções que contribuam para a mitigação do aquecimento global - um dos maiores desafios do século XXI - e com o fomento do desenvolvimento local. Leal (2007), a respeito da experiência da Cooperbio, afirma que o projeto da agricultura familiar e camponesa inclui produção e tecnologia, cultura e relações sociais e interação com a natureza, cuja virtude de sua economia está em se constituir em unidade de produção e consumo, em ser espaço de convivência.

Depreende-se das experiências analisadas que a viabilização da inserção da agricultura familiar na cadeia de produção do biodiesel, de modo a promover geração de renda e autonomia ocorre com a estruturação de sistemas integrados de produção de biocombustíveis com os produtos da agricultura familiar existentes ou potencializados com o processo. Leal (2007) exemplifica os benefícios dessa relação, avaliando que a utilização da cana-de-açúcar possui grande presença na alimentação humana e também serve de forrageira para alimentação animal (12 toneladas de ponta de cana-de-açúcar/ha/ano). Esta fornece reforço alimentar animal em períodos de baixa produção agrícola e, com isso, garante a manutenção ou mesmo aumenta a produção de leite e derivados reservados para o consumo das famílias.

Os dejetos animais, o vinhoto e o bagaço são adubos ricos que ajudam na reestruturação física do solo. Também pela experiência prática, avalia que a produção de girassol seguida de milho aumenta a produtividade do milho em 30%, devido à ciclagem de nutrientes como Potássio (150 Kg/há), e fósforo (50 Kg/há), o que reduz a demanda por insumos químicos. Idealmente, a estratégia para não comprometer a produção de alimentos em detrimento à produção voltada para o biodiesel, em médio prazo, a produção para consumo humano deveria ocorrer a partir do girassol, canola, gergelim, amendoim e outros por se tratarem de óleos mais nobres do ponto de vista nutricional, ao contrário do óleo de soja, comumente utilizado. (Leal, 2007)

Por outro lado, a produção em grande escala é fator-chave para inserção econômica e não é por outra razão que nos últimos dois anos foi possível identificar uma série de iniciativas embrionárias de esmagamento pela agricultura familiar. Elas são elaboradas e ganham corpo, no entanto, na medida em que o poder público apóia ou financia, direta ou indiretamente, tais projetos. A Petrobras, o Banco do Brasil, o Banco Nacional de Desenvolvimento Econômico e Social (BNDES) vêm realizando investimentos sem precedentes nas organizações da agricultura familiar, voltados para a produção de matéria-prima para os biocombustíveis, bem como para o seu beneficiamento.

A previsão da Petrobras, em 2006, era de investir cerca de R$ 200 milhões somente no Rio Grande do Sul para instalação de usinas de biodiesel, em parceria com organizações de agricultores familiares, garantindo a compra desta produção, como forma de habilitar-se para o recebimento do Selo Social. O Programa Nacional de Fortalecimento da Agricultura Familiar (Pronaf), do Governo Federal e o BNDES vêm, por sua vez, viabilizando a estruturação de unidades de extração do óleo vegetal por esses atores.

## Conclusão

O Programa Nacional de Produção e Uso do Biodiesel (PNPB) tem como um de seus objetivos a inserção da agricultura familiar na cadeia de produção do biodiesel como produtora de grãos oleaginosos. Observa-se, contudo, tal objetivo não vem sendo alcançado e a produção de nacional de biodiesel vem sendo obtida, principalmente, a partir da soja originária do agronegócio.

O presente trabalho identificou os entraves e apontou os caminhos para inserção da agricultura familiar no mercado de biodiesel, através da avaliação de experiências de sucesso no cultivo de oleaginosas para produção de biodiesel e na implantação de unidades de esmagamento, em iniciativas lideradas por associações/cooperativas de agricultores familiares.

Alguns fatores contribuem de forma relevante para o sucesso da integração da agricultura familiar na cadeia produtiva do biodiesel, tais como elementos culturais; presença de mecanismos institucionais e organizacionais que minimizem a assimetria de informação nas interações associativas/cooperativas; existência de apoio externo de entidades governamentais e não-governamentais; nível de capacitação, profissionalização e liderança dos gestores das associações/cooperativas; e existência de planejamento estratégico. No mercado de biodiesel, em particular, a identificação de elementos que permitam a estruturação de cooperativas auto-sustentáveis é fundamental para a viabilização da agricultura familiar, já que a eficiência operacional garante a inserção competitiva do biodiesel frente a combustíveis fósseis.

REFERÊNCIAS


Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (ANP). Leilões. Rio de Janeiro: ANP, 2009a (disponível em: http://www.anp.gov.br/biocombustiveis/leilao_biodiesel.asp).

Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (ANP). Preços de Produtores. Rio de Janeiro: ANP, 2009b (disponível em: http://www.anp.gov.br/petro/precos_de_produtores.asp).

Barnwal, B.K. and Sharma, M.P. Prospects of biodiesel production from vegetable oils in India. *Renewable and Sustainable Energy Reviews*, v. 9, n. 4, p. 363-378, 2005.

Brasil. Lei No. 11.097. Diário Oficial da União, 14 de Janeiro de 2005.

Cruzio, Helnon de Oliveira. *Como organizar e administrar uma cooperativa*. Rio de Janeiro: Editora FGV, 2002.

International Energy Agency. *Biofuels for Transport: an International Perspective*. Paris: International Energy Agency, 2004.

Kojima, M. and Johnson, T. Potential for Biofuels for Transport in Developing Countries. *World Bank ESMAP Report*, 2005.

Leal, M. 2007. Agricultura Camponesa e Biomassa: Um Outro Projeto é Possível. Disponível em: http://www.cooperbio.com.br/.

Ministério de Desenvolvimento Agrário (MDA). Instrução Normativa No. 1. *Diário Oficial da União*, 05 de julho de 2005.

Ministério de Minas e Energia (MME). *Balanço Energético Nacional – 2006*. Brasília: MME, 2007.

Mance, E.A. *Como organizar redes solidárias*. Rio de Janeiro: Editor DP&A, 2002.

Nogueira, F. Da terra nua ao prato cheio: produção para consumo familiar nos assentamentos rurais do Estado de São Paulo. In *Caderno de resumos da III Jornada de Estudos em Assentamentos Rurais*. Feagri – Unicamp, Campinas, 2007.

Noronha, Adolfo V. *Cooperativismo*. São Paulo: Cupolo, 1976

Rathmann, R., Benedetti, O., Plá, J.A. e Padula, A.D. Biodiesel: Uma alternativa estratégica na matriz energética brasileira? *II Seminário de Gestão de Negócios*, Curitiba, 2005.

Singer, Paul. *Introdução à economia solidária*. São Paulo: Editora Perseu Abramo, 2002.

Tyson, K.S. and McCormick, R.L. 2006 *Biodiesel Handling and Use Guidelines*. Washington, D.C.: US Department of Energy, 2nd Edition, 2006.

# 27. Dry and wet mechano chemical synthesis of $CuInGaSe_2$ nanoparticles

B.Vidhya[1], S.Velumani[1*] and J.A.Chávez-Carvayar[2]

[1]Ingeniería Eléctrica (SEES), CINVESAV, México D.F.

[2]Instituto de Investigaciones en Materiales, UNAM, México D.F.

velu@cinvestav.mx

Abstract

$CuInGaSe_2$ belongs to the family of I-III-$VI_2$ semiconducting materials with tetragonal chalcopyrite structure which is a very prominent absorber layer for photovoltaic devices. Nanoparticle based coating process for CIGS is considered to be promising technique with relatively simple procedures and low initial investment. Based on these aspects mechano chemical synthesis of CIGS nanoparticles is investigated in this work. High purity elemental copper granules (>99.9% pure), selenium and indium powders (>99.9% pure) and fine chips of gallium were used as the starting material. The ball milling was carried out using a SPEX-8000 mixer/mill at 1200 rpm. Four different types of milling were performed, ie milling of dry elemental sources alone, milling with few ml of ethyl alcohol, with tetra ethylene glycol (wet) and with few drops of ethylene diamine (semi-dry). All the wet products were dried before analysis. X-ray diffraction analysis of all the milled powders show the presence of (112), (220)/ (204), (312) / (116), (400) and (332) peaks corresponding to the chalcopyrite CIGS structure with a preferred orientation along the (112) peak. The samples ball milled with tetra ethylene glycol and ethylene diamine shows the presence of peaks corresponding to Se and InSe respectively. The average grain size calculated gives a maximum and minimum value of 8.93nm and 7.55nm for different samples. Scanning electron micrograph reveals the presence of some flake like structures and granules of different shapes in the sample ball milled with ethyl alcohol and ethylene diamine. Composition analysis reveals the increase in at% of Copper from 22.86 to 29.07 with twice the increase in milling time just for elemental sources (dry), whereas this increase is lower 25.27,26.05 and 23.95 at% with the addition of ethyl alcohol, tetra ethylene glycol and ethylene diamine respectively. Transmission Electron Micrograph also confirms the presence of nanoparticles. Optical

studies were carried out with the powder made as a paste with appropriate solvent and coated on glass substrate and the results were compared with the reported and standard values.

*Key words*: CIGS, Mechanochemical synthesis

## Introduction

Copper Indium Gallium diselenide(CIGS) is one of the few thin film materials presently being evaluated as the absorber layer in polycrystalline solar cell devices. CIGS is an alloy of two ternary semiconductors, $CuInSe_2$ and $CuGaSe_2$ with bandgap of 1.0 and 1.7 eV(at 300K), respectively. The direct energy gap of CIGS results in a large optical absorption coefficient, which in turn permits the use of thin layers(1-2$\mu$m) of active material[1-2]. CIGS solar cells are also known for their long-term stability. Several research groups have prepared device quality CIGS by using different thin film deposition processes. The techniques used for growing CIGS thin films by simultaneous co-deposition of Cu, In, Ga and Se include –physical vapour deposition (PVD) [3], Chemical deposition [4-5] and electrodeposition [5]. The deposition of precursor films of In-Ga-Se in the first step, Cu-Se in the second step and again the deposition of In-Ga-Se in the final stage also involves physical vapour deposition and sputtering [6]. PVD technique is difficult to scale up because of film non-uniformity and low material utilization. Sputtering techniques are suitable for large area deposition. However, they require expensive vacuum equipment and sputtering targets. Therefore a non-vacuum technique with a capability to prepare large area uniform precursor films using low cost capital investment is very attractive for the growth of CIGS layers for photovoltaic applications.

Among the low cost processing techniques, nanoparticle based coating process is considered to be promising as an alternative non-vacuum technique with relatively simple procedures and low initial investment [7]. The nanoparticle based processes generally involves a two step fabrication method, in which the synthesis of nanoparticles is followed by a non-vacuum coating method and then the precursor films are subjected to sintering to form an appropriate absorber layer for a solar cell [7-8]. In this process, the major benefit comes from the nanosize effect of the particles which lowers the melting temperature of the material [9] due to high surface energy and hence result in an exothermal reaction during sintering. In the recent years Solvothermal technique, Low temperature colloidal synthesis and mechano-chemical synthesis are the most common methods used for the synthesis of CIGS nanoparticles [10-12]. Among them the solvothermal technique is time consuming. For example a reaction temperature of 280$^{o}$C for 36hrs and then cooling to room temperature has been reported by Y.G.Chun et al [10]. Low temperature colloidal synthesis uses $Na_2Se$ as one of the starting materials, which is highly toxic [11]. Thus mechanochemical synthesis is considered as a suitable method which employs the elemental sources and uses comparatively less time [12]. The present work has its uniqueness in which we have reported the dry, semi dry and wet ball milling of CIGS.

Experimental

Starting materials of high purity elemental copper granules (>99.9% pure), selenium and indium powders (>99.9% pure) and fine chips of gallium were weighed to give a molar ratio of 1:0, 5:0, 5:2. This blended elemental mixture and Stainless balls were loaded in a stainless container inside an argon-filled glove box. In order to prevent oxidation of the powders, the weighing procedure was made in Argon gas atmosphere using a glove box. The ball-to-powder weight ratio was maintained at 10:1. The ball milling was carried out using a SPEX-8000 mixer/mill at 1200 rpm. Milling of the elemental sources only(dry), milling with few ml of ethyl alcohol and tetra ethylene glycol(wet) and with few drops of ethylene diamine(semi-dry) have been carried out. The details of milling process and parameters are listed in table1. All the wet products were subjected to drying before analysis.

Table 1.Constituents and milling parameters

| Sample | Constituents | Milling time (hrs) | Total grams( milled) | Grain size D(nm) |
|---|---|---|---|---|
| A | Elemental and metal powders<br>(Cu,In,Ga and Se)powder1 | 1.5 | 12 | 8.93 |
| B | Powder 1 (dry) | 1.5 | 2 | 8.14 |
| C | Powder1+5ml ethanol (wet) | 1.5 | 2 | 7.91 |
| D | Powder1+5ml tetra ethylene glycol (wet) | 1.5 | 2 | 7.92 |
| E | Powder1+5 drops of ethylene diamine (semi-dry) | 1.5 | 2 | 7.55 |

Results and discussions

The X-ray diffraction pattern of the prepared powders is shown in figure1. Broadening of the peaks is presumably due to the small size of the particles. Three main peaks appear corresponding to the (112), (220)/(204) and (312)/(116) planes of the chalcopyrite structure[12-13]. Apart from this, we can also observe that Ethyl alcohol doesn't affect the already formed CIGS structure, whereas Tetra ethylene glycol creates a lattice distortion and separates the Se, which is evident from the peaks corresponding to Se as shown in figure1.D. Ball milling with ethylene diamine leads to the formation of the binary phase InSe. The lattice parameters 'a' and 'c' have been calculated using the equation (1) given below. The average grain size was calculated using the relation (2).

$1/d^2 = 4/3[(h^2+hk+k^2)/a^2] + [1/c^2]$ ------------ (1)

$D = (0.94\lambda)/(\beta\cos\theta)$ ----------- (2)

Where β is the FWHM.

There is slight variation in the grain size, as shown in table 1.This shows that the addition of various solutions also influences the milling process and thus the grain size.

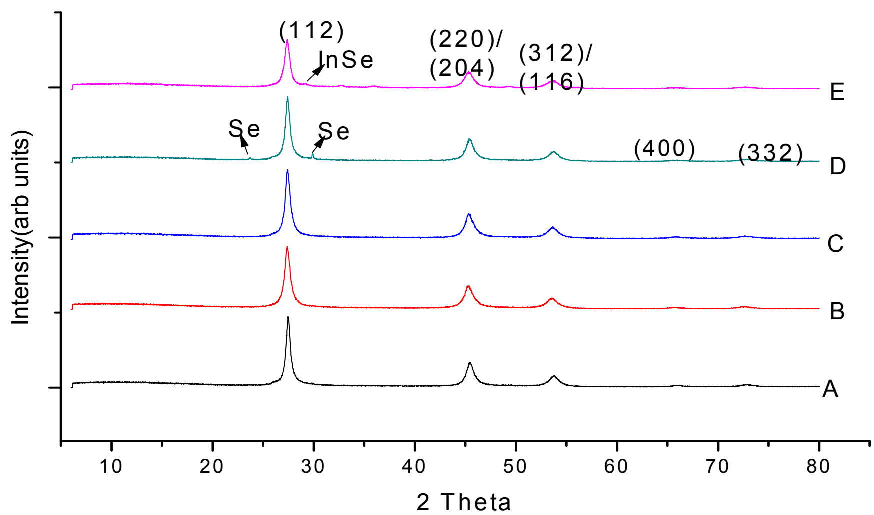
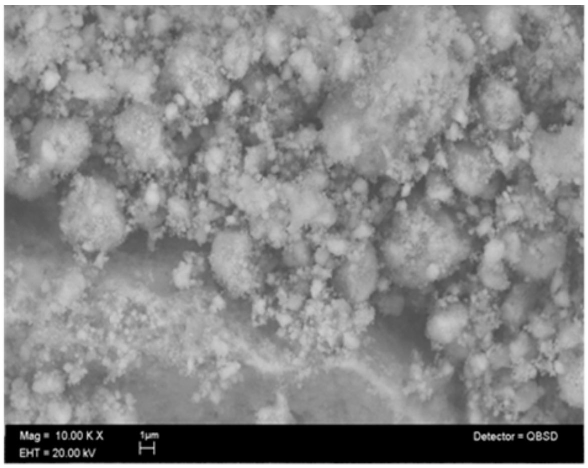
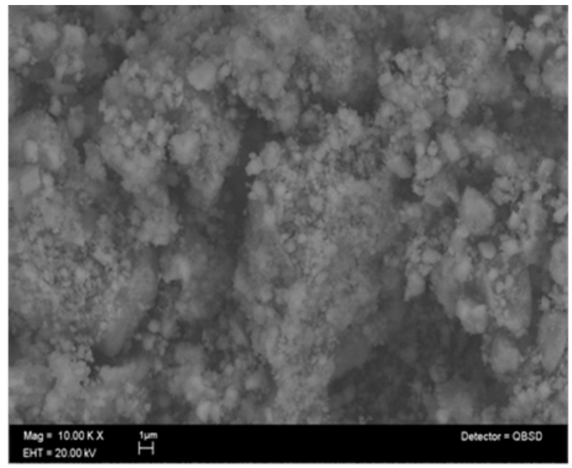


Figure 1.XRD patterns of CIGS nanopowders

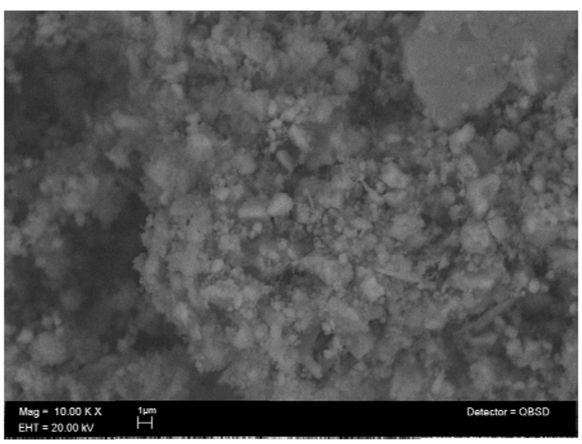
Figure 2 shows the SEM micrographs of the CIGS nanoparticles. It can be seen that there is a mixture of nano particles and some micro structures of different shapes. The sizes of these microstructures are not uniform. For example in sample (A) alone spherical structures ranging from several hundred nanometres to few micrometers can be observed. Also figure 2. (C and E), reveals the presence of some flake like structures and granules of different shapes in the samples ball milled with ethyl alcohol and ethylene diamine respectively. There is an obvious deviation from the XRD results on the crystal sizes of the products. But a careful observation of the SEM image indicates that those spheres and other microstructures are self-assembled from smaller nanoparticles. Similar observation has been made by A.Ahn et al [13] for CIGS nanoparticles prepared by low temperature colloidal process, but they have obtained a non-perfect crystalline structure which is obvious from their XRD results and the broad and diffuse rings observed in the Selected Area Diffraction Pattern of the sample.



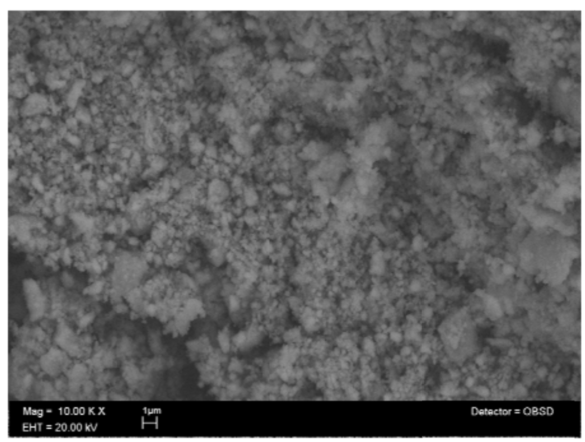

A) 1.5 hrs milled



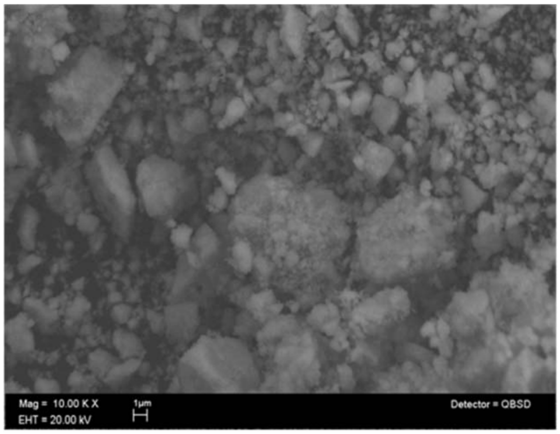

B) 3 hrs milled




**C) 1.5 hrs dry followed by addition Of 5ml ethyl alcohol and milled for 1.5 hrs more**




**D) 1.5 hrs dry followed by addition Of 5ml tetra ethylene glycol and milled for 1.5 hrs more**




E) 1.5 hrs dry followed by addition
Of 5 drops of ethylenediamine and milled
for 1.5 hrs more

Figure 2.SEM image of CIGS nano powders

Composition analysis of the CIGS nano powders is shown in table 2.The atomic percentage of all the four elemental constituents Cu, In, Ga and Se vary in each sample. Thus it can be confirmed that the milling time as well as the chemicals added has a strong influence on the composition of the quaternary compound CIGS. TEM was employed to further examine the crystal sizes of the product, as shown in figure 3. The TEM micrograph shows an agglomerate of nanoparticles in which dark particles are surrounded by non-dense materials. At the same time, from the SAED pattern it can be observed that there is a good crystalline order, which is in agreement with the XRD results.

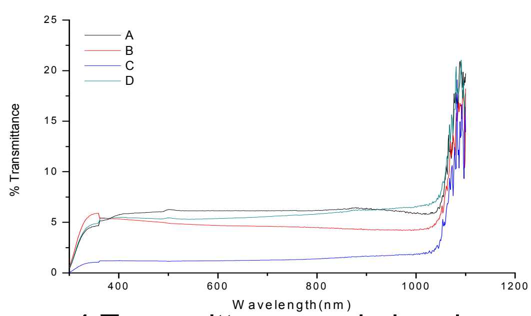
Table 2.EDX Analysis

| Sample no | At% of Cu | At% of In | At% of Ga | At% of Se | Cu/(In+Ga) |
|---|---|---|---|---|---|
| A | 22.86 | 13.65 | 14.00 | 49.50 | 0.8267 |
| B | 29.07 | 12.50 | 11.65 | 46.78 | 1.2265 |
| C | 25.27 | 13.81 | 11.02 | 49.90 | 1.0177 |
| D | 26.05 | 13.27 | 10.49 | 50.20 | 1.0963 |
| E | 23.95 | 14.45 | 12.17 | 49.43 | 0.8996 |

Figure 3.TEM image of CIGS nano powders

## Optical Studies

Optical studies were carried out with the powder made as a paste with appropriate solvent and coated on glass substrate. The transmittance and absorbance spectra were determined, with the powder made as a paste with an organic solvent as reported elsewhere [7] and coated on glass substrate. The samples were sintered at 400 degrees, to ensure the removal of the solvent from the surface. It can be observed that it shows a very low transmittance over the visible range of wavelength from 400-800nm. Also all the samples almost shows the same behaviour. For Sample C, the coating was thicker compared to the other samples, and it shows an obvious drop in the %Transmittance, which is in agreement with the increase in absorbance of this sample. With the proper control of thickness and sintering temperature, thin films with suitable properties for photovoltaic cells can be deposited, by a simple and low cost technique.



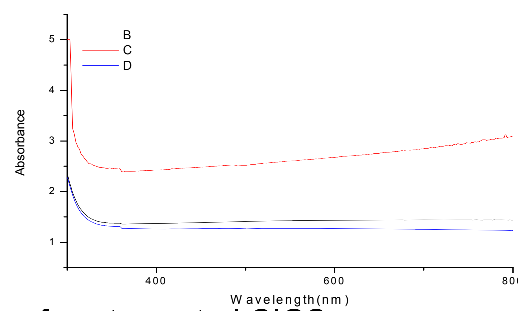



Figure 4.Transmittance and absorbance spectra of paste coated CIGS

## Conclusions

CIGS nano particles have been prepared by mechanochemical synthesis. Here we have made the ball milling of dry elemental constituents and then studied the effect of ball milling this powder with ethyl alcohol, tetra ethylene glycol and ethylenediamine .To the best of our knowledge ,there are no results reported on the semidry and wet mechanochemical synthesis of CIGS nano particles. The XRD result shows the chalcopyrite structure of CIGS. We could observe the Se and InSe phases apart from the CIGS peaks in the samples ball milled with terta ethylene glycol and ethylenediamine. Nanostrucuture of the particles is revealed by the broad XRD peaks. Even though SEM results show bigger particle size, it is formed by a large number of ordered nanoparticles, but TEM results reveals the nano structures. Optical studies show that the transmittance of paste coated CIGS on glass substrates is very low of the order of 6% or even less for thicker films over the visible range of the spectra. It is also observed that the absorbance is higher for the thicker film. Thus CIGS nanoparticles can be prepared by a simple ball milling process and cost effective paste coating technique can be used to deposit CIGS thin films suitable for Solar cell applications.

References

[1] Chanwit Chityuttakan ,Panita Chivetkitvanich,Kajornyod Yoodee and Samphong Chatraphron , “In situ monitoring of the growth of Cu(In,Ga)Se2 thin films”, Solar Energy Materials and Solar Cells 90(2006)3124-3129.

[2]S.Ishizuka,K.Sakurai,A.Yamada,K.Matsubara,P.Fons,K.Iwata,S.Nakamura,Y.Kimura, T.Baba,H.Nakamura,T.Baba,H.Nakanishi,T.Kojima and S.Niki , “Fabrication of wide-gap Cu(In1-xGax)Se2 thin film solar cells:a study on the correlation of cell performance with highly resistive i-ZnO layer thickness” , Solar Energy Materials and Solar Cells 87(2005)541-548.

[3]Doron Azulay,Oded Millo,Isaac Balberg,Hans-Werner Schock,Iris Visloy-Fisher and David Cahen, “ Current routes in polycrystalline CuInSe2 And Cu(In,Ga)Se2 films” , Solar Energy Materials and Solar Cells 91(2007)85-90.

[4] R.N.Battacharya,W.Batchelor,J.E.Granata,F.Hasoon,H.Wiesner,K.Ramanathan,J.Keane and R.N.Noufi , “CuIn1-xGaxSe2 – based photovoltaic cells from electrodeposited and chemical bath deposited precursors” ,Solar Energy Materials and Solar Cells 55(1998)83-94.

[5] K.Bouabid,A.Ihlal,A.Manar,A.Outzourhit and E.L.Ameziane , “CuIn1-xGaxSe2 thin films prepared by one step electrodeposition” ,J.Phys.IV France 123(2005)53-57.

[6] A.M.Hermann,C.Gonzalez,P.A.Ramakrishanan,D.Balzar,C.H.Marshall,J.N.Hilfiker and T.Tiwald , “Growth and Characterization of large area Cu(In,Ga)Se2 films” ,Thin Solid Films 387(2001)54-56.

[7] M.Kaelin,D.Rudmann and A.N.Tiwari , “Low cost processing of CIGS thin film solar cells”, Solar Energy 77 (2004)749-756.

[8] SeJin Ahn, KiHyunKim and KyungHoon Yoon , “Cu(In,Ga)Se2 thin film solar cells from nanoparticle precursors “ ,Current Applied Physics 8(2008)766-769.

[9]SeJin Ahn,Chae Woong Kim,JaeHo Yun,JeongChul Lee and KyungHoon Yoon, “Effect of heat treatments on the properties of Cu(In,Ga)Se2 nanoparticles “ ,Solar Energy Materials and Solar Cells,14 June(2007).

[10]Y.G.Chun,K.-H.Kim and K.-H.Yoon , “Synthesis of CuInGaSe2 nanoparticles by solvothermal route” ,Thin Solid Films 480-481(2005)46-49.

[11] SeJin Ahn, KiHyunKim and KyungHoon Yoon , “ Nanoparticle derived Cu(In,Ga)Se2 absorber layer for thin film solar cells” , Colloids and Surfaces A: Physicochem.Eng.Aapects 21 April(2007).

[12]C.Suryanarayana,S.H.Yoo and J.R.Groza , “Consolidation of mechanically alloyed Cu-In-Ga-Se powders” ,Journal of Materials Science Letters 20(2001)2179-2181.

[13] SeJin Ahn, KiHyunKim,Young Gab Chun and KyungHoon Yoon, “ Nucleation and growth of Cu(In,Ga)Ae2 nanoparticles in low temperature colloidal process” , Thin Solid Films 515(2007)4036-4040.

# 28. The WOLF at the Door: Creating a Competitive Market for Isolated Electric Systems

**Mark B. Lively**

Utility Economic Engineers

19012 High Point Dr.

Gaithersburg, Maryland, USA

301-428-3618 (phone and fax)

MbeLively@aol.com

Key Words: Electricity; Isolated; Competition

Abstract: Many international organizations are pushing local electric utilities to install competitive markets for purchasing electric energy from private developers, generally with a sophisticated bidding system such as those used by independent system operators in the US. In some cases, the international organizations even advocate the utility divest itself of generation, so that new entrants do not suffer from the disadvantage of the utility insisting on using its own generation first. The cost to the utility, and to society, associated with creating a bidding system is large and can be avoided by basing the competitive market on the physics of the electric system. A competitive market based on the physics of the electric system would also allow smaller entities to participate in the market without having to be sophisticated enough to participate in a conventional bidding system. The concept is called Wide Open Load Following or WOLF.

Electric system operators attempt to keep system frequency at a set point, either 50 or 60 Hertz, depending on the portion of the world. Departures from the set point indicate that the electric system has too much electricity (higher frequency) or not enough electricity (lower frequency.) For a predetermined nominal price, a surplus or shortage indicates to an economist that the nominal price is too high (creating a surplus) or too low (creating a shortage.) The size of the deviation of frequency from the set point can be used to modify the nominal price to create a settlement price for unscheduled flows of electricity. The new settlement price becomes a *de facto* short run marginal cost, against which non-utility participants can compete. For participants competing with the utility's own generation, the unscheduled flow is any delivery to the utility. To make the system even more robust and more nearly competitive, the unscheduled flow can be any flow between the participant and the utility, in either direction. Some participants could then be buying electricity from the utility at the same market price that other participants are facing when they sell electricity to the utility. Consumers with standby generation (as a hotel might have for use during blackouts) could earn money selling power from the standby generation when frequency is very low. Most of the time such standby generation would not be used.

## 1. Background

Historically, the electric industry has generally been characterized as vertically integrated, with the same entity owning the generation, the transmission lines, and the distribution facilities. Except for the first few years of the electric industry, the term vertically integrated has been a slight misnomer. Early in the industry's history, participants realized that economies of scale and scope allowed utilities to operate at a lower cost by combining disparately owned facilities into a larger system. Thus, separate utilities would merge, or find some other way to unite their operations, to provide service to their mutual customers at a lower overall cost. Eventually regulation led the utilities to share these lower costs with their customers, generally under the nomenclature of cost based rates.

The merger of many small utilities led to utility holding companies in the US and mega-utilities in other parts of the world. But in the US, disparately owned utilities also formed interconnections to reduce their separate costs of serving their separate customers. As a result, the electric grid in the US has been referred to as the largest single machine in the world even though that machine is owned by many different entities. Certainly the interconnected systems in other parts of the world are comparable in size and complexity of ownership.

In response to the mergers of many utilities into large behemoths, the US government passed the Public Utility Holding Company Act of 1935 (PUHCA). PUHCA made utilities of any entity that sold electricity to another entity for resale to the public. Thus, the chemical arm of the petrochemical company could sell electricity to the petroleum arm and neither be considered to be a utility. But when either of these arms sold electricity to a normal utility that arm and the rest of the petrochemical company would be considered to be a utility. Thus, if PUHCA were still applicable, regulators could treat Exxon Mobil, Inc. as a regulated utility from top to bottom, since many of its refineries sell electricity to the local utility. But PUHCA is no longer applicable and Exxon Mobil, Inc., is not treated as a utility.

In the US, many industrial firms that needed steam and could generate electricity cheaply chose not to do so in order to avoid being treated as a utility, or they chose to generate only the electricity that was needed for their own plants. For the latter cases, some industrial firms operated on an isolated basis, with no utility connection. Other industrial firms bought supplemental electricity from the local utility but had relays that opened the connection whenever the flow of electricity might be a sale to the utility.

The US government changed this Procrustean approach to electric generation and sales with the passage of the Public Utility Regulatory Policy Act of 1978 (PURPA). PURPA allowed certain industrial sales of electricity to utilities to be exempted from the PUHCA. With PURPA, industrial facilities with large steam loads began installing cogeneration plants to produce both steam and electricity. Some of the electricity was used by the industrial facility and the rest was sold to the local utility, without causing the industrial facility to become a utility subject to traditional regulation of all of its activities, such as when they sell gasoline or paper.

PURPA began the movement in the US toward a further restructuring of the electric industry. Industrial facilities were now cogenerating some of the electricity that was to be sold to the consumers. Eventually, new independent generators also wanted part of the action. These entrepreneurs wanted to build utility style power plants that only sold electricity, contrasting with the PURPA style generation that nominally sold electricity only as a secondary part of their business.

However, both the industrial facilities selling electricity under PURPA and the independent generators feared the monopsony power of the utility. The utilities already had their own generation and either refused to buy power or offered to buy the electricity at very low prices. For the competitive generators the solution was political, having laws to force the utilities to buy all of their power from unaffiliated companies. The unaffiliated generators fall into three categories:

The industrial facilities once favored by PURPA,

The newly built independent generators, and,

The newly independent generators that were spun off by the traditional vertically integrated electric utilities.

To improve further the independence of the sourcing of electricity, megautilities were created called Independent System Operators (ISOs). Some states, such as California, required their utilities to buy all of their electricity requirements through their ISO. Any generation still owned by the utility[102] still had to compete in the ISO auctions. Most people have heard of the disaster experienced by the California ISO in 2000/2001.

## 2. Current Approaches to Paying for Bulk Electricity

Most electric utilities have free-flowing AC ties with other electric utilities. The free-flowing AC ties concept means that neither electric utility on either side of the interconnection can directly control the amount of electricity that is flowing on the tie-line. When one utility has a surplus, some of that surplus is dumped on the grid of the other utility, as Germany is reputed to do in regard to deliveries to Poland when Germany has a surfeit of wind, or as California is reputed to do in regard to deliveries to

[102] The amount of generation stilled owned by the California utilizes was generally minor during this period.

the rest of the Western Interconnection when there is a surplus of generation related to the spring snow melt. The converse is true when one utility suffers from a shortage such as the sudden loss of generation.

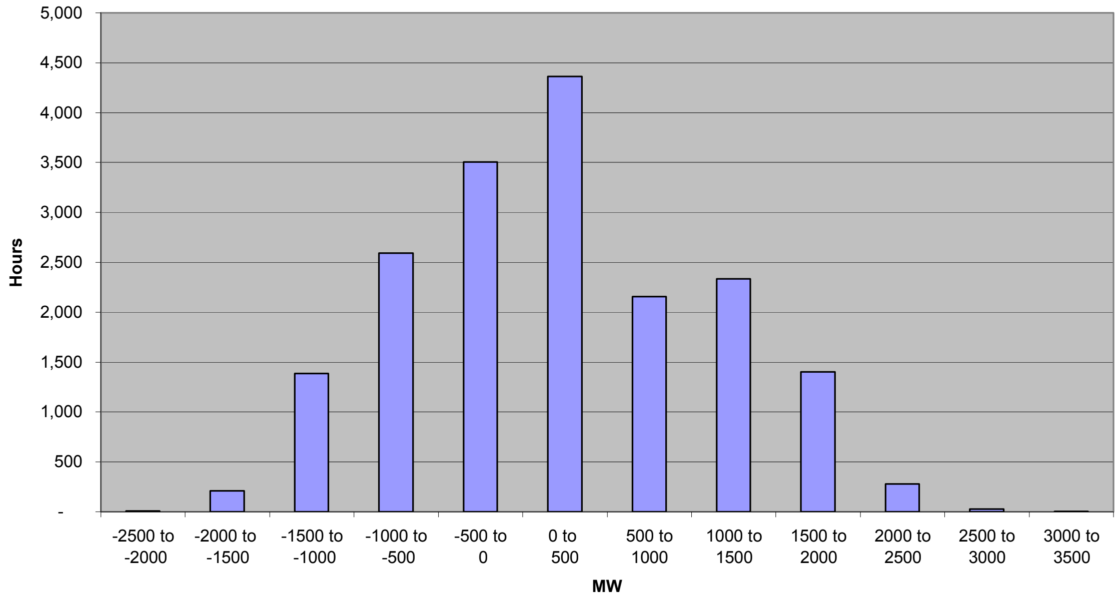
I refer to this free exchange of electricity as a form of tie-riding freeloading.[103] This free interchange of electricity may be the largest source of power available to the utility industry other than from its own generators and constitutes a form of barter. Utilities participating in ISOs do not have this barter mechanism available to them, but the ISOs themselves are often major participants in the barter, as is shown for PJM ISO in Figure 1.

Figure 1 shows the number of hours that PJM experienced variously levels of inadvertent interchange with the rest of the Eastern Interconnection, which consists of most of the US and Canada. Each hour PJM has scheduled transactions with neighboring utilities and ISOs, sometimes buying electricity, sometimes selling electricity, often buying and selling at the same time. At the same time PJM measures the amount of electricity that is being delivered to other utilities or received from them. Inadvertent interchange is the net of all of these amounts, effectively the amount of electricity PJM is giving away during an hour, or receiving if inadvertent interchange is negative. The largest bar is for when PJM is giving away a small amount of electricity, 0-500 MW, at least small for an ISO the size of PJM.

Figure 1

[103] See "Tie Riding Freeloaders."

**Histogram of PJM Hourly Imblances**
**25 Months Ending April 2004**
**Figure 1**




There has been a growing trend for consumers to install their own generation with the intent of using such generation only during periods when power is unavailable from the local utility. I will refer to these generators as backup generators. These backup generators are typically small and very inefficient, with a fuel cost that is often multiples of the cost of fuel to central power plants. The high fuel cost is due both to the premium fuel these small generators require[104] and to the higher heat rates of the generators.[105] Despite the fuel cost differences, the market for installing backup generators is flourishing. The market is flourishing because of the desire for power when the grid might not be able to provide the power. California had about 30 GW of small backup generation installed when the California ISO instituted its rotating blackouts in 2000/2001.[106] California's peak load during this time frame was about 50 GW, less than twice as much as the capacity of the backup generators. Unfortunately, California did not have in place systems to make use of these small backup generators and instituted rolling blackouts.

---

[104] Small generators may require refined petroleum products similar to that used in automobiles.
[105] Small generators may use 30,000 BTUs of premium fuel to produce a KWH of electricity, while central station power plants often operate in the range of 8,000-10,000 BTUs/KWH.
[106] See "Saving California With Distributed Generation."

PURPA introduced the avoided cost concept for paying Qualifying Facilities (QF). The most common application of the avoided cost concept involved the utility determining the fuel costs that it would have incurred each hour in the absence of the energy provided by the QFs. Houston Lighting & Power (HL&P) was one of the largest purchasers of QF energy in the 1980s. There were allegations of HL&P inappropriately manipulating the fuel price used in the calculations of avoided costs. There were reverse allegations that the QFs would inappropriately manipulate the reported split between internal consumption and sales to HL&P to create pseudo cycling problems for HL&P. The HL&P pricing program reacted to the pseudo cycling problems by shutting down highly efficient base load generation and dispatching less efficient peak plants, at least for purposes of determining the inflated avoided costs on which the QFs were to be paid.

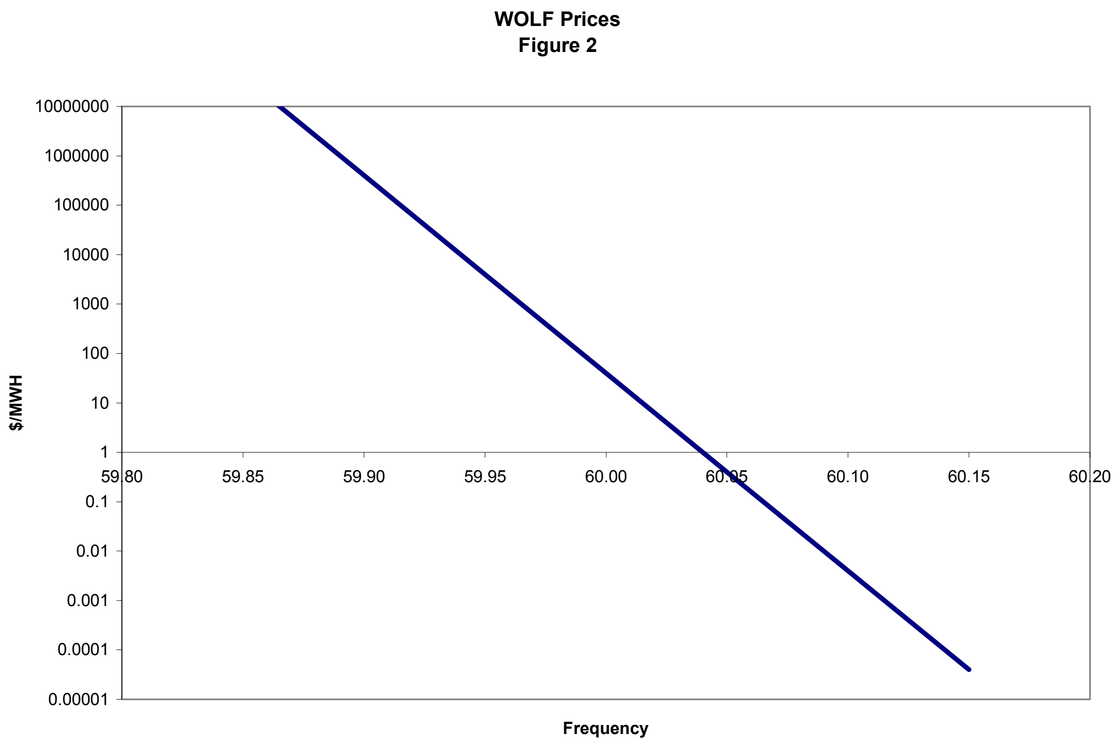
HL&P, the QFs, and the regulators formed the Texas Study Group on Cogeneration, which in 1983 hired the Ernst & Whinney Washington Utility Group (WUG) to determine another approach for avoided costs, an approach that included capacity payments. The WUG developed the Committed Unit Basis (CUB) for evaluating long term contracts for the delivery of electricity. CUB looked at the types and amounts of generation that the utility would have built but for the anticipated presence of QF power. The fixed cost of the alternatively committed generation was converted into an annual payment that was to escalate with anticipated inflation. Operating costs, such as fuel costs, were based on the utility's average cost for the specified alternatively committed generation. CUB was adopted in the rules of the Texas Public Utilities Commission and some of the disputes went away, or at least there was a marked reduction in the squabbles about the monthly dispatch program. The CUB concept is mimicked in many long term contracts for the purchase of the unit power, whether from an independent generator or when one utility sells unit power to another utility.

## 3. WOLF—A Pricing Approach to Mimic the Physics of Electricity

Wide Open Load Following (WOLF) sets the price for electricity on a real time basis using a formula that has concurrent system frequency as an independent variable. The formula in (1) provides a exponential approach to setting the WOLF price.

$$\text{Price} = \text{Nominal Price} * 10^{-\text{Frequency Deviation/Scaling Factor}} \quad (1)$$

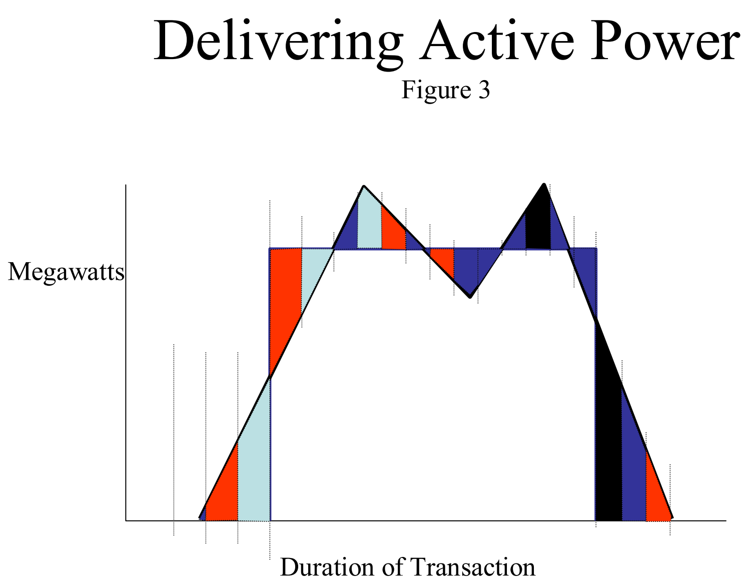
Figure 2




The prices produced by the formula in (1) are illustrated in Figure 2. As frequency goes up across the figure from left to right, the prices decline. Thus the line slants for the top left where prices are high and frequency is low to the bottom right where the price is low and frequency is high. The vertical scaling is logarithmic, while the horizontal scaling is linear. The heavy blue line has a Nominal Price of $40/MWH, which is the price at 60 Hertz. The Scaling Factor for the heavy blue line is 0.025 Hertz. Thus, prices change by a factor of 10 for every 0.025 Hertz change in the frequency. The price at 59.975 Hertz is thus $400/MWH and $4,000/MWH at 59.950 Hertz. When frequency is high, the price is $4/MWH at 60.025 Hertz and $0.40/MWH at 60.050 Hertz.

The prices shown in Figure 2 are for unscheduled flows priced using WOLF. Not all generation on the system will be priced at WOLF, nor should it be. WOLF is only for the generation that is different from the scheduled generation, whether higher than scheduled generation or lower than scheduled generation. The concept is illustrated in Figure 3.

Figure 3



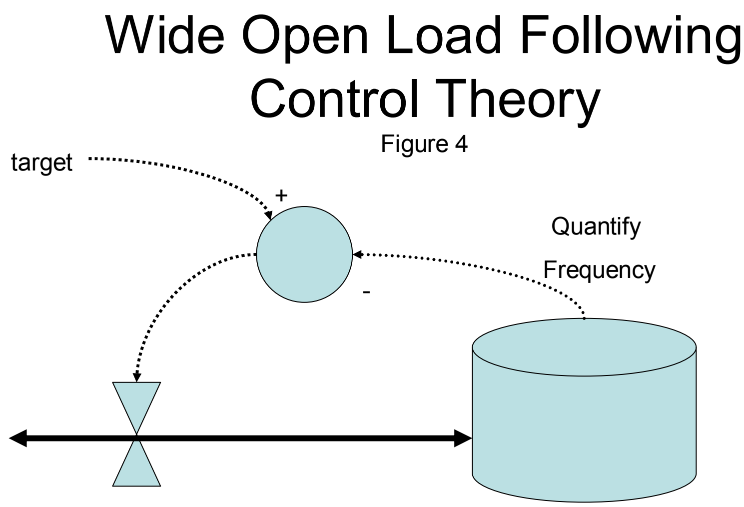

The rectangular shape within Figure 3 represents the scheduled delivery by a generator to the grid. Often generators make commitments for an hour or even for several days to deliver a specific level of power, represented by the horizontal line of the top of the rectangular shape. The sides of the rectangular shape represent the times when the generator is scheduled to begin and end its delivery to the grid. The scheduled delivery thus has the flat top and flat sides of the rectangular shape. The actual delivery is illustrated by the jagged line ramping up from zero, overshooting the targeted power level, undershooting, overshooting, and then ramping back down to zero. WOLF provides prices for the colored areas of Figure 3, with a different price for each area. The price for the scheduled delivery would be set outside of the WOLF mechanism, perhaps under a mechanism similar to CUB or the joint dispatch used by many ISOs.

An important aspect of Figure 3 is that the WOLF price is applicable both to when the generator is producing in excess of its contractual commitment and when the generator is producing less than its contractual commitment. The excess and its WOLF treatment are obvious in Figure 3. The excess occurs both during the initial and final ramps and during the periods when the generator overshot the schedule. The WOLF payment is simply for the amount of energy in excess of the schedule, especially when the schedule was zero during the ramps. When the generator produces less than its contractual commitment, the generator is paid for its contractual commitment. But then the generator is charged the WOLF price for any shortage. Since the WOLF price can be very large, the generator can be producing electricity but still make a net payment since it did not live up to its commitment.

WOLF mimics the engineering concepts used to operate the electric grid. Electric systems consist of many interconnected generators, nominally all[107] spinning at 50 or 60 cycles per second, also known as Hertz. The US standard is 60 Hertz. Energy can be added to the system by increasing the fuel to a generator or water into a turbine. For decades electric utilities have sought to minimize their production costs through least cost dispatch programs. The programs adjust the production levels of available generators so that each generator has the same marginal cost of production, as moderated by (1) marginal electric line losses between the generators and (2) any line constraints between the generating units. Unit commitment programs decide which generators should be turned on and off, since the start-up/shut-down process often takes several hours, or days for some large generators such as large coal and nuclear plants.

Figure 4

[107] Some generators are connected to the system electronically and don't share the same rotational speed. The electronic connection achieves the nominal frequency. Transmission overloads can let generators slip relative to each other, a serious problem.



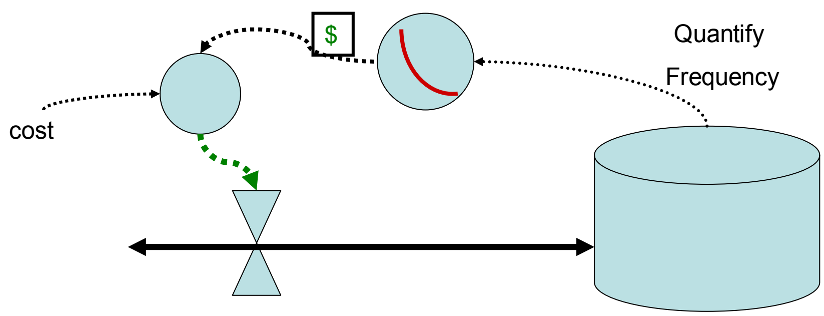

Sometimes there are unanticipated changes in the demand for electricity, unanticipated in that generation levels have not been changed in anticipation of the load change. These unmet load changes result in system frequency deviation from the 60 Hertz standard. Utilities install Automatic Generation Control (AGC) on most generators. AGC responds to frequency deviations by ramping the associated generator, even if that generator does not provide the cheapest steady state response. Once AGC has met the load change, indeed often while the AGC is still meeting the load change, the system operator begins dispatching the generators to achieve the uniform system-wide marginal cost. The AGC concept is illustrated in Figure 4.

Figure 4 uses the flow diagrams associated with water systems to illustrate how engineers manage the electric system. The tank on the right can be thought of as the kinetic energy on the network in the form of rotating generators and motors. The level of the kinetic energy can be indicated by system frequency. The circle at the top left of Figure 4 compares the actual system frequency to the target system frequency. Based on whether the comparison is positive or negative, there is a signal to the control valve to increase or decrease the inputs to the kinetic energy of the system, thus increasing or decreasing generation.

Figure 5

## Wide Open Load Following Control Theory

Figure 5




WOLF mimics the engineering approach to the physical management of the system by using the same concepts in Figure 4, with slight modification to reflect prices instead of just the command and control concepts of engineering. Figure 5 shows that WOLF converts the system frequency signal into a price. That price is evaluated by each generator to determine how profitable operations are at various load levels. If the WOLF price is higher than the marginal cost of operating the generator, the generator will have an economic incentive to increase generation. Conversely, if the WOLF price is less than the marginal cost of operating the generator, the generator will have an economic incentive to reduce generation.

Figure 6

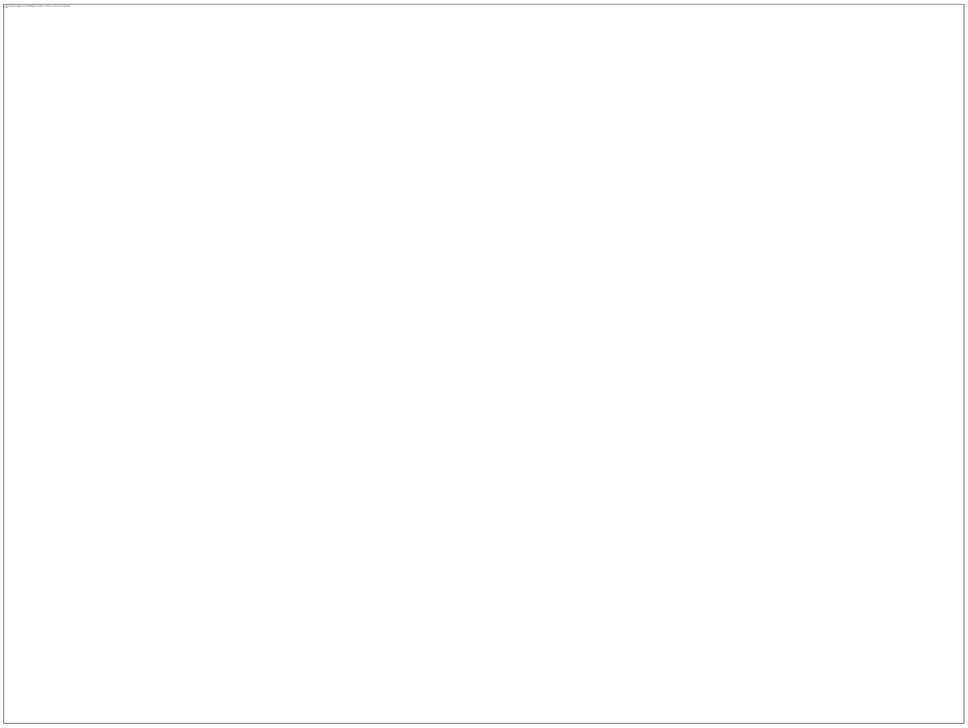


Figure 6 shows how WOLF combines physics and economics to produce an appropriate price for unscheduled flows of electricity. The basic part of Figure 6 provides conventional supply and demand curves, and the equilibrium price associated with their intersection. Every few seconds, electric systems measure system frequency and their inadvertent flows with other systems. From these data points, the electric systems calculate Area Control Error (ACE), the surplus of targeted generation over actual load. In Figure 6, ACE is shown as being negative, that is, the demand for electricity is greater than the utility is generating at that time. The height of the ACE line plotted in Figure 6 reflects the Nominal Price in the WOLF price formula shown in Equation (1). Since ACE is negative, the Nominal Price is obviously less than the Equilibrium Price. The engineers have designed AGC to increase generation under these circumstances. WOLF produces a settlement price that is higher than the nominal price, providing an incentive for generators to increase their generation above the level associated with the Nominal Price.

4. Modifying the Basic WOLF Formula

The formula presented as equation (1) has two undefined constants, the Nominal Price and the Frequency Deviation/Scaling Factor. The Nominal Price determines the height of the line in Figure 2 while the Frequency Deviation/Scaling Factor determines the tilt of the line in Figure 2. Some utility systems already have in place methods to estimate an hourly settlement price. These hourly settlement prices can be used as the Nominal Price in Equation (1). Alternatively, the Nominal Price can be reset periodically based on the time error that has occurred on the system. Similarly, the Frequency Deviation/Scaling Factor would be set based on the engineering and political decisions on the variation that should be allowed for system frequency.

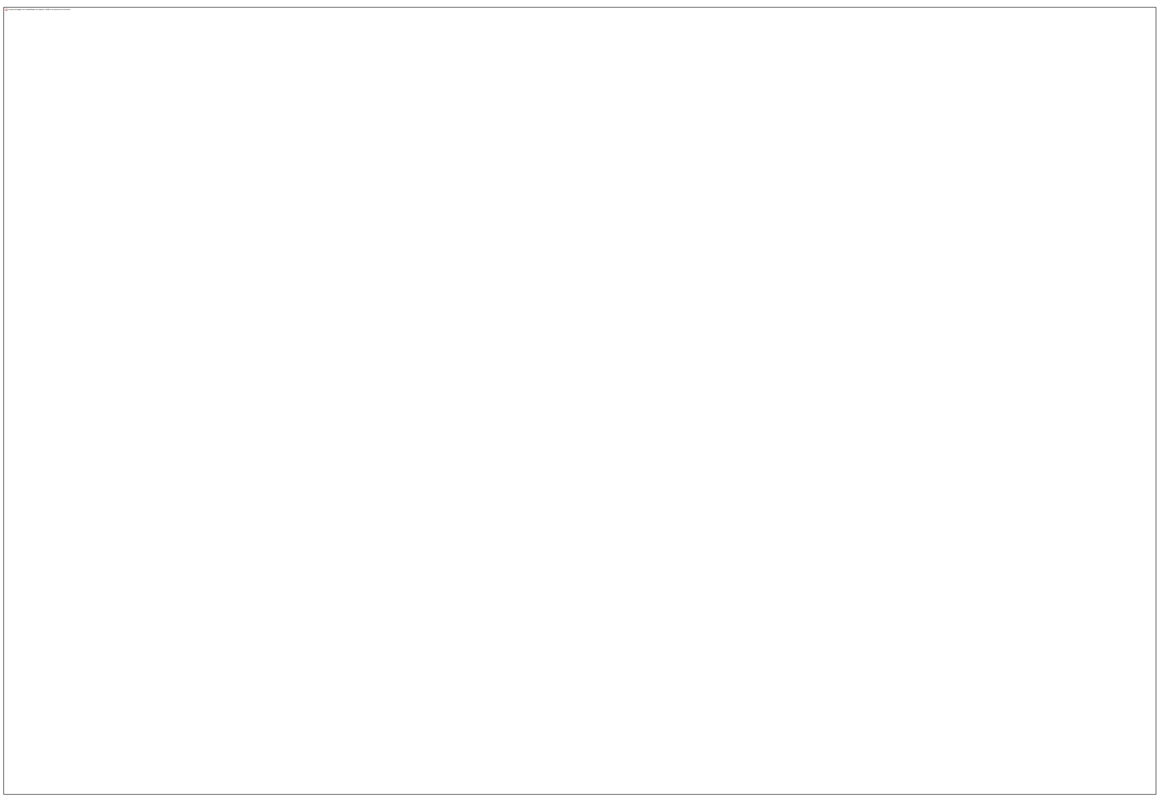
An example for resetting the Nominal Price is appropriate. The graph in Figure 2 has been explained as having a Nominal Price of $40/MWH. Under the hypothetical situation that the best Nominal Price is actually $100/MWH, participants in the WOLF pricing plan will generate less power than they would with a Nominal Price of $40/MWH. The power shortage will result in the system frequency being less than the nominal frequency, tending to create a bias. That bias will be 0.010 Hertz and the frequency will be 59.990 Hertz on average. The lower frequency will cause a time error to occur. The presence of the time error should then be used to modify the Nominal Price, increasing it.

Figure 7

The result of changing the Nominal Price to $100/MWH as the result of the above analysis is illustrated in Figure 7. The heavy dark blue line is a replication of the line from Figure 2, which has a Nominal Price of $40/MWH. The thinner, light blue line is based on a newly assumed price of $100/MWH. The two lines are parallel, with the same slope.

A different Nominal Price may be appropriate for different periods of the day. The method identified above for changing the Nominal Price on an absolute basis could also be used to develop different Nominal Prices for different periods of the day, week, or year. Once these time-specific Nominal Prices have been put into place, the method identified above can be used to slowly modify the Nominal Prices, as would be appropriate when there is a significant change in the cost of fuel, generating mix, or load levels. Thus, for day light hours, which typically have higher costs, the Nominal Price might be the $100/MWH while the Nominal Price for the night time hours, which typically have lower costs, might be the $40/MWH.

The slopes of the curves in Figures 2 and 7 were based on a Frequency Deviation/Scaling Factor of 0.025 Hertz. One way to evaluate the reasonableness of any proposed Frequency Deviation/Scaling Factor is to price a uniform power level over all time periods based on the historic distribution of frequencies. The difference between the average price using the formula in Equation (1) and the Nominal Price could be considered to be the value of reliability.

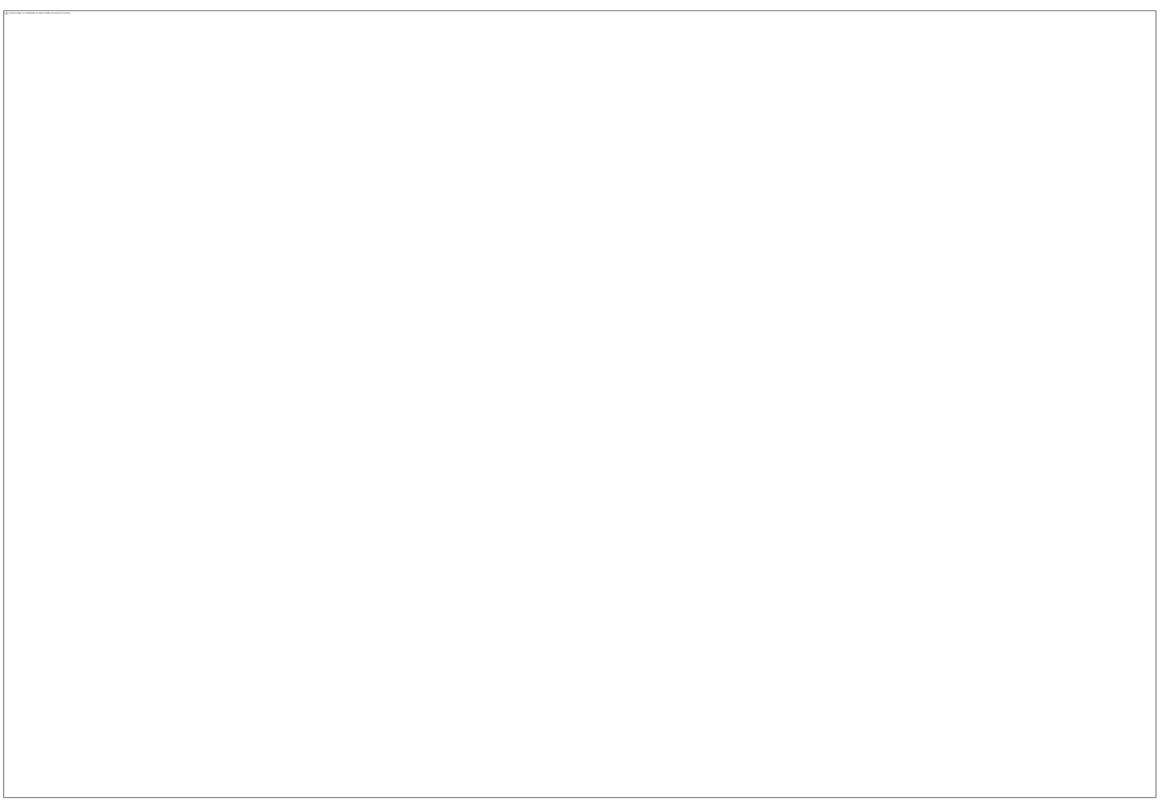


The simple analysis of pricing historic frequency deviation may not give an accurate estimate of how the system will behave after WOLF pricing is introduced. India introduced a similar pricing plan in 2002/2003, as shown in Figure 8.[108] Prices change linearly with the change in system frequency between a frequency range of 49.0 Hertz and 50.5 Hertz. Above 50.5 Hertz the price is zero. Below 49.0 Hertz the price is capped. The price has been changed at least three times since India started pricing Unscheduled Interchange by region in 2002 and 2003. In 2007, India introduced a kink

[108] See "WOLF at the Door: Valuing Intermittent Wind Power For Electricity Dispatchers?"

in the curve to have the price increase more rapidly with lower frequencies. I have placed a WOLF curve in Figure 7 to demonstrate how an exponential price would compare to the linear prices that India now uses. An advantage of WOLF is the simplicity with which the price can be modified when conditions change. An increase in the price of fuel or the scarcity of water will result in lower frequency and a desire to increase the Nominal Price.

The effect of India's introduction of UI pricing is illustrated graphically in Figure 8. This is a plot of the system frequency on a minute by minute basis during three months. Essentially, each point on the graph represents the number of minutes when system frequency was at the stated level. The horizontal granularity of the graph is 0.05 Hertz. The Southern Region instituted UI pricing as of the first of 2003. The blue graph depicts system frequency a year before UI pricing was instituted. The average frequency for the month was 48.69 Hertz. The most common frequency was 48.00 Hertz on a system that has a nominal frequency of 50.00 Hertz. The red graph is the first month for which UI was in effect. The green line is for August 2004, one and a half years later.



The ISOs in the US operate competitive markets. These competitive markets sometimes have resulted in bids and prices that are negative. The negative bids reflect the must run no matter what desire of generators. One incentive for such a must run practice is the tie between on-peak and off-peak. Some generators can not vary their generation rapidly. If they want to provide power on-peak for a high price, the generators need to operate during the off-peak period in order to be available on peak. The negative bid price is their solution.

Tax credits can also distort the bidding process. ERCOT sometimes has negative prices for almost all of the time periods of a day in West Texas, where wind generators are trying to obtain access to the crowded transmission grid to move their electricity to the more industrialized areas near Dallas and Houston.[109] A tax credit of $20/MWH would incent a wind generator (with zero variable cost) to bid as low as -$20/MWH, at which point the wind generator breaks even between the tax credit and the payment for the right to dump power.

India's UI tariff mostly handles the issue by forcing the price to zero above 50.5 Hertz. The WOLF pricing formula in Equation (1) goes toward zero but never reaches zero because of the exponential formulation of Equation (1). Negative prices could be handled by Equation (2).

When Frequency Variation is >0.5 Hertz; (2)

Price = Nominal Price * Scaling Factor * (0.5 Hertz-Frequency Variation)/0.5 Hertz

This would extend the ramp shown for UI pricing below zero, with the rate at which it descends dependant on the Scaling Factor.

The dispatch of generation is geographically differentiated using line losses and transmission constraints. WOLF prices need to be geographically differentiated when line losses are significant or there are transmission constraints.

---

[109] See "The Evolution of a Competitive Electricity Market in Texas", page 8.

AC power systems can measure two amounts, active power and reactive power.[110] AC power systems deliver energy in cycles, approximately 60 times per second in the US. Some of the energy is used to create electromagnetic fields, such as changing a piece of iron into a magnet. Some energy is used to do work, such as turning the magnet as part of a motor. Sixty times a second, the magnet is turned on, turned off, turned on with the opposite polarity, and then turned off. That means that the energy used to create the electromagnetic field flows into the device, out, in, and out, sixty times a second. This energy that flows into the device and back to the source during a cycle is reactive power. The energy that stays in the device to do the work of turning the magnet is active power, the topic of this paper. Total power is the sum of active and reactive power. Reactive power needs to be priced on a real time basis through a modification of the WOLF pricing mechanism.

5. Uses and Conclusions

WOLF can be used to create a competitive market for electricity where there are not enough separately owned generators to ensure a competitive market. During the California debacle of 2000/2001, the generators were able to set the market artificially, setting their bids at levels that some people considered to be unrealistic. WOLF forces a balancing of supply and demand. Only when that balance is precarious does the settlement price move much higher.

WOLF can also provide a way to reward customers who are willing to interrupt loads in response to problems on the system. The most common approach to achieve such interruptions involves an under frequency relay (UFR). UFRs sense low frequency and send signals to open switches. The most productive UFRs interrupt aluminum smelters for a few seconds or minutes at a time.[111] Though the interruptions might be short, the extremely high WOLF price associated with the types of frequencies associated with the operation of UFRs can make the payments in excess of a dollar per KW, with relatively small impact on the smelter.

---

[110] See "Thirty-One Flavors or Two Flavors Packaged Thirty-One Ways: Unbundling Electricity Service"
[111] See "February 26, 2008 EECP Step 2 Report", pages 4 and 7.

India's UI pricing substantially led to a balancing of their system, even though the UI pricing curves have not been as extreme as the WOLF pricing curves discussed in this paper. WOLF has a simplicity advantage over India's UI pricing mechanism, in that the WOLF price can be changed automatically as events overtake the system.

## 6. References


Lively, M.B., "Tie Riding Freeloaders--The True Impediment to Transmission Access," *Public Utilities Fortnightly,* 1989 December 21.

Lively, M.B., "Saving California With Distributed Generation: A Crash Program To Use Small, Standby Diesel Generators To Keep The Lights On," *Public Utilities Fortnightly*, 2001 June 15.

Lively, M.B., "Thirty-One Flavors or Two Flavors Packaged Thirty-One Ways: Unbundling Electricity Service" *The National Regulatory Research Institute Quarterly Bulletin*, Summer 1996. This article originally appeared as comments titled "31 Flavors or Two Flavors Packaged 31 Ways," *Promoting Wholesale Competition Through Open Access Non-discriminatory Transmission Services by Public Utilities*, FERC Docket RM95-8-000, 1995 November 2.

Zarnikau, J., "The Evolution of a Competitive Electricity Market in Texas," *28th USAEE/IAEE North American Conference*, New Orleans, Louisiana, 2008 December 4-6.

Lively, M.B., "WOLF at the Door: Valuing Intermittent Wind Power For Electricity Dispatchers?" *28th USAEE/IAEE North American Conference*, New Orleans, Louisiana, 2008 December 4-6.

ERCOT February 26, 2008 EECP Step 2 Report, March 18, 2008

# 29. A low-carbon electricity mix as an alternative scenario to a future electricity supply dominated by industrial hydropower plants in Latin America.

**Oehninger, E.B. – Thomassin, G.**

Leading author address: IFP School - 1 & 4, avenue de Bois-Préau 92852 Rueil-Malmaison Cedex – France - Tel : +33 6 07 63 89 16

ernst.oehninger@agroparistech.fr

Key words: electricity mix, hydropower, low carbon.

Abstract: According to a report by the Economic Commission for Latin America and the Caribbean (ECLAC), the region will continue to expand next year and, for the first time in 40 years, will complete a seven-year cycle of over 3% average annual growth in per capita GDP (taking into account higher inflation, declining current account surpluses and deteriorating terms of trade). In the field of energy consumption it is important to link economic growth and energy demand. The energy intensity, a well known economic indicator, helps us to understand this relationship. In this scenario of economic growth, two options are possible; the improvement of energy demand management or the growth of energy supply. We focus on the second option and try to see how to tackle such a thorny issue.

There are a lot of ways to classify electricity production. One of them is according to their carbon emission rate, which is the most relevant in a context of global warming awareness. Industrial hydroelectric plants dominate the electricity supply in Latin America. For example in Brazil 84% of the total electricity supply is furnished by large hydropower (IEA 2007). Despite the fact that large hydropower is a low-carbon energy source, its implementation is controversial due to its environmental impact, the risk of shortage during drought seasons and complex political issues.

The interest of this work is not to weigh the pros and cons of hydroelectricity but to integrate it in a low carbon electricity mix based on few examples from the European model. For this purpose we analyze the state of the art and the potential of developing low-carbon energy sources, such as solar, nuclear, wind, biomass and small hydro power plants. This work also focuses on the concept of decentralized energy generation such as solar water heaters,

photovoltaic modules, ground couple heat exchanger and wood-fired heating equipment. Taking into account the geographic specificities, the solutions proposed are not the same for each region. Yet the regional cooperation in Latin America, referring to what is being done in Europe, can trigger the achievement of such a model.

## 1.Introduction

From Mexico to Central America right down to Patagonia, Latin America is an enormously wealthy region in terms of natural resources that can be used to generate energy. Blessed by the sun, abundant water resources, zones with strong winds and high biomass potential, Latin-Americans are in an enviable position compared to other continents, yet they have not exploited these resources on any grand scale.

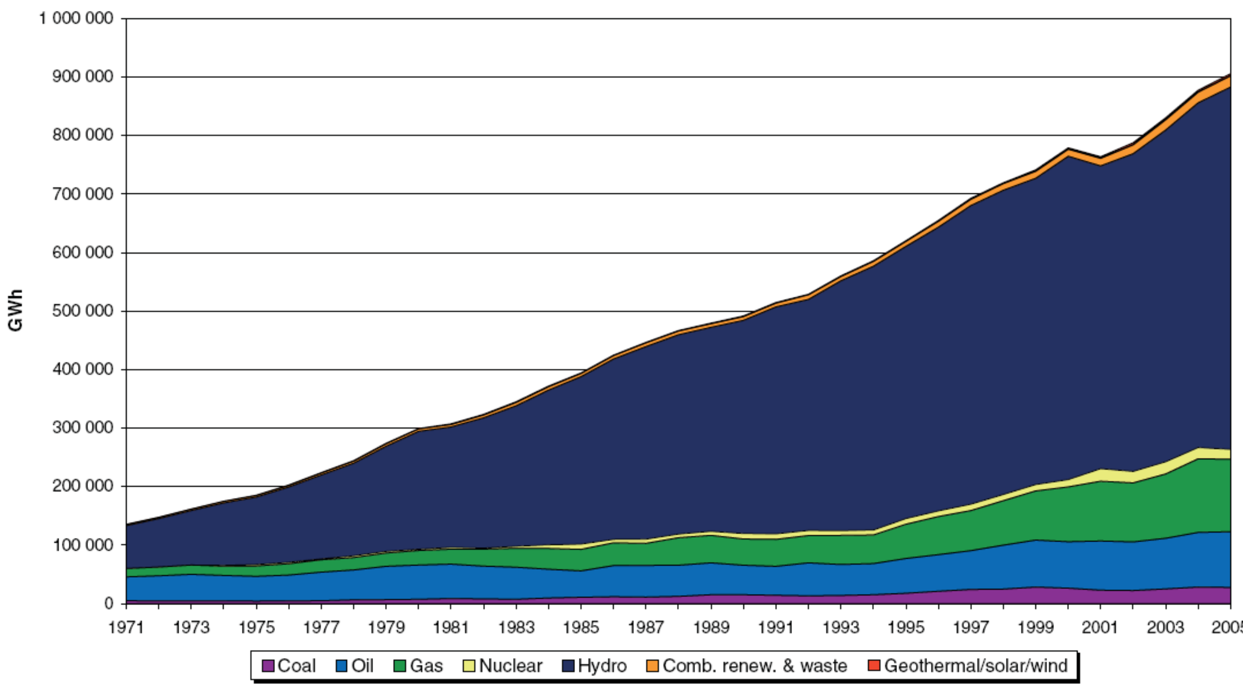
While major steps have been taken toward the development of renewable sources of energy, alternative technologies are still in the early stages and installed capacity is low. However, if we take into account the large hydroelectric plants that generate more than half the electricity consumed by the region, Latin America is a leader in renewable energy. These types of plants have been embraced by the region as a direct consequence of their great potential and low production costs compared to other energy sources.

Evidently the region has great potential, but its energy needs are equally great and continue to increase on a par with sustained economic growth in excess of 5% in recent years, rising to 10% in the case of certain countries, many of which have not made the necessary investments to meet future demand. As demand increases, supplies dwindle and the threat of a full-blown energy crisis looms, Latin America now finds itself scrambling to find solutions that will enable it to sustain its economic growth, including the sporadic rationing of reserves.

Faced with severe energy shortfalls, several countries have placed their hopes in the integration of regional supply networks to meet demand in the short-term. Contrary to expectations, electricity has flowed reluctantly across borders and prized supplies of natural gas have come to play an increasingly important role as countries battle for energy independence, loath to put their futures at the mercy of other nations. And this is understandable, given that nations with the most abundant hydrocarbon resources generally have the most fickle long-term energy policies, with the exception of Brazil.

To this discouraging panorama must be added the high price of fossil fuels and the global threat posed by climate change. So what are our options? It boils down to renewable or nuclear energy. The latter raises many doubts and few countries view it as a viable short-term option for technical reasons and the complication of disposing of the toxic waste it produces.[1]

Figure 1: Evolution of Electricity Generation by source




Source : IDB

## 2. Wind Energy Potential in Latin America

As regards wind energy, the increasing number of projects in the pipeline, together with investment in new plants and modifications to the existing regulatory framework, point to the exponential growth we have seen in other parts of the world. In the medium term, we can expect to see a substantial increase in installed capacity from its current level of 500MW to several thousands of MV in the near future throughout the length and breadth of the continent.

Latin America has enormous untapped potential, boasting two of the best sites in the world for the wind-driven generation of electricity: Patagonia, in the south of the continent, and the Isthmus of Tehuantepec in Mexico, whose winds are comparable to those in the North Sea area. And these are not the only places with excellent wind conditions. Prior estimates of technically viable potential put the region's output at several hundreds of thousands of MW, making a wind-powered future more than foreseeable.

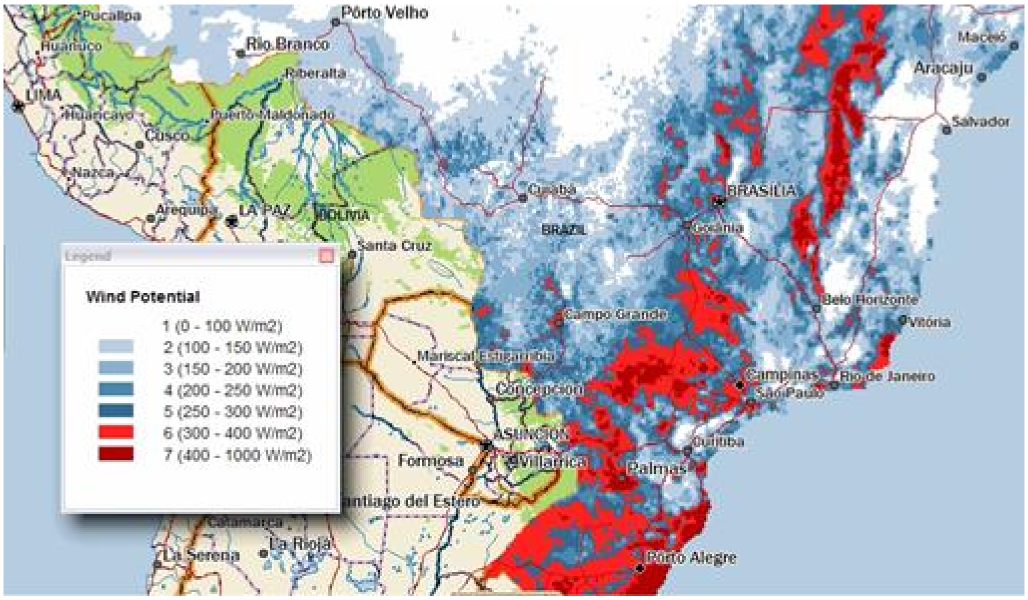
One of the more serious attempts to promote the use of renewable energy is Brazil's PROINFA program, which provides investment incentives and has managed to kick-start this fledgling market. Likewise, Chile recently promulgated a Renewable Energy Law, which establishes the goal of a 15%-increase in the use of renewable energy sources by 2010. This policy is already yielding results in the form of new wind energy projects, including a 500MW wind-powered plant that looks set to become the largest of its kind in Latin America.[2]

Table 1: Wind Energy Potential in Latin America

| COUNTRY | POTENTIAL (MW) | INSTALLED |
|---|---|---|
| Brazil | 140.000 | 247 |
| Mexico | 40.000 | 88 |
| Central America and the Caribbean | >100.000 | 144 |
| Colombia | 20.000 | 20 |
| Argentina | 10.000 | 27 |
| Venezuela | 10.000 | - |
| Chile | 5.000 | 20 |
| Total | >>200.000 | 546 |

Source: Latin America Wind Energy Association

Figure 2 : Wind Power Potential in South of Brazil




3. Solar Energy (Photovoltaic)

Photovoltaic (or PV) systems convert sun light energy into electricity. The term "photo" is derived from the Greek word "phos," which means "light." "Volt" is named for Alessandro Volta (1745-1827), a pioneer in the study of electricity. "Photo-voltaics," then, literally means "light-electricity."

Photovoltaic (PV) solar power is one of the most promising renewable energy sources in the world. Compared to nonrenewable sources such as coal, gas, oil, and nuclear, the advantages are clear: PV is totally non-polluting, has no moving parts to break down, and does not require much maintenance. A very important characteristic of photovoltaic power generation is that it can be installed on an individual rural school or health clinic or house, allowing specific users to generate their own power, quietly and safely. Additional solar panels can be added, as more is needed in a community, thereby allowing power generation to keep in step with growing needs.

In a surprising number of cases, PV power is the cheapest form of electricity in remote areas. The use of solar energy is not new. In fact, development of solar energy dates back more than 100 years, to the middle of the industrial revolution. Over the years, photovoltaic power has become increasingly efficient and practical.

While appropriate only in a limited number of urban applications, in remote areas of developing countries it is highly practical and often the only option. A remote site (a school, health clinic or home) can be virtually self-sufficient with solar energy. Photovoltaic systems typically have four principal components: solar panels, (modules), an energy storage device (battery), a charge and consumption controller, and an inverter. Since solar panels produce direct current (DC) and most conventional equipment operates on alternating current (AC), the inverter is used to change the DC current to AC current. The energy is then stored for use during overcast periods and at night. It can be stored as chemical energy in batteries, or as potential energy in pumped water tanks.

Solar energy, on account of the special geographic and social characteristics of the region, and thanks to its lower cost could, contribute substantially to the development of isolated rural communities.  The first solar cells cost around $200 dollars per watt. Today they cost less than $3 dollars per watt. [3]

Figure 3: Amount of solar energy in hours, received each day on an optimally tilted surface during the worst month of the year.

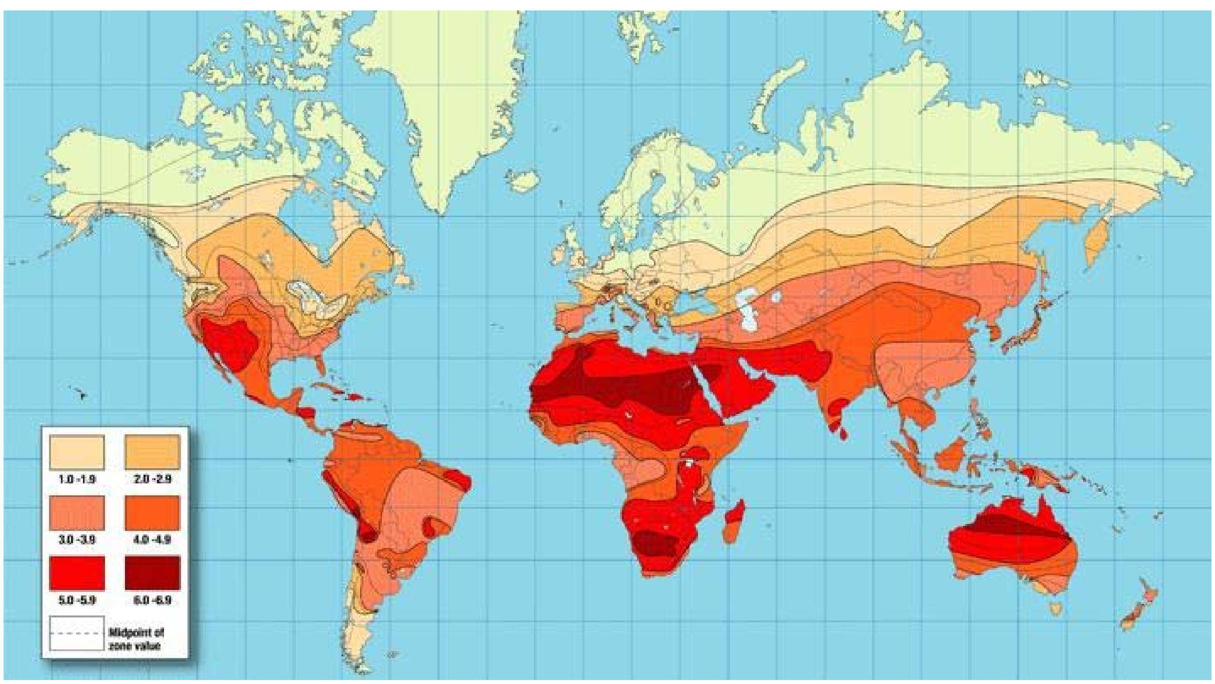
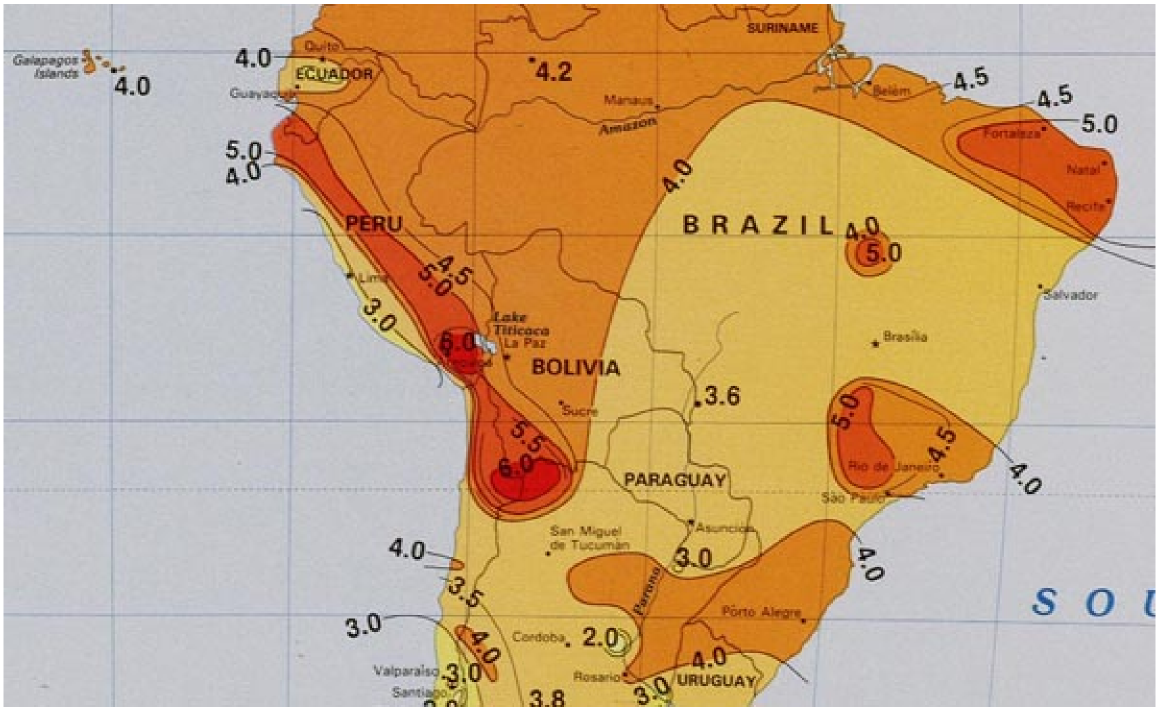



Figure 4: Amount of solar energy in hours, for South America.



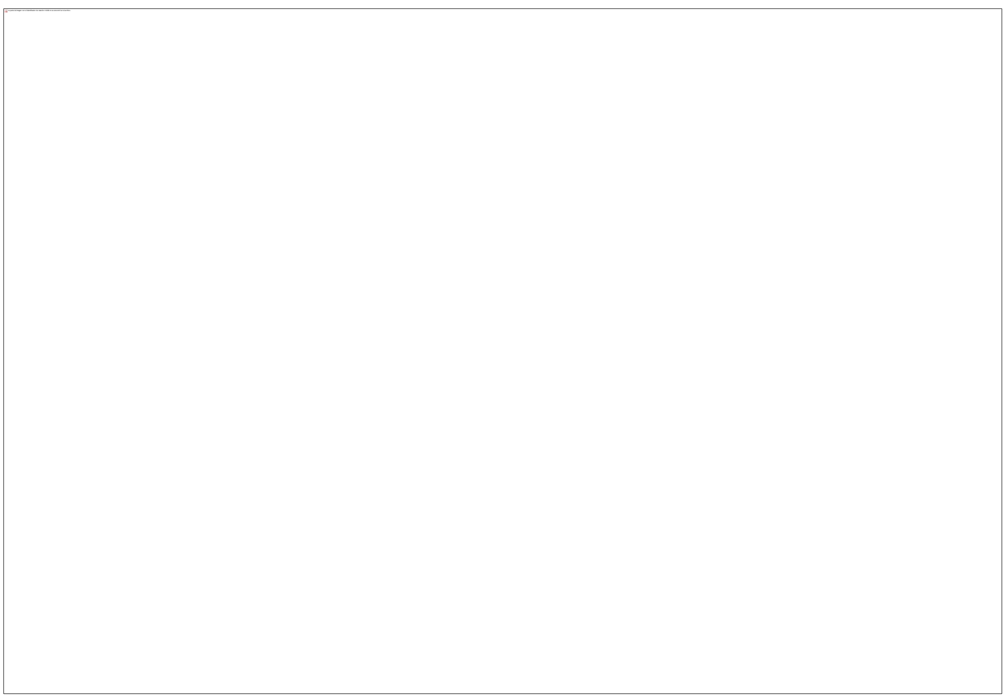

4. Biomass energy

Increased production of biomass for energy has the potential to offset substantial use of fossil fuels, but it also has the potential to threaten conservation areas, pollute water resources and decrease food security. The net effect of biomass energy agriculture on climate could be either cooling or warming, depending on the crop, the technology for converting biomass into useable energy, and the difference in carbon stocks and reflectance of solar radiation between the biomass crop and the preexisting vegetation. The area with the greatest potential for yielding biomass energy that reduces net warming and avoids competition with food production is land that was previously used for agriculture or pasture but that has been abandoned and not converted to forest or urban areas. At the global scale, potential above-ground plant growth on these abandoned lands has an energy content representing _5% of world primary energy consumption in 2006. The global potential for biomass energy production is large in absolute terms, but it is not enough to replace more than a few percent of current fossil fuel usage.

Biomass energy sources are among the most promising, most hyped and most heavily subsidized renewable energy sources. They have real potential to heighten energy security in regions without abundant fossil fuel reserves, to increase supplies of liquid transportation fuels and to decrease net emissions of carbon into the atmosphere per unit of energy delivered. However, increased exploitation of biomass energy also risks sacrificing natural areas to managed monocultures, contaminating waterways with agricultural pollutants, threatening food supplies or farm lifestyles through competition for land and increasing net emissions of carbon to the atmosphere, as a consequence of increased deforestation or energy-demanding manufacturing technologies. The opportunities are real, but the concerns are also justified. As investments in biomass energy increase, there needs to be an active, continuing discussion on strategies for balancing the pros and cons of biomass energy.

The data shows biomass growth will be greatest in the OECD, particularly Europe and North America. There will also however be high growth in Latin America and South Asia. The pattern is similar for biopower generation. [4]

Figure 5:



Source: IEA World Energy Outlook 2007

The 2020 capacity projections for the non-OECD countries, shown separately below, clearly shows the relative importance of Latin America and the emergence of China and Africa.

Figure 6:

Source: IEA World Energy Outlook 2007

5. Geothermal power

Our earth’s interior provides heat energy from nature. This heatyields warmth and power that we can use without polluting the environment.

Geothermal heat originates from earth’s fiery consolidation of dust and gas over 4 billion years ago. At the earth’s core temperatures may reach over 9,000 degrees Fahrenheit.

The heat from the earth’s core continuously flows outward. It transfers (conducts) to the surrounding layer of rock, the mantle. When temperatures and pressures become high enough, some mantle rock melts, becoming magma. Then, because it is lighter (less dense) than the surrounding rock, the magma rises, moving slowly up toward the earth’s crust, carrying the heat from below.

Sometimes the hot magma reaches all the way to the surface, where we know it as lava (which often comes from volcanoes). But most often the magma remains below earth’s crust, heating nearby rock and water (rainwater that has seeped deep into the earth)—sometimes as hot as 700 degrees Fahrenheit. Some of this hot geothermal water travels back up through faults and cracks and reaches the earth’s surface as hot springs or geysers, but most of it stays deep underground, trapped in cracks and porous rock. This natural collection of hot water is called a geothermal reservoir.

From earliest times, people have used geothermal water that flowed freely from the earth’s surface as hot springs. The oldest and most common use was, of course, just relaxing in the comforting warm waters. But eventually, this “magic water” was used (and still is) in other creative ways. The Romans, for example, used geothermal water to treat eye and skin diseases and, at Pompeii, to heat buildings. As early as 10,000 years ago, Native Americans used hot springs water for cooking and medicine. For centuries the Maoris of New Zealand have cooked “geothermally,” and, since the 1960s, France has been heating up to 200,000 homes using geothermal water.

Today we drill wells into the geothermal reservoirs to bring the hot water to the surface. Geologists, geochemists, drillers, and engineers do a lot of exploring and testing to locate underground areas that contain this geothermal water, so we’ll know where to drill geothermal production wells. Then, once the hot water and/or steam travels up the wells to the surface, it can be used to generate electricity in geothermal power plants or for energy saving non-electrical purposes (such as in agriculture, to help plants grow in greenhouses; aquaculture, to shorten the time needed to grow fish and shrimp; industry, to pasteurize milk and to dry lumber; and space heating in buildings and districts).

Figure 7: Hottest Known Geothermal Regions

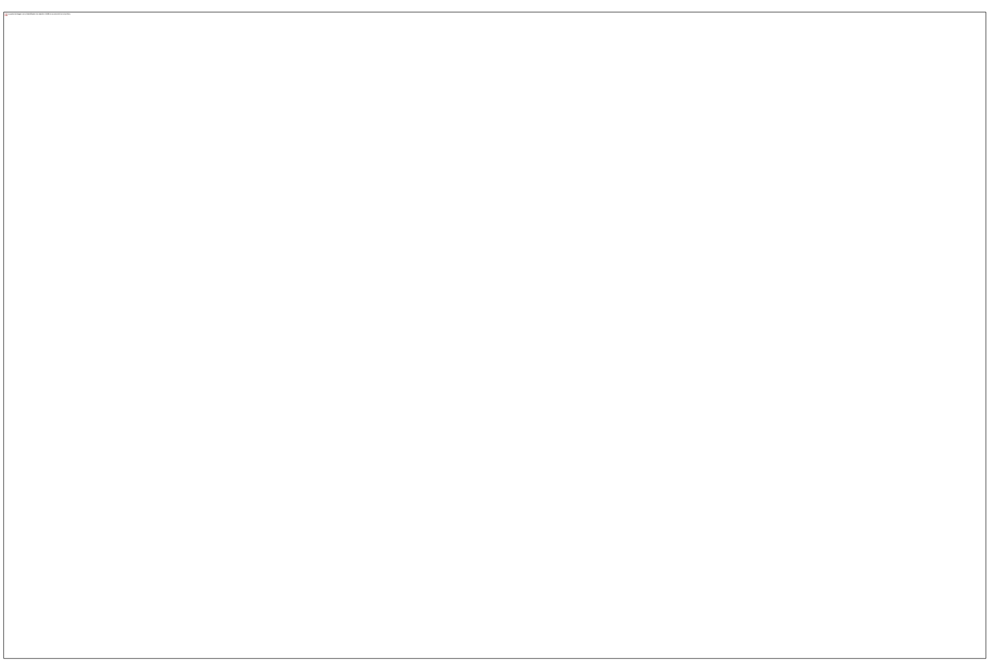


Figure 8: Regions with high Geothermal Potential in Latin America

Geothermal reservoirs that are close enough to the surface to be reached by drilling can occur in places where geologic processes have allowed magma to rise up through the crust, near to the surface, or where it flows out as lava. The crust of the earth is made up of huge plates, which are in constant but very slow motion relative to one another. Magma can reach near the surface in three main geologic areas: (1) where earth's large oceanic and crustal plates collide and one slides beneath another, called a subduction zone. The best example is the Ring of Fire—the areas bordering the Pacific Ocean; (2) spreading centers, where these plates are sliding apart (such as Iceland and the rift valleys of Africa); and (3) places called hot spots—fixed points in the mantle that continually produce magma to the surface. Because the plate is continually moving across the hot spot, strings of volcanoes are formed, such as the chain of Hawaiian Islands.

Geothermal heat pumps

Use can be almost worldwide. The earth's temperature a few feet below the ground surface is relatively constant everywhere in the world (about 45–58 degrees Fahrenheit), while the air temperature can change from summer to winter extremes. Unlike other kinds of geothermal heat, shallow ground temperatures are not dependent upon tectonic plate activity or other unique geologic processes. Thus geothermal heat pumps can be used to help heat and cool homes anywhere. [5]

Table 2: Geothermal Potential in Latin America

Source: People and Place: Geothermal Energy in Latin America

## 6. Perspectives and Conclusion

The development of the electricity supply sector is characterized by a dynamically growing renewable energy market and a continually increasing share of renewable electricity. This compensates for the phasing out of nuclear energy and a reduction in fossil-fuelled condensing power plants to the minimum required for grid stabilization. By 2050, 90% of electricity produced in Latin America will come from renewable energy sources. 'New' renewable - wind, biomass, geothermal and solar energy - will contribute 60% of the capacity. The following strategy paves the way for a future renewable energy supply:

The phasing out of nuclear energy and increasing electricity demand will be compensated for initially by bringing into operation new highly efficient gas-fired combined-cycle power plants, plus an increasing capacity of wind turbines. In the long term, wind will be the most important single source of electricity generation.

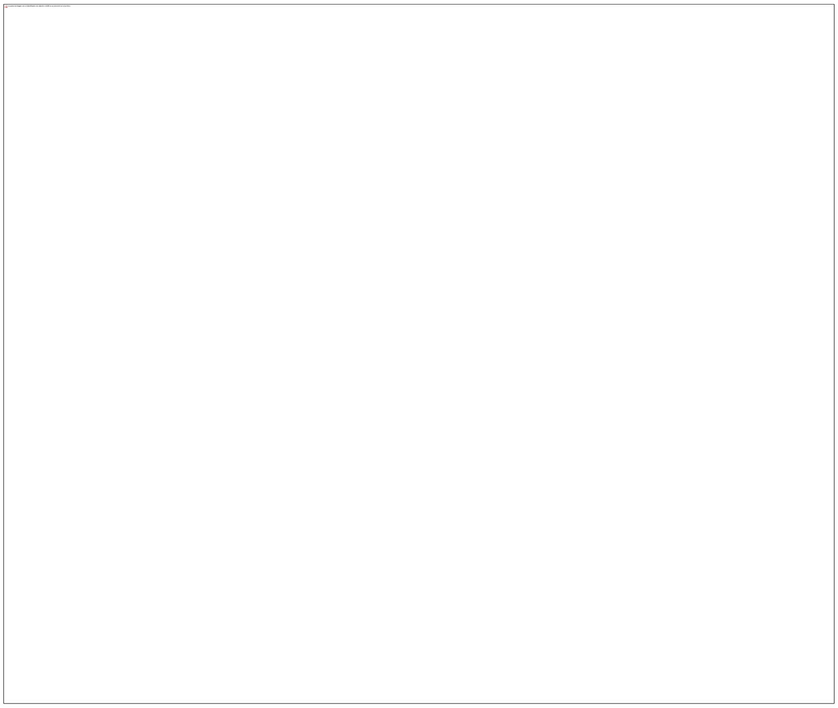
PV, geothermal and solar thermal energy will make substantial contributions to electricity production. In particular, as non-fluctuating renewable energy sources, hydro (still) and solar thermal power, combined with efficient heat storage, are important elements in the overall generation mix.

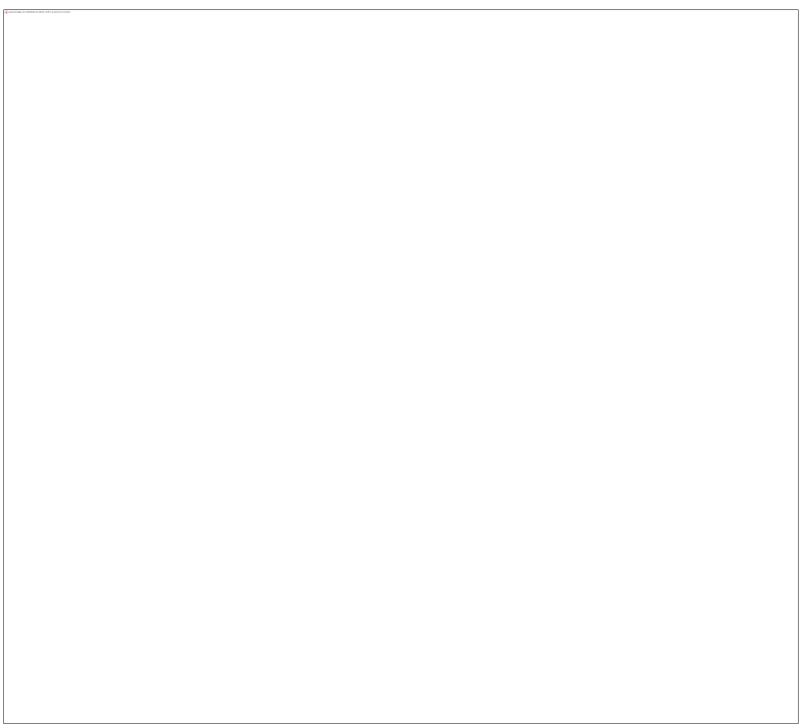
Because of nature conservation concerns, the use of hydro power will be limited and will not grow as much as in the reference scenario.

The installed capacity of renewable energy technologies will increase from the current 130 GW to 660 GW in 2050. Increasing renewable capacity by a factor of five within the next 43 years requires policy support and well-designed policy instruments. Because electricity demand is still growing there is a large demand for investment in new capacity over the next 20 years. As investment cycles in the power sector are long, decisions for restructuring the Latin American supply system need to be taken now.

To achieve an economically attractive growth in renewable energy sources, a balanced and timely mobilization of all renewable technologies is of great importance. This mobilization depends on technical potentials, actual costs, cost reduction potentials and technological maturity. Up to 2020, hydro-power and wind turbines will remain the main contributors to the growing market share. After 2020, the continually growing use of wind will be complemented by electricity from photovoltaic's, solar thermal power plants and biomass. [6]

In light of the region's insatiable energy needs and the potential of the renewable sources we have already discussed, it would seem this is the way ahead. Yet we have a long way to go as far as regulatory issues are concerned before these technologies can take off in Latin America. Virtually every country has taken steps to promote the use of renewable energy sources, but most of these initiatives are not aggressive enough or need to be reworked if they are to achieve their objectives any time soon.





Source: IDB

## 7. References

Trujillo, Mauricio (2007). Latin American Wind Energy Association (LAWEA)

Global Wind Report 2007. GWEC Global Wind Energy Council.

ENERGY SECURITY December 2008. IDB – Inter-American Development Bank

Field, Christopher B. 2005 - Biomass energy: the scale of the potential resource

Arsenault, Natalie (2006). People and Place: Geothermal Energy in Latin America.

Teske, Sven (2007). Energy Revolution: A sustainable world energy outlook.

# 30. Valor Adicionado aos Consumidores Livres de Energia Elétrica no Brasil por Contratos Flexíveis: Uma Abordagem pela Teoria das Opções

**Leonardo Lima Gomes – Mario Domingues – Luiz Eduardo Brandao**

Resumo

O processo de reestruturação do Setor Elétrico Brasileiro, iniciado em 1997, propiciou o surgimento de um mercado livre de energia. O contrato bilateral que estabelece as quantidades de energia a serem entregues, a duração da entrega e o preço contratado tornou-se o principal instrumento de negociação neste cenário. Com o passar do tempo, os contratos no ambiente livre ficaram mais sofisticados, passando a incorporar flexibilidades como: permitir uma faixa de escolha por parte do comprador da quantidade de energia a ser entregue (opção de escolha da quantidade) ou; permitir que o comprador exerça o direito de parar ou reduzir substancialmente o consumo durante determinado intervalo pré-acordado (opção de redução). Este trabalho se propõe a responder o quanto pode valer estas flexibilidades embutidas nos contratos de energia elétrica no Brasil. As flexibilidades foram modeladas e avaliadas como opções de compra e de venda, utilizando-se simulação dos preços mensais de energia. Foram realizadas análises de sensibilidade em relação ao tamanho das flexibilidades, aos preços contratados e às taxas de desconto ajustadas ao risco. Com resultado verificou-se que o valor conjunto (agregado aos consumidores) das opções de escolha da quantidade e de redução pode ultrapassar 20% do valor do contrato no mercado livre brasileiro.

Palavras-chaves: opções, energia elétrica, contratos, flexibilidade, mercado de energia.

Abstract

The process of restructuring the Brazilian electricity sector, begun in 1997, has given rise to a market for free negotiation of power supply between large consumers and producers. The bilateral agreements establishing the quantities of energy to be delivered, duration and price have become the main negotiating instrument in this scenario. With the passage of time, these power supply agreements have become more sophisticated, incorporating more flexible features. Among these are the options by the purchaser to choose the quantity of energy to be supplied (amount option) or to substantially reduce the amount or even to cease the supply during a predetermined interval (reduction option). This study examines the value of these flexibilities in the Brazilian electricity market. We modeled and valued the flexibilities as call and put options, using monthly energy price simulations, and ran sensitivity tests in relation to the size of the flexibilities, the prices contracted and the risk-adjusted discount rates. The results provide evidence that the joint value (aggregated to consumers) of the options for choice of quantity and reduction can exceed 20% of the contract value.

Keywords: options, electricity, contracts, flexibility, electricity market.

Introdução

Até 1997 o Setor Elétrico Brasileiro (SEB) era basicamente um monopólio estatal administrado por empresas federais e estaduais. A partir do segundo semestre do mesmo ano foram iniciadas as privatizações e, em paralelo, uma forte reestruturação do setor.

A partir de então, o SEB passou a experimentar um acentuado processo de mudança, iniciado nos moldes do Projeto de Reestruturação do Setor (Projeto RE-SEB), coordenado pelo Ministério de Minas e Energia, tendo como algumas das principais características:

A desverticalização da produção, transmissão, distribuição e comercialização;

Os segmentos de produção e comercialização passaram a ser uma atividade competitiva com preços contratados definidos pelo mercado;

O livre acesso dos geradores e comercializadores às redes de transmissão e distribuição;

Criação do Mercado Atacadista de Energia (MAE) hoje chamado de Câmara de Comercialização de Energia Elétrica (CCEE), ambiente onde a livre competição deve condicionar a formação de preços;

O processo de reestruturação iniciado em 1997 propiciou o surgimento de um mercado livre de energia, fundamentalmente, entre geradoras, comercializadoras e empresas com grande consumo de energia (consumidores livres). O contrato bilateral, que estabelece basicamente as quantidades a serem entregues, a duração e o preço contratado, tornou-se o principal instrumento de negociação entre os agentes do setor.

De acordo com o decreto nº 5.163 de 30 de Julho de 2004, regulamentou-se a existência do Ambiente de Contratação Livre (ACL), definido como o segmento do mercado no qual se realizam as operações de compra e venda de energia elétrica, objeto de contratos bilaterais livremente negociados, conforme regras e procedimentos de comercialização específicos.

A importância do mercado livre no Brasil fica evidenciada na Tabela 1, do consumo por classe registrado em Dez/2006, uma parcela de 18,8% deve-se à classe do consumidor livre.

Tabela 1 – Percentual do Consumo por Classe em Dez/2006

| Classe do Agente | Consumo Total Registrado [MWh] | Percentual |
|---|---|---|
| Autoprodutor | 1.787.639,91 | 5,0% |
| Comercializador | 7.252,76 | 0,0% |
| Consumidor Livre | 6.692.731,58 | 18,8% |
| Distribuidor | 26.056.148,69 | 73,2% |
| Gerador | 800.212,77 | 2,2% |
| Importador | 0 | 0,0% |
| Produtor Independente | 260.807,85 | 0,7% |
| Total | 35.604.793,57 | 100,0% |

Fonte: Câmara de Comercialização de Energia Elétrica (CCEE)

Devido a algumas necessidades dos compradores de energia elétrica, reveladas a partir da incapacidade de prever exatamente o consumo, com o passar do tempo os contratos bilaterais ficaram mais sofisticados. Estes passaram a incorporar algumas flexibilidades como: permitirem uma faixa de escolha por parte do comprador da quantidade de energia a ser entregue (opção de escolha da quantidade) ou; permitirem que o comprador exerça o direito de parar o consumo durante determinado intervalo pré-acordado (opção de redução).

A opção de escolha da quantidade surge devido ao anseio do comprador de ajustar a energia comprada ao seu consumo. Essa opção vale para todos os meses contratuais (considerando o mês como o período de apuração). Já a opção de redução surge no mercado como um produto capaz de adaptar o fornecimento às paradas programadas ou intempestivas da planta consumidora.

Assim, neste contexto, as flexibilidades embutidas nos contratos passaram a ter importante papel no mercado de energia elétrica. A questão chave que este trabalho se propõe a responder é: *Quanto podem valer as flexibilidades (opção de escolha da quantidade e opção de redução) embutidas em contratos de energia elétrica no Brasil?*

No sentido de responder a esta questão, as flexibilidades foram modeladas e avaliadas como opções financeiras (de compra e de venda), utilizando-se simulação dos preços mensais de energia denominados de Preços de Liquidação das Diferenças (PLDs). Foram realizadas análises de sensibilidade em relação ao tamanho das flexibilidades, aos preços contratados e às taxas de desconto.

O trabalho está organizado da seguinte forma, inicia-se com a revisão da literatura de finanças sobre opções. Em seguida, são descritas quais são as principais características do mercado brasileiro de energia elétrica, dos contratos de energia elétrica no Brasil e como as flexibilidades podem estar embutidas nestes instrumentos. Após a revisão da literatura e a descrição do mercado de energia elétrica, a metodologia é apresentada. Posteriormente, é realizado um exemplo numérico com dados e análises de sensibilidade que se aproximam da realidade do mercado brasileiro de energia elétrica, obtendo-se valores para as flexibilidades analisadas individual e conjuntamente. Em seguida, são feitas as conclusões deste estudo.

## Revisão da Literatura

### Teoria de Finanças Sobre Opções

As opções são exemplos de derivativos, ou seja, são ativos cujo valor deriva do valor de outros ativos de referência (ativo objeto).

Existem dois tipos de opções, as opções de compra e as de venda. Considerando a opção de compra, o proprietário da opção tem o direito de comprar o ativo objeto a um preço pré-determinado. No caso da opção de venda, o detentor da opção tem o direito de vender o ativo a um preço pré-determinado.

O preço pré-determinado é conhecido como preço de exercício da opção. As opções são classificadas como americanas quando podem ser exercidas em qualquer data, até o momento do vencimento, e classificadas como européias quando só podem ser exercidas na data do vencimento. É importante enfatizar que as opções dão ao proprietário o direito de exercício, mas não a obrigação.

Como há o direito e não uma obrigação de exercício e uma probabilidade de resultado positivo futuro em função do exercício, as opções têm valor, também chamado de prêmio.

No sentido de avaliar o prêmio de uma opção, o trabalho precursor no desenvolvimento da teoria de finanças sobre opções foi o de Black e Scholes (1972). Os autores desenvolveram uma equação de precificação de uma opção de compra obtida pela eliminação de arbitragem para uma carteira livre de risco montada com ações (ativo objeto) e opções sobre esta ação. Igualando-se o retorno desta carteira à taxa de juros livre de risco, obteve-se uma equação diferencial estocástica cuja solução analítica representa o valor da opção.

A teoria de finanças sobre opções, inicialmente focada na opção como um derivativo do mercado financeiro, evoluiu principalmente na avaliação de flexibilidades embutidas em projetos e contratos. Esta teoria é conhecida como Teoria das Opções Reais.

Teoria das Opções Reais

A literatura recente de análise de projetos e contratos vem descrevendo métodos de avaliação extremamente similares aos métodos tradicionais de opções financeiras. Essas novas metodologias são chamadas de Teoria das Opções Reais (TOR) (Trigeorgis, 1996; Amran e Kulatilaka, 1999) e são capazes de captar o valor da flexibilidade gerencial e mostram grande capacidade de explicar ações e negociações ocorridas no ambiente real do mercado.

Os métodos tradicionais de avaliação de projetos e contratos, como o Valor Presente Líquido e Taxa Interna de Retorno, são considerados de gerenciamento passivo. Entretanto, os gerentes continuamente decidem mudanças administrativas e operacionais face à resolução de incertezas, com objetivo de agregar valor ao projeto ou contrato. Tais flexibilidades são valiosas e devem ser incorporadas na análise. A TOR permite a incorporação de flexibilidades ante os métodos tradicionais de avaliação de investimentos.

Encontra-se na literatura estudos de opções reais em diferentes áreas e contextos corporativos, tais como: na avaliação de investimentos em mercados exteriores (Gauthier e Rouzeau, 1997), na avaliação de investimentos em tecnologia da informação (Kulatilaka, Balasubramanian e Storck, 1999), na determinação do valor de empresas de internet (Schwartz e Moon, 2000) e, até mesmo, para avaliar e planejar programas de televisão (Gerske, Kopca e Tochtermann, 2000).

As opções reais, ao contrário das opções financeiras, não possuem aditividade de valor. Isto significa que sinergias, criadas entre opções de um mesmo projeto ou projetos inter-relacionados, bem como interações com decisões financeiras da empresa, podem ser capturadas e avaliadas. (Trigeorgis, 1993).

Diretamente relacionado a este artigo, encontram-se trabalhos que se propuseram a avaliar opções embutidas em contratos comerciais. Um desses trabalhos foi o desenvolvido por Trigeorgis (1996), no qual se avalia opções embutidas em contratos de *leasing*.

Adicionalmente, há aplicações da teoria de opções ao setor elétrico. Algumas delas são citadas a seguir.

Aplicações da Teoria de Finanças Sobre Opções ao Setor Elétrico

Deng, Johnson e Sogomonian (DJS) (1998) avaliaram termelétricas como opções e consideram que o custo do combustível representa o custo variável de operação e o preço de exercício das opções. Ethier (1999) fez uma avaliação semelhante, complementando o modelo de DJS, através da introdução da possibilidade de saltos no processo estocástico do preço da energia elétrica.

Winsen (1999) adicionou à formulação de DJS a possibilidade de proteção através de contratos de *swap* (troca de fluxos de caixa), nos quais a termelétrica concorda em pagar um preço flutuante de curto prazo em troca de recebimentos fixos. Foi realizado um estudo de caso de avaliação de uma termelétrica no mercado australiano, considerando diversas possibilidades de contratação.

Johnson, Nagali e Romine (1999) separaram a flexibilidade operacional por duração em flexibilidade mensal, diária e na ponta/fora da ponta. Utilizando a formulação de DJS, eles fazem uma comparação do valor de operar uma termelétrica entre as diferentes flexibilidades.

A operação de uma termelétrica possui restrições que reduzem o valor da flexibilidade operacional conforme foi mostrado por Tseng e Barz (1997). As restrições consideradas por eles foram: restrições de rampa, ou seja, restrições de tempo requerido para reiniciar a operação da planta e restrições de acoplamento, isto é, uma unidade de geração térmica não pode trocar entre o modo ligado e o modo desligado a uma frequência arbitrária, sendo necessária a permanência em um dos modos por um tempo mínimo.

Características do Mercado Brasileiro de Energia Elétrica

Nesta seção, serão descritas características do mercado brasileiro de energia elétrica a fim de que se possa compreender a modelagem realizada neste trabalho. Inicia-se pelas características dos contratos bilaterais.

Formato dos Contratos Bilaterais

A unidade básica negociada em contratos de energia elétrica é o *megawatt-hora* (MWh), sendo os preços negociados em *reais por megawatt-hora* (R$/MWh). Um contrato deve especificar as quantidades de energia elétrica a serem entregues durante determinados intervalos de tempo. Por exemplo, seja um contrato especificado para dois meses de entrega, março e abril de 2006. O contrato determina que o fornecedor deverá entregar 74.400 MWh em março e 72.000 MWh em abril. Se o preço contratado for de 50 R$/MWh, o faturamento do fornecedor deverá ser de R$ 50x74.400 em março e de R$ 50x72.000 em abril.

No exemplo anterior, ao se dividir a quantidade de energia em MWh pelo número de horas de cada mês, encontra-se o valor de 100 *megawatt* (MW) para ambos. É bastante comum, também, que a quantidade negociada esteja em MW, mais especificamente em MWmédio para indicar que é uma média no período. Assim, no exemplo, a quantidade negociada de 100 MWmédio para março e abril, equivale a 100x744 MWh em março e 100x720 MWh em abril.

Outro item básico a ser especificado no contrato é o local de entrega. O mercado brasileiro é dividido em quatro sub-mercados, sudeste/centro-oeste, sul, nordeste e norte, originados a partir das restrições de transmissão. Dependendo da situação do armazenamento de água, da oferta e da demanda, cada sub-mercado pode apresentar preços bastante diferentes. Daí a importância da especificação do local da entrega.

Exemplificando, considere um contrato com as seguintes características:

Ponto de Entrega: Centro de Gravidade do Submercado Sudeste/Centro-oeste;

Duração: Janeiro a Dezembro de 2007;

Quantidade: 50 MWmed;

Preço: 90 R$/MWh.

A energia será entregue no submercado sudeste/centro-oeste sem perdas de distribuição de janeiro a dezembro de 2007 ao preço fixo de 90 R$/MWh. As quantidades em MWh serão calculadas mensalmente pelo produto 50 MWmed x número de horas no mês.

Flexibilidades Embutidas nos Contratos Bilaterais de Energia Elétrica no Brasil

A existência das flexibilidades é explicada por necessidades ou desejos dos agentes do mercado livre traduzidos em cláusulas contratuais. Um consumidor livre, por exemplo, necessita de flexibilidade para consumir, dado que os valores de consumo medidos consolidados mês a mês variam. Se esse consumidor contratar um suprimento de energia para exatamente o que consome, sua necessidade estará atendida. No entanto, a flexibilidade embutida de pagar exatamente pelo que consome não agrega valor ao seu contrato. Por um desejo e uma condição de mercado favorável, este consumidor poderá escolher a quantidade contratada. Aí sim, a flexibilidade terá valor como explicado a seguir.

Uma das principais flexibilidades é a permissão de uma faixa de escolha por parte do comprador da quantidade de energia a ser entregue (opção de escolha da quantidade). Normalmente, os contratos com essa flexibilidade especificam o intervalo de escolha em mais ou menos um percentual da quantidade contratada. Por exemplo, considerando uma quantidade contratada de 50 MWmed, o intervalo de escolha pode estar sendo especificado em $\pm$20% dessa quantidade, ou seja, entre 40 (limite inferior) e 60 MWmed (limite superior).

Sendo assim, a cada período de apuração (geralmente mensal), o comprador poderá escolher a quantidade que quer comprar entre 40 e 60 MWmed ao preço contratado. Supondo que o comprador tenha de fato uma necessidade de 50 MWmed, por que então ele escolheria uma quantidade de suprimento diferente? Considerando que os preços de curto prazo (PLDs) em um determinado mês estejam abaixo do preço do contrato, o comprador poderia escolher comprar 40 MWmed ao preço contratado, e os 10 MWmed restantes a um preço menor que o contratado, gerando uma economia. Ao contrário, considerando que os preços de curto prazo em um determinado mês estejam acima do preço do contrato, o comprador poderia escolher comprar 60 MWmed ao preço contratado, e os 10 MWmed de excesso ele venderia no mercado de curto prazo a um preço maior, gerando um ganho adicional. Observa-se então que a opção de escolha da quantidade agrega valor ao contrato.

Outra flexibilidade importante, embutida em alguns contratos de energia, é a permissão que o comprador exerça o direito de parar ou reduzir substancialmente o consumo/a entrega durante determinado intervalo pré-acordado (opção de redução). Conceitualmente, esta opção deveria contemplar a interrupção completa do fornecimento uma vez que está condicionada a paradas normalmente programadas das unidades consumidoras. No entanto, como a apuração (exercício) da opção é mensal e em várias situações práticas as paradas ocorrem em períodos menores que um mês, pode-se necessitar de reduções mensais significativas não sendo exatamente uma interrupção total do contrato.

O que diferencia a redução da opção de escolha da quantidade e da opção de redução é o tamanho da redução, explicado pelo fato que originou cada opção. Normalmente, a opção de escolha da quantidade não ultrapassa 20%. Já no caso da opção de redução, a redução é substancial por estar condicionada a paradas das unidades consumidoras, normalmente de no mínimo 50% até uma interrupção total.

O intervalo pré-acordado pode ser, por exemplo, todo mês de dezembro incluído no período de vigência do contrato. Se a redução permitida for parcial, o contrato também deverá especificar o tamanho, sendo em geral um percentual da energia contratada. Por exemplo, uma redução permitida de 60% de uma energia contratada de 50 MWmed, corresponderia a uma redução permitida de 30 MWmed. Um comprador exerce a opção de redução quando os preços de curto prazo são menores que o preço contratado.

Os valores agregados por estas flexibilidades só existem porque há um mercado de curto prazo onde as opções podem ser exercidas. Os preços que balizam os preços de curto prazo são os estabelecidos pela Câmara de Comercialização de Energia Elétrica (CCEE). A CCEE publica os Preços de Liquidação das Diferenças (PLDs) semanais e um preço médio mensal de referência (média ponderada dos PLDs semanais). A seção seguinte explica como esses preços são calculados e como podem ser simulados.

Existem outras flexibilidades embutidas em contratos de energia elétrica no Brasil que não estão consideradas neste trabalho, tais como: a de extensão do período de contratação ao preço contratado, a flexibilidade de sazonalização (rearranjo das quantidades mensais contratadas mantendo-se constante a quantidade anual) e a flexibilidade de modulação (rearranjo de quantidades dentro do mês mantendo-se constante a quantidade mensal contratada).

## Formação e Simulação dos Preços de Liquidação das Diferenças (PLDs)

O PLD é utilizado para liquidar a compra e a venda de energia no mercado de curto prazo. A formação do preço da energia comercializada no mercado de curto prazo se faz pela utilização dos dados considerados pelo Operador Nacional do Sistema (ONS) para a otimização da operação. O significado do PLD dentro do contexto da otimização da operação será explicado na seção 3.5.

O Brasil adotou um esquema de decisão de operação (geração de energia elétrica) centralizado realizado por modelos acoplados de otimização (atualmente, um modelo de médio prazo que está acoplado a um de longo prazo, chamado Newave) cujo objetivo é minimizar o custo total de operação do sistema hidrotérmico ao longo de um horizonte de planejamento. Esses modelos utilizam o método de programação dinâmica dual estocástica (Pereira e Pinto, 1991). A fim de conceituar melhor a formação de preço no sistema hidrotérmico brasileiro, torna-se necessária uma abordagem sobre como é feita a operação sob uma ótica econômica. As seções a seguir apresentam essa abordagem.

## Operação de um Sistema Hidrotérmico

A característica mais evidente de um sistema com geração hidroelétrica é poder utilizar a energia “grátis” que está armazenada nos reservatórios para atender à demanda evitando, desta maneira, gastos de combustível com as unidades térmicas. Entretanto, a disponibilidade de energia hidro está limitada pela capacidade de armazenamento nos reservatórios. Isto introduz uma dependência entre a decisão operativa de hoje e os custos operativos no futuro.

Em outras palavras, se utilizarmos hoje as reservas de energia hidro, com o objetivo de minimizar os custos térmicos, e ocorre uma seca severa no futuro, pode haver um racionamento de custo elevado para a sociedade. Se, por outro lado, preservamos as reservas de energia hidro através de um uso mais intenso de geração térmica, e as afluências futuras são elevadas, pode ocorrer um vertimento nos reservatórios do sistema, o que representa um desperdício de energia e, consequentemente, um aumento no custo operativo. Esta situação está ilustrada na Figura 1.

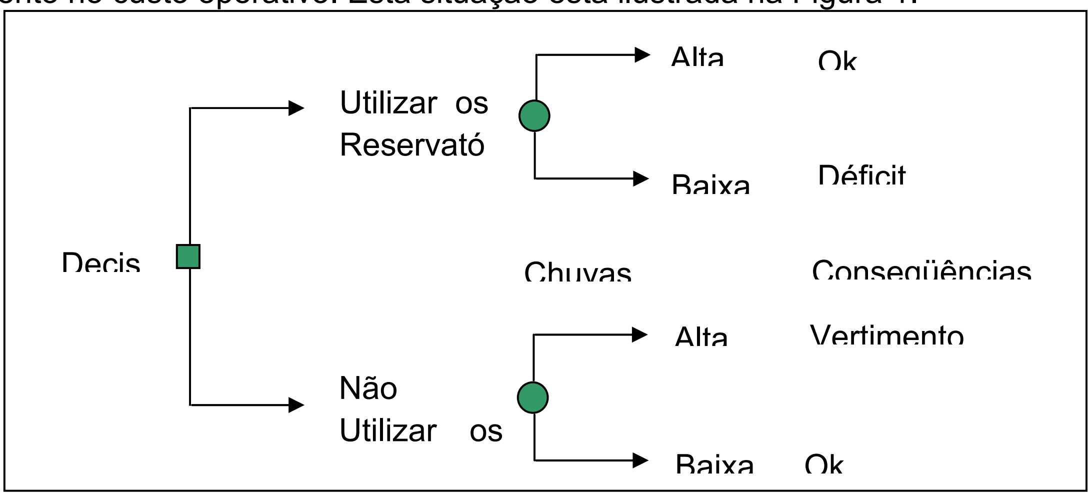


Figura 1 - Processo de Decisão para Sistemas Hidrotérmicos

O operador de um sistema hidrotérmico deve comparar o benefício imediato do uso da água e o benefício futuro de seu armazenamento, conforme ilustrado na Figura 2.

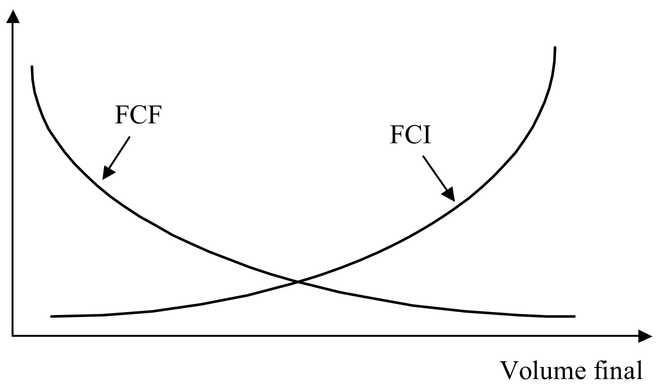



Figura 2 – Custo imediato e Futuro

A *função de custo imediato* - FCI - representa os custos de geração térmica no estágio *t*, ou seja, no estágio imediato, presente. Observa-se que o custo imediato aumenta à medida que diminui a energia hidro disponível, isto é, quanto menor for a decisão de geração hídrica, maior será a de geração térmica.

Por sua vez, a *função de custo futuro* - FCF - está associada ao custo esperado de geração térmica e racionamento do final do estágio *t* (início de *t*+1) até o final do período de estudo. Esta função diminui à medida que aumenta o volume armazenado final, pois haverá mais energia hidro disponível no futuro.

O uso ótimo da água armazenada corresponde ao ponto que minimiza a soma dos custos imediato e futuro. Como é mostrado na Figura 3, o ponto de mínimo custo global também corresponde ao ponto onde as derivadas da FCI e da FCF com relação ao armazenamento de água se igualam. A derivada da FCI e da FCF no ponto ótimo também é conhecida como valor da água, pois representa a taxa custo R$ (ou valor) por volume de água deixado no reservatório para formar o volume final.

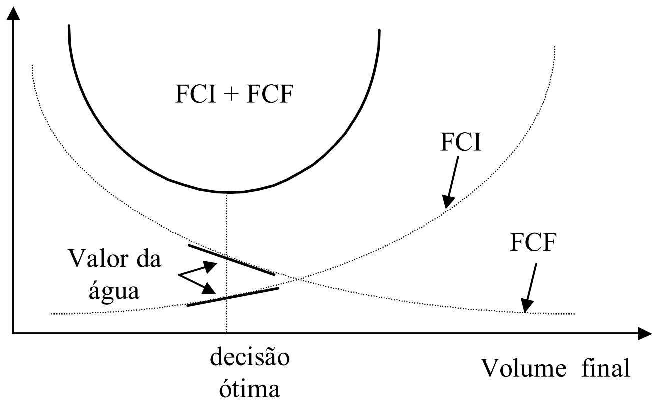



Figura 3 - Uso Ótimo da Água

Cálculo do PLD

Será apresentado, mais detalhadamente, como é realizada a decisão de operação sob a ótica econômica e calculado o PLD. Na formulação a seguir, estamos supondo que a função de custo futuro para cada estágio foi calculada. O problema de decisão da operação hidrotérmica para o estágio *t* é formulado como:

$$z_t = \quad \text{Min} \; [c_j \times g_{tj} + \text{FCF}(v_{t+1})]$$

Sujeito às seguintes restrições operativas:

Balanço hídrico;

Limites de armazenamento de água e turbinamento;

Limites na geração térmica;

Atendimento à demanda.

A função objetivo é minimizar a soma de duas classes de custos:

*Custo operativo imediato* - dado pelos custos térmicos $\{c_j \times g_{tj}\}$ no estágio *t*. Onde $c_j$ é o custo variável da térmica j e $g_{tj}$ é a geração da térmica j no estágio t. O racionamento é representado por uma térmica fictícia de capacidade infinita e custo operativo igual ao custo de interrupção.

*Valor esperado do custo operativo futuro* - dado pela função de custo futuro FCF($v_{t+1}$). Também como discutido anteriormente, esta função depende dos volumes armazenados ao final do estágio, representados pelo vetor $v_{t+1}$.

O problema de otimização pode ser resolvido por um algoritmo de programação linear. Além da decisão operativa ótima, o esquema de programação calcula os multiplicadores simplex, ou preços sombra, associados a cada restrição. Em particular, o PLD do sistema é o multiplicador simplex associado à restrição de atendimento à demanda, significando o custo de produção de 1 MWh adicional no ponto ótimo de minimização de custos (em R$/MWh).

Após a revisão da literatura e já abordados os conceitos sobre o mercado brasileiro de energia elétrica necessários ao entendimento da modelagem, a metodologia de modelagem e cálculo das flexibilidades como opções pode ser explicada.

Metodologia

Modelagem das Flexibilidades

A opção de escolha da quantidade será modelada, para cada mês do contrato, como a soma de uma opção de compra com uma opção de venda. Considerando uma quantidade contratada de 50 MWmed com o intervalo de escolha em $\pm 20\%$, o comprador terá uma opção de compra de 10 MWmed e uma opção de venda de 10 MWmed para cada mês do contrato, sendo o preço de exercício o contratado. A Figura 4 ilustra as duas opções.

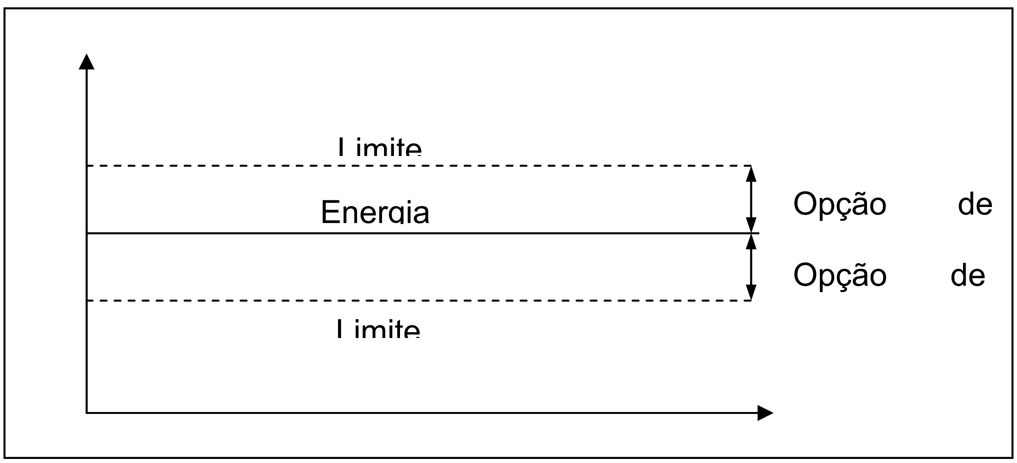



Figura 4 – Ilustração da Modelagem da Opção de Escolha da Quantidade

O valor da opção de escolha da quantidade ($OEQ_{0,t}$) em t=0 para um determinado momento t de exercício será igual à soma do valor em t=0 da opção de compra ($OC_{0,t}$ - exercício em t) com o valor em t=0 da opção de venda ($OV_{0,t}$) com momento de exercício em t. Ou seja:

$$OEQ_{0,t} = OC_{0,t} + OV_{0,t}$$

Sendo:

$$OC_{0,t} = E_0(OC_t) / (1+k)^t \quad ; \quad OC_t = \max(0, E_t^{compra}(PLD_t - P_t^c)) \quad (1)$$

$OV_{0,t} = E_0(OV_t)/(1+k)^t$ ; $OV_t = \max(0, E_t^{venda}(P_t^c - PLD_t))$ (2)

Onde:

$P_t^c$ – Preço contratado de energia em t

$E_t^c$ – Energia contratada no instante (mês) t

$E_t^{compra}$ – Montante de energia embutido na opção de compra

$E_t^{venda}$ – Montante de energia embutido na opção de venda

$PLD_t$ – Média mensal do Preço de Liquidação das Diferenças (PLD) no mês t

$OC_t$ – Valor da opção de compra no instante t (momento de exercício)

$OV_t$ – Valor da opção de venda no instante t (momento de exercício)

k – taxa de desconto ajustada ao risco

O valor das opções de compra e de venda é, portanto, obtido como o valor esperado dos pagamentos simulados das opções descontado a valor presente. Este método de avaliação é usualmente empregado em finanças para avaliar opções (Hull, 2003, p. 493), (Pilipovic, 1997, p. 134), porém normalmente utilizando taxas de desconto neutras ao risco.

Em relação à taxa de desconto (k), da teoria de finanças, ao se avaliar um derivativo de um ativo base, se for possível montar uma carteira livre de risco com ambos, a taxa de desconto apropriada para avaliar o derivativo é a taxa livre de risco. Caso não seja viável assumir a premissa que é possível montar uma carteira livre de risco, utiliza-se uma taxa de desconto ajustada ao risco (Dixit e Pindyck, 1994, p. 114). Neste trabalho, sendo o mercado brasileiro de energia elétrica insipiente, optou-se por assumir que não é possível montar carteiras livres de risco. Assim, a taxa de desconto será considerada uma taxa ajustada ao risco. Não se sabe exatamente qual é a taxa, mas, estima-se qual o intervalo em que a mesma se encontra.

A flexibilidade é válida para todos os intervalos de apuração (meses) ao longo do contrato. Assim, o valor total da flexibilidade de escolha da quantidade ($VOEQ_{0,i,T}$) será igual ao somatório dos valores de todas as opções de escolha da quantidade ($OEQ_{0,t}$) em t=0 para t, variando do instante em que o contrato inicia (t = i) até o momento em que o contrato termina (t = T).

$$VOEQ_{0,i,T} = \sum_{t=i}^{t=T} OEQ_{0,t} \quad (3)$$

A opção de redução, ou seja, a permissão que o comprador exerça o direito de parar ou reduzir substancialmente a quantidade de energia durante determinado intervalo pré-acordado será modelada como uma opção de venda. Supondo que o intervalo pré-acordado seja todo mês de dezembro incluído no período de vigência do contrato e que a redução permitida seja de 60% sobre uma energia contratada de 50 MWmed, um comprador terá a opção de redução de 30 MW ($E_t^{venda}$) em todo mês de dezembro ao longo do contrato, exercendo esta opção quando os PLDs forem menores que o preço contratado.

O valor da opção de redução ($OR_{0,t}$) em t=0 para um determinado instante t de exercício será igual a:

$OR_{0,t} = E_0(OR_t)/(1+k)^t$ ; $OR_t = \max(0, E_t^{venda}(P_t^c - PLD_t))$
(4)

Onde:

$P_t^c$ – Preço contratado de energia em t

$E_t^{venda}$ – Montante de energia embutido na opção de venda

$PLD_t$ – Média mensal do Preço de Liquidação das Diferenças (PLD) no mês t

$OR_t$ – Valor da opção de redução no instante t (momento de exercício)

k – taxa de desconto ajustada ao risco

Sendo a flexibilidade válida para todos os intervalos pré-acordados ao longo do contrato, o valor total das opções de redução ($VOR_{0,t1,tn}$) será igual ao somatório dos valores de todas as opções de redução ($OR_{0,t}$) em t=0, considerando todos os n possíveis momentos de exercício (t = t1 a t = tn).

$$VOR_{0,t1,tn} = \sum_{t=t1}^{t=tn} OR_{0,t} \qquad (5)$$

Cálculo e Simulação dos PLDs

Neste trabalho, para formar e simular os PLDs, foi utilizado o modelo Newave (elaborado pelo Centro de Pesquisas de Energia Elétrica (CEPEL) versão 11.2/2004) que otimiza a estratégia de geração de longo prazo de acordo com o conceito apresentado nas seções anteriores, formando preços com discretização mensal.

O PLD é limitado a um piso e um teto de preço definidos pela Agência Nacional de Energia Elétrica (ANEEL).

O modelo Newave possui dois módulos. No primeiro é calculada a política ótima de operação ao longo do horizonte de planejamento, representando um “mapa de decisão” em função do que vier a ocorrer ou ser simulado em termos de afluências (chuvas) aos reservatórios. No segundo módulo são feitas simulações do custo marginal de operação.

Neste estudo, após a utilização do modelo Newave para calcular a política ótima de operação hidrotérmica ao longo de um período de planejamento, será feita uma simulação com a qual se obtêm séries de custos marginais de operação, e, aplicando-se os limites, obtêm-se séries de PLDs. A simulação será realizada mediante a geração de séries sintéticas de afluências aos reservatórios utilizando um modelo periódico auto-regressivo (PAR(p)) de séries temporais (Maceira e Bezerra, 1997).

É importante ressaltar que o modelo Newave é utilizado na formação dos preços de curto prazo (PLD) publicados na CCEE.

Os PLDs foram simulados (2.000 séries) para o horizonte do contrato a partir do modelo Newave. Foram utilizados os dados de entrada empregados no programa mensal de operação de fevereiro/2004 coordenado pelo ONS. Foram considerados um piso de preço de 17,60 R$/MWh e um teto de 534,30 R$/MWh regulados pela ANEEL a partir da audiência pública AP046/2003.

A grande diferença entre o piso de 17,60 R$/MWh e o teto de 534,30 R$/MWh é explicada pelas condições de operação de um sistema hidrotérmico. Quando há água armazenada em excesso, o preço da energia é quase nulo. Para garantir uma receita mínima aos geradores ou outros agentes que têm sobra de energia, a ANEEL estabelece o piso. Em momentos quando o nível médio dos reservatórios de água está muito baixo e há chuvas muito abaixo da média, necessita-se contar com a geração de termelétricas com custos variáveis de operação da ordem de 400 a 500 R$/MWh (termelétricas à óleo diesel). O teto é estabelecido a fim de se garantir a operação de praticamente todas as termelétricas.

Na próxima seção, realiza-se um exemplo numérico de cálculo das flexibilidades embutidas, apresentando-se os resultados de diversas análises de sensibilidade para a obtenção do valor das opções.

Exemplo Numérico

Características do Contrato Estudado (Caso Base)

Será estudado um contrato sendo negociado em fevereiro/2004 (t=0) com as seguintes características:

Ponto de Entrega: Centro de Gravidade do Submercado Sudeste/Centro-oeste;

Duração: Julho/2007 (t=i=5) a Dezembro/2008 (t=T=34);

Quantidade Nominal: 50 MWmed;

Preço: 90 R$/MWh;

Opção de Escolha da Quantidade: $\pm$10%;

Opção de Redução: Redução total nos meses de dezembro.

Ressalta-se que o contrato foi negociado em fevereiro/2004 nas condições do mercado naquele mês, no entanto, o início da entrega da energia ocorre em julho/2007. É comum no mercado livre de energia elétrica que empresas já negociem contratos cujo início de fornecimento ocorre alguns anos à frente.

Salienta-se também que para o caso base, a opção de escolha da quantidade terá uma flexibilidade de $\pm$10%. Ou seja, durante a análise de sensibilidade quando as demais variáveis forem alteradas, a flexibilidade se manterá em $\pm$10%. Há uma análise de sensibilidade na qual o valor da flexibilidade muda. Nesta análise, a flexibilidade máxima considerada será de $\pm$20%.

A variação máxima de $\pm$20% na opção de escolha da quantidade foi definida com base nas condições de mercado para este tipo de flexibilidade. Para justificar a escolha da variação máxima, foi feita a seguinte pergunta consultando-se a carteira de dois grandes agentes do mercado de energia: Qual é a flexibilidade máxima passível de exercício em todos os meses contratuais considerando toda a sua carteira de contratos de compra ou de venda?

Para o caso base, foi considerada uma taxa de desconto real ajustada ao risco de 8% ao ano, podendo variar entre 5 e 15% ao ano na análise de sensibilidade.

Simulação dos PLDs

Considerando os preços simulados, o gráfico a seguir apresenta os valores médios mensais, assim como alguns percentis variando de 10 a 90%. Comparando-se estes valores, observa-se que as distribuições de densidade de probabilidade mensais são bastante assimétricas atribuindo probabilidades mais altas a intervalos de preços menores. As médias mensais são substancialmente superiores à mediana durante todo o tempo.

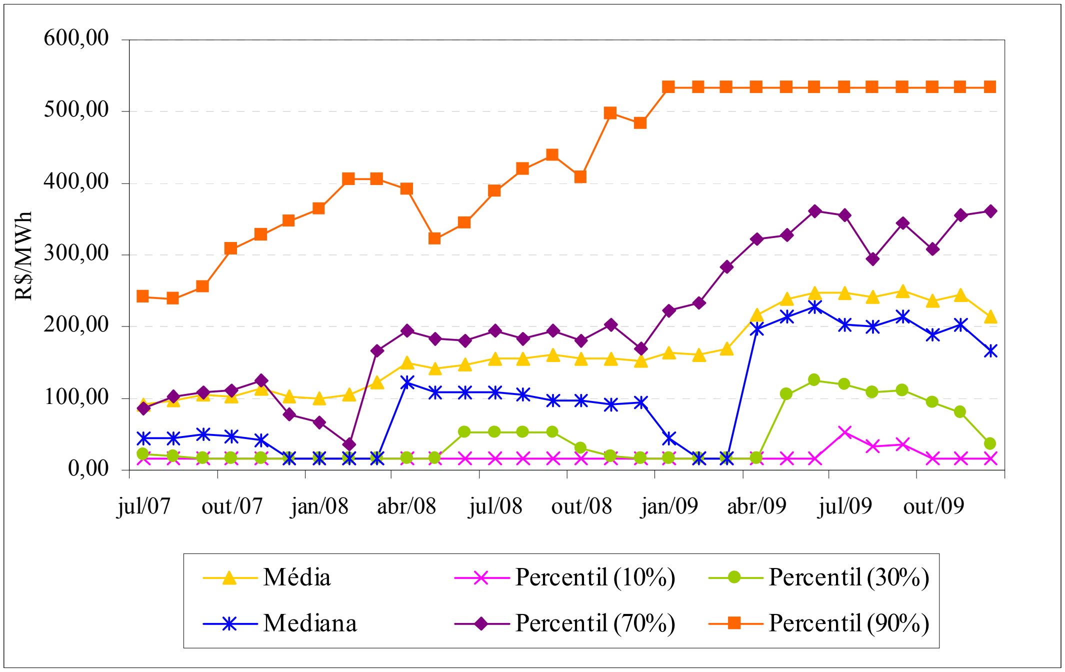



Figura 5 – Evolução de Algumas Estatísticas Mensais

Complementando a figura anterior, o gráfico a seguir apresenta distribuições de probabilidade mês a mês para quatro intervalos de preços. Observa-se grande probabilidade de preços baixos. A probabilidade dos preços estarem entre o piso e 20 R$/MWh é de aproximadamente 25% na média do período, e dos preços estarem abaixo de 50 R$/MWh encontra-se em torno de 50% na média do período.

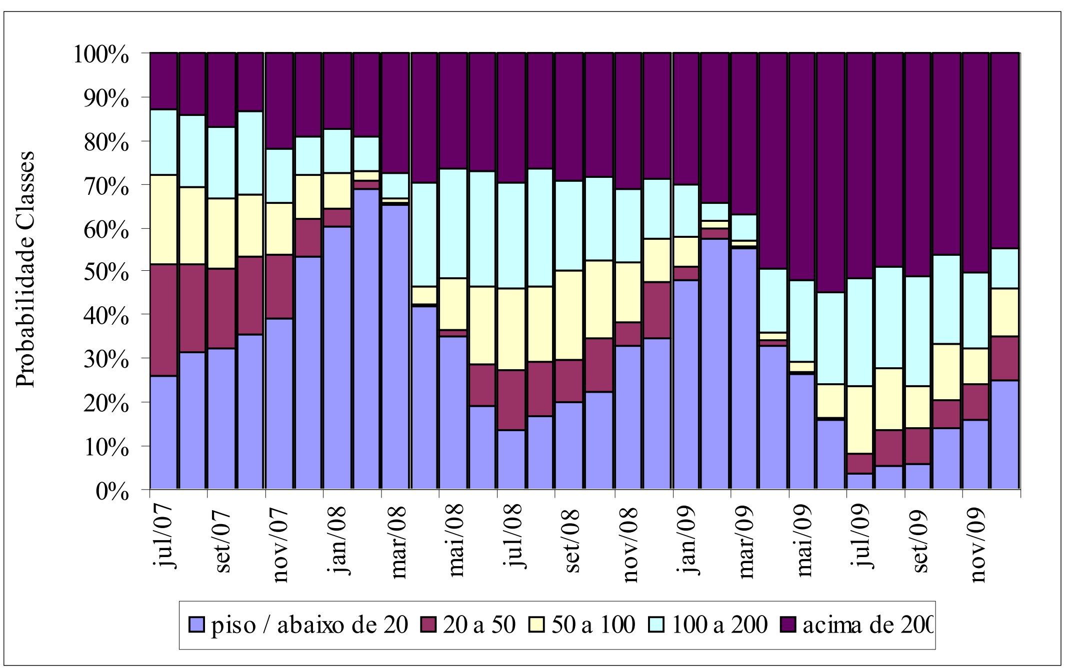


Figura 6 – Distribuições de Probabilidade Mensais (Preços em R$/MWh)

Análise de Sensibilidade e Resultados

Cada opção será analisada separadamente em relação a algumas variáveis. Para facilitar comparações dos valores das opções com os preços contratados, os valores serão calculados em R$/MWh obtidos pela divisão dos valores originais das opções em R$ pela quantidade de energia nominalmente contratada em MWh. Será obtido também o valor conjunto das opções, pois nem sempre o valor conjunto das opções é igual à soma dos valores individuais de cada uma delas (Trigeorgis, 1993). Isto será verificado neste trabalho.

Foram feitas análises de sensibilidade em relação ao tamanho da flexibilidade, ao preço contratado, e à taxa real de desconto. Em cada análise de sensibilidade, as premissas do caso base são mantidas excetuando-se a variável que está sendo analisada.

Análise de Sensibilidade: Valor da Opção de Escolha da Quantidade

Começando pela opção de escolha da quantidade, observa-se pela Figura 7 que seu valor total sobe até em torno de 23,15 R$/MWh (corresponde a mais que 25% do preço contratado) para uma flexibilidade de $\pm$20%. O ganho de valor a cada $\pm$1 % de flexibilidade adicional é de 1,16 R$/MWh. Observa-se também que o valor das opções de venda é superior ao valor das opções de compra. Isto ocorre devido aos preços simulados apresentarem probabilidade bem maior de ficarem perto do piso e bem abaixo do preço de contrato.

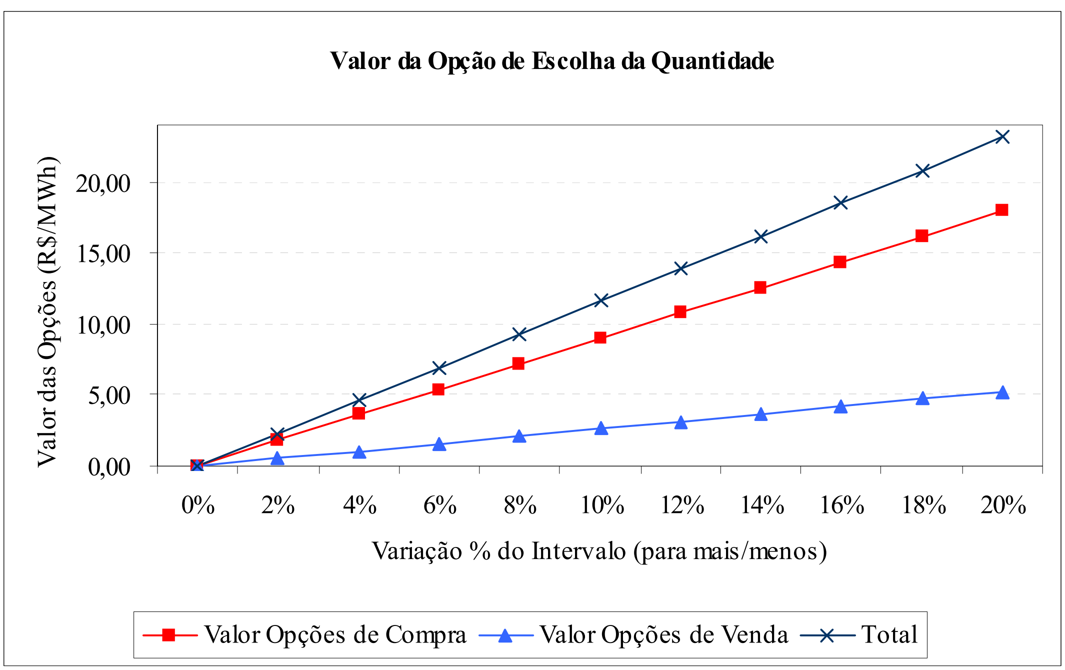


Figura 7 – Valor da Opção de Escolha da Quantidade x Flexibilidade (%)

Em relação ao preço contratado, observa-se pela Figura 8 que o valor total da opção encontra-se em torno de 11,50 R$/MWh quase não variando para preços contratados de 80 a 100 R$/MWh. Observa-se também que, aumentando-se o preço contratado (preço de exercício) o valor das opções de compra decresce a uma taxa maior que a taxa de crescimento do valor das opções de venda. Ressalta-se que a linearidade ocorre porque a sensibilidade é feita sobre o preço de exercício. É amplamente conhecido que o valor de opções varia de forma não linear quando calculado em função do preço do ativo objeto (aqui os PLDs).

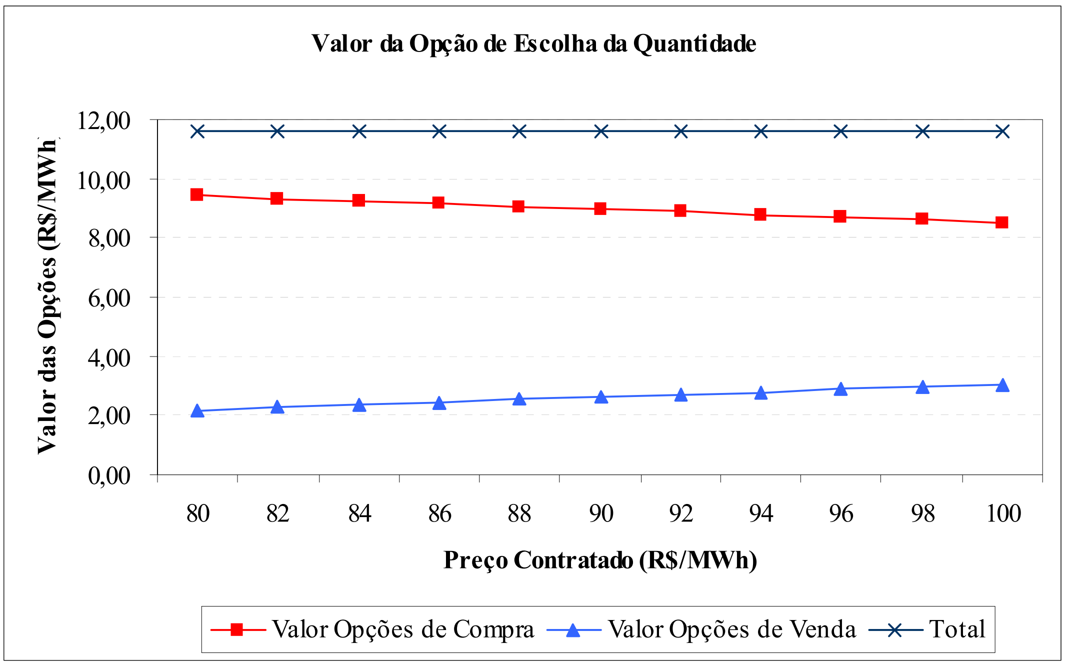



Figura 8 – Valor da Opção de Escolha da Quantidade x Preço Contratado

Em relação à taxa de desconto ajustada ao risco, observa-se pela Figura 9 que se segue que o valor total da opção varia entre 12,17 e 10,37 R$/MWh para taxas de desconto entre 5 e 15% respectivamente. Portanto, apesar de não se conhecer com precisão a taxa de desconto, sabe-se que o valor da opção de escolha da quantidade varia pouco com as taxas de desconto comparando-se com as sensibilidades em relação às outras variáveis estudadas, principalmente em relação à flexibilidade.

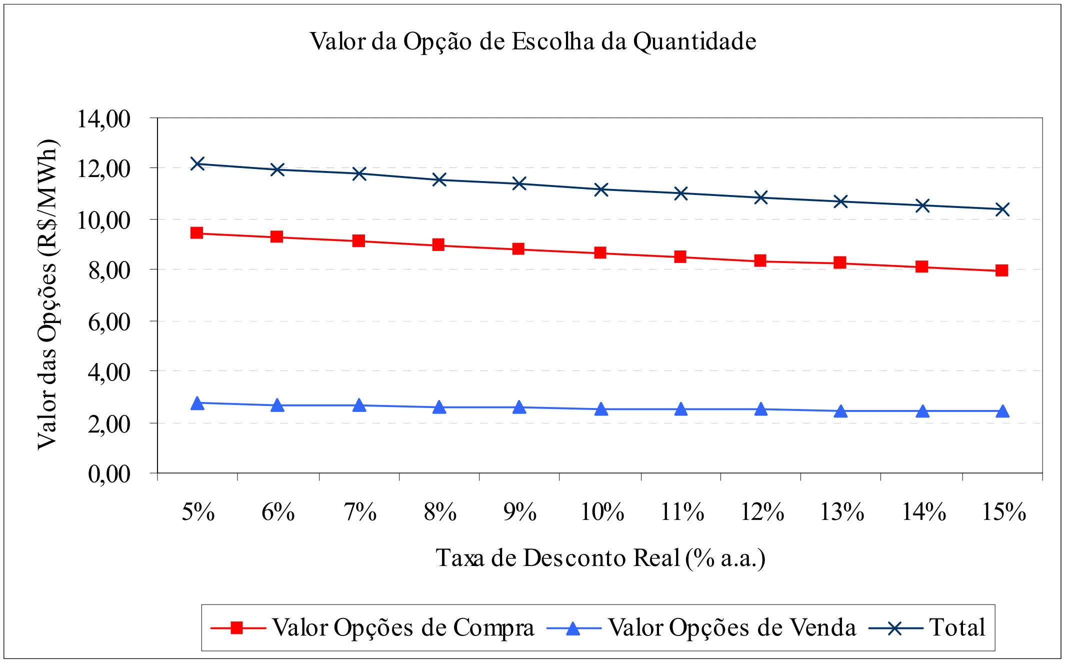



Figura 9 – Valor da Opção de Escolha da Quantidade x Taxa de Desconto Ajustada ao Risco

Análise de Sensibilidade: Valor da Opção de Redução

Considerando, agora, a opção de redução, observa-se pela Figura 10 que seu valor varia entre em torno de 0,83 a 1,66 R$/MWh para reduções permitidas de 50 a 100%, ou seja, ficando abaixo de 2% do preço contratado de 90 R$/MWh para o caso base.

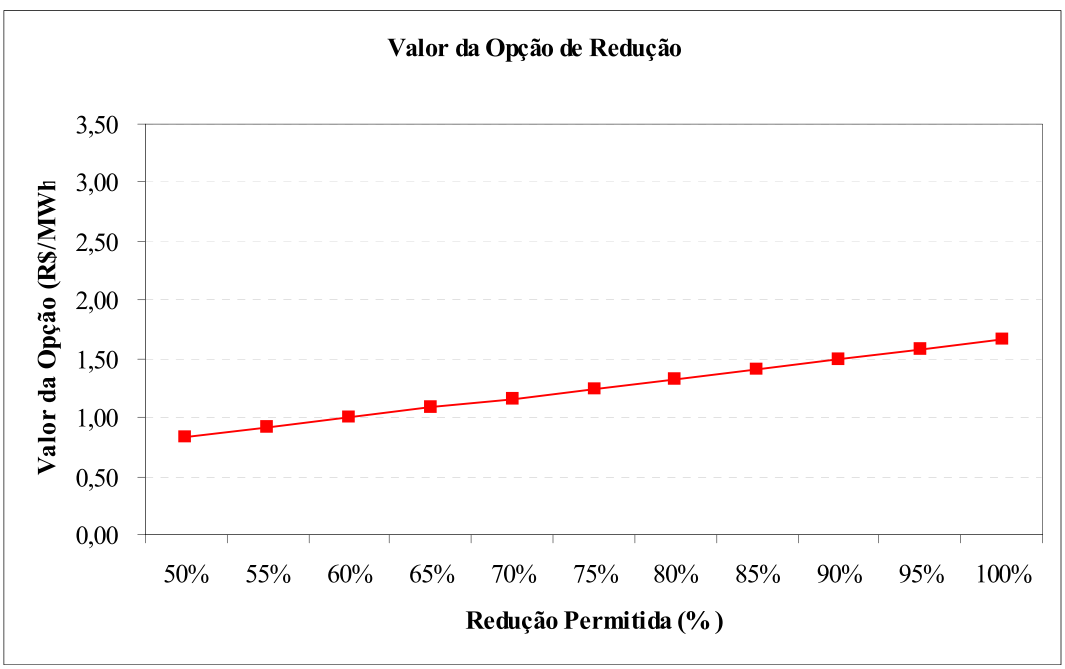


Figura 10 - Valor da Opção de Redução x Tamanho da Redução (%)

Fazendo uma sensibilidade em relação ao preço contratado, a Figura 11 mostra que o valor total da opção varia entre 2,63 e 3,63 R$/MWh para preços contratados de 80 a 100 R$/MWh. Como era de se esperar o valor da opção de venda aumenta com o preço de exercício.

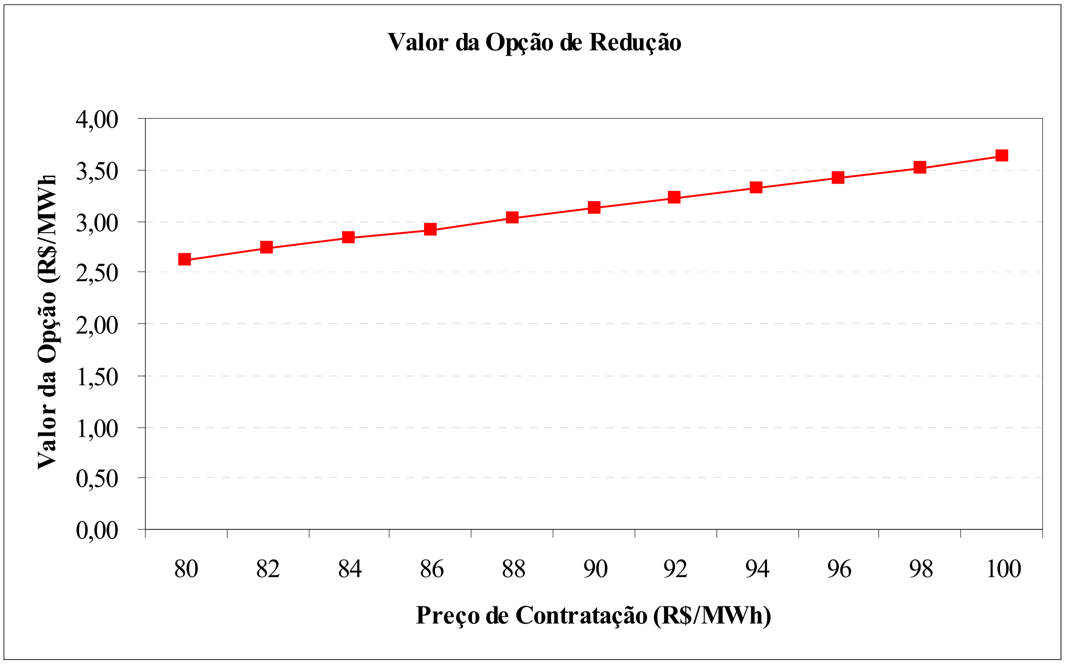



Figura 11 - Valor da Opção de Redução x Preço de Contratação

Em relação à taxa de desconto ajustada ao risco, observa-se pela Figura 12 que o valor total da opção varia entre em torno de 3,26 a 2,84 R$/MWh para taxas de desconto entre 5 e 15% respectivamente. Portanto, como citado anteriormente, apesar de não se conhecer com precisão a taxa de desconto, sabe-se que o valor da opção de redução varia pouco com as taxas de desconto comparando-se com as sensibilidades em relação às outras variáveis estudadas.

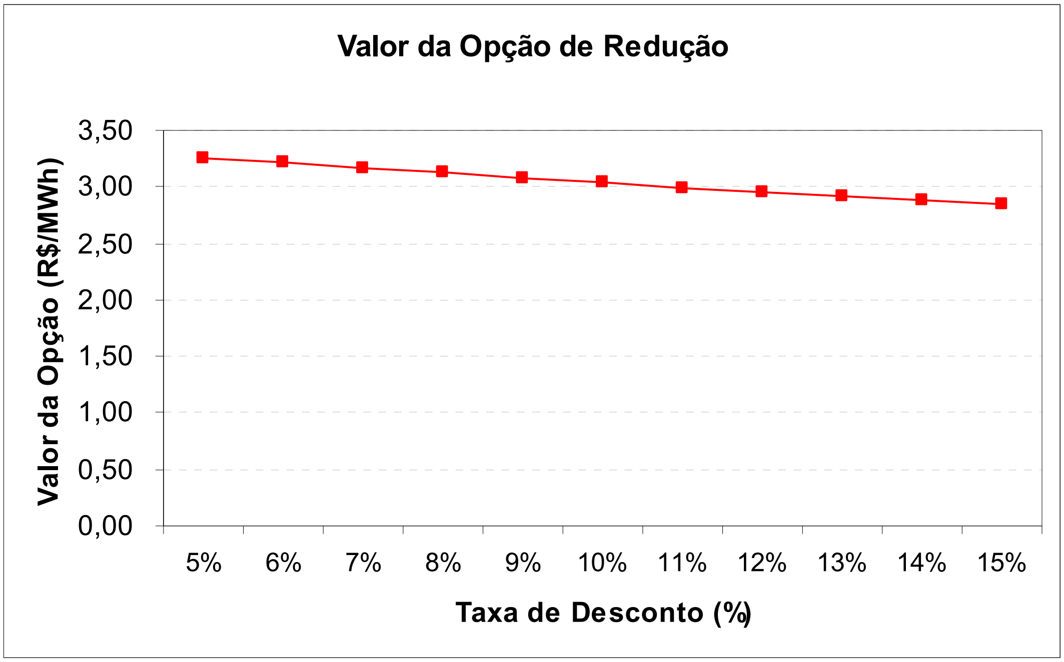



Figura 12 - Valor da Opção de Redução x Taxa de Desconto Ajustada ao Risco

Análise de Sensibilidade: Valor Conjunto das Opções

O valor conjunto das opções não é simplesmente o resultado da soma dos valores individuais. Isto ocorre porque, considerando ambas as opções no mesmo contrato, há uma superposição de flexibilidades. Nos meses de exercício da opção de redução, como já existe uma flexibilidade de redução por parte da opção de escolha da quantidade, na verdade, o valor agregado pela opção de redução só pode ser associado à possibilidade de redução complementar gerada por esta opção. Por exemplo, seja a flexibilidade de escolha da quantidade de ± 10% e a flexibilidade de redução de 50%. Como já existe a possibilidade de redução de 10% na primeira opção, o valor adicionado pela segunda opção se refere à diferença, ou seja, 40%, e não aos 50% descritos no contrato. A Tabela 2 apresenta valores mostrando o efeito da interação entre as opções.

Tabela 2 – Valor Conjunto x Soma dos Valores Individuais das Opções

| Valor Individual da Opção de Escolha da Quantidade | | | | | | |
|---|---|---|---|---|---|---|
| Flexibilidade | 10% | | Valor da Opção | | 11,58 | R$/MWh |
| Valor Individual da Opção de Redução | | | | | | |
| Flexibilidade Redução (%) | 50% | 60% | 70% | 80% | 90% | 100% |
| Valor Opção (R$/MWh) | 0,83 | 1,00 | 1,16 | 1,33 | 1,49 | 1,66 |
| Soma Valores (R$/MWh) | 12,41 | 12,58 | 12,74 | 12,91 | 13,07 | 13,24 |
| Valor Conjunto (R$/MWh) | 11,53 | 11,70 | 11,86 | 12,03 | 12,19 | 12,36 |

| Valor Individual da Opção de Escolha da Quantidade | | | | | | |
|---|---|---|---|---|---|---|
| Flexibilidade | 20% | | Valor da Opção | | 23,15 | R$/MWh |
| Valor Individual da Opção de Redução | | | | | | |
| Flexibilidade Redução (%) | 50% | 60% | 70% | 80% | 90% | 100% |
| Valor Opção (R$/MWh) | 0,83 | 1,00 | 1,16 | 1,33 | 1,49 | 1,66 |
| Soma Valores (R$/MWh) | 23,98 | 24,15 | 24,31 | 24,48 | 24,64 | 24,81 |
| Valor Conjunto (R$/MWh) | 22,24 | 22,41 | 22,57 | 22,74 | 22,90 | 23,07 |

Verifica-se que o valor conjunto das opções quando a flexibilidade da opção de escolha da quantidade é de 10% é menor que a soma dos valores individuais das opções em 0,88 R$/MWh. Para um valor de flexibilidade da opção de escolha da quantidade de 20%, o valor conjunto das opções é 1,74 R$/MWh menor que a soma dos valores individuais. Observa-se que para os dois níveis de flexibilidade, a interferência de uma opção na outra é de uma redução de valor de aproximadamente 8% obtida pela divisão da redução do valor conjunto (0,88 R$/MWh - flexibilidade de 10%) pelo valor original da opção de escolha da quantidade (11,58 R$/MWh - flexibilidade de 10%).

O valor conjunto das opções pode chegar a 23,07 R$/MWh, o que corresponde aproximadamente a 25% do preço contratado de 90 R$/MWh.

Considerações Finais

Neste trabalho, a fim de se analisar uma questão prática que surge no mercado livre brasileiro de energia elétrica, integrou-se a teoria de finanças sobre opções com regras e especificidades do SEB. Foram avaliadas flexibilidades embutidas em contratos bilaterais.

Foram abordados dois tipos de flexibilidade embutida em contratos bilaterais. As flexibilidades, aqui chamadas de opção de escolha da quantidade e opção de redução, foram modeladas como opções de compra e de venda.

Os resultados obtidos indicaram que o valor conjunto das opções de escolha da quantidade e de redução pode ultrapassar 20% do valor do contrato. Este resultado pode ser bastante relevante em negociações de energia elétrica no mercado livre brasileiro.

O valor da opção de escolha da quantidade para uma flexibilidade de $\pm 20\%$ chega a valer 23,15 R$/MWh e corresponde, aproximadamente, a 25% do preço contratado. Considerando a opção de redução, seu valor variou entre 0,83 e 1,66 R$/MWh para reduções permitidas de 50 a 100%, ou seja, ficou abaixo de 2% do preço contratado de 90 R$/MWh.

Observou-se pelas análises de sensibilidade que o efeito da taxa de desconto no valor das opções é, consideravelmente, menor que o efeito da variação dos preços de contratação de energia e do tamanho das flexibilidades.

Foi possível verificar, também, que o valor conjunto das opções de escolha da quantidade e de redução é um pouco menor que a soma dos valores individuais das opções. A interferência de uma opção na outra é de uma redução de valor de aproximadamente 8%.

Como sugestão para trabalhos futuros, a pesquisa poderia avançar incluindo-se mais flexibilidades embutidas em contratos. Existem outras flexibilidades que podem ser estudadas, como a de escolha da sazonalização anual do contrato, no qual são permitidas variações mensais desde que a quantidade total anual de energia elétrica seja mantida. Outra flexibilidade é a opção extensão do contrato por um preço prédefinido. Pode-se analisar também a opção de cancelamento do contrato mediante o pagamento de uma multa e a opção de seção do contrato para uma terceira parte.

Adicionalmente, a metodologia desenvolvida neste artigo pode ser adaptada para avaliar flexibilidades operativas de termelétricas e hidrelétricas no contexto do SEB.

Como contribuição deste artigo para os agentes consumidores de energia elétrica, no Brasil, destaca-se que grandes empresas (consumidores livres) podem comprar energia elétrica no mercado livre obtendo descontos em relação às tarifas reguladas aplicadas pelas distribuidoras e poderão obter grande proveito das flexibilidades embutidas nos contratos negociados no mercado livre ao conhecerem seu valor.

Assim, as empresas poderão negociar contratos de forma mais consciente em relação ao valor das flexibilidades, a fim de reduzir seus custos de aquisição de energia, tornando-se mais competitivas nacional e mundialmente (principalmente as empresas eletro-intensivas).

Referências Bibliográficas

AMRAM M.; KULATILAKA N.: Real options: managing strategic investments in an uncertain world. Harvard Business School Press, 1999.

BLACK, F.; SCHOLES, M. The Valuation of option contracts and a test of market efficiency, Journal of Finance, p. 399-418, 1972.

COOPERS; LYBRAND. Projeto RE-SEB: relatório final. Ministério de Minas e Energia Disponível em: http://www.mme.gov.br . Acesso em: dez. 1997.

DENG S.; JOHNSON B.; SOGOMONIAN A: Exotic electricity options and the valuation of electricity generation and transmission. In: Proceedings of the Chicago Risk Management Conference, may 1998.

DIXIT, A. K.; PINDYCK R. S. Investment under uncertainty. Princeton: Princeton University Press, 1994.

ETHIER R. G.: Valuing electricity assets in deregulated markets: a real options model with mean reversion and jumps, Working Paper, Department of Agricultural, Resource, and Managerial Economics, Cornell University, February 1999.

GAUTHIER, L.; ROUZEAU E.: New approaches to corporate forex exposure. Economic & Financial Computing, winter 1997.

GERSZKE, K.; KOPCA U.; TOCHTERMANN T. C. A.: Black-Scholes Meets Seinfeld, The Mckinsey Quarterly Journal, n. 2, 2000.

HULL, J. C. Options, futures and other derivatives. 5 ed. New Jersey: Prentice Hall, 2003.

KULATILAKA N.; BALASUBRAMANIAN P.; STORCK J., Using real options to frame it investment problem. Real Options and Business Strategy Applications to Decision-Making, Risk Publications, 1999.

JOHNSON B.; NAGALI V.; ROMINE B. R.: Real options theory and the valuation of generating assets: a discussion for senior managers. The New Power Markets: Corporate Strategies for Risk and Reward, Risk Books, 1999.

MACEIRA, M. E. P. ; BEZERRA C. V.. Stochastic stream flow model for hydroelectric systems. In: Proceedings of PMAPS, 1997.

______. et al. Application of the NEWAVE model in the energy evaluation of the Brazilian north/northeast and south/southeast interconnected systems. In: Symposium of Specialists in Electric Operational and Expansion Planning, VI. Anais… Salvador, Brazil, May24th to 29 th, 1998.

PEREIRA M. V. F.; PINTO L. M. V. G.. Multi-stage stochastic optimization applied to energy planning. Mathematical Programming, 52, 1991.

PILIPOVIC, Dragana. Energy Risk: valuing and managing energy derivatives. New York: McGraw-Hill, 1997.

SCHWARTZ E. S.; MOON M. Rational pricing of internet companies, Financial Analysts Journal, May/June, 2000.

TRIGEORGIS, L. The Nature of option interactions and the valuation of investments with multiple real options. Journal of Financial and Quantitative Analysis, 28-1, 1993.

______. Evaluating leases with complex operating options, European Journal of Operational Research, 75-1, 1996.

______. Real options, managerial flexibility and strategy in resources allocation. Cambridge, Massachussets: MIT Press, 1996.

TSENG C.; BARZ G.: Short-term generation asset valuation, PSERC, 1997.

WINSEN J. K.: Real options and the valuation of generation assets: an Australian national electricity market example. The New Power Markets: Corporate Strategies for Risk and Reward, Risk Books, 1999.

# 31. The role of global LNG markets in securing South America's natural gas supply

**Yris Olaya Morales*, Arturo Vasquez Cordano**, Carol Dahl****

*Universidad Nacional de Colombia **Colorado School of Mines

Yris Olaya Morales

Cra. 80 No. 65-223

Facultad de Minas

Universidad Nacional de Colombia

Medellín, Colombia

(574) 4255352, fax (574) 2341002

yolayam@unal.edu.co

LNG market, South America, natural gas

Abstract:

The EIA expects consumption of natural gas in South America to grow above 5% per year between 2010 and 2015 (EIA, 2008). During the 1990s, regional integration was considered the best solution to meet this gas demand growth, but the political and supply disruptions of the 2000s have changed this position.

Liquefied natural gas (LNG) is now seen as an attractive option for increasing gas supply reliability and developing natural gas resources in South America. For example, instead of increasing their pipeline imports, Argentina and Brazil imported their first LNG cargoes in 2008 and Chile expects to begin LNG imports in 2010. Producing countries also look to other markets as the construction of liquefaction plants in Peru and Brazil progresses. Unlike pipeline gas, LNG is not necessarily linked to an exclusive supplier or destination, thus allowing diversification of risk. LNG, however, is a capital-intensive industry and given the changing conditions of world gas markets, it is important that importers and exporters in South America understand the competitive forces operating in global LNG markets.

Our question is from where and at what prices can LNG be supplied to South America? This question is relevant because LNG is traded in global markets with changing conditions. For example, during the Asian crisis, demand for LNG decreased, liberating liquefaction and transportation capacity. This excess capacity was behind the increase in short-term transactions and in contract flexibility observed during the early 2000s. LNG production capacity is now tight and growing more slowly than demand, which keeps prices high, and raises questions about the ability of the industry to expand into new markets.

To understand how competitive forces in global LNG markets affect the viability of regasification and liquefaction projects proposed and built in South America, we expand our research of LNG markets, by adding new terminals and nodes to a competitive spatial equilibrium model of Olaya (2006). The model finds the competitive flows and prices of LNG, and allows us to test how these flows and prices change under different cost and demand scenarios. In this way, we can evaluate how South American countries can compete for LNG supply and markets. The main contribution of this work is to increase the understanding of the influence of global markets in the energy security and development of South American gas markets.

JEL Classification: C61, D40, L71.

## Introduction

Despite having abundant reserves, and intra-national natural gas infrastructure, changes in economic and political conditions have prevented international gas trade in South America and, as a result, Chile, Brazil and Argentina are turning to LNG as a more reliable source of natural gas.

LNG trade expanded from less than 9% in 1990 to more than 20% of global gas trade in 2005. By 2003, liquefaction and transportation costs had decreased by more than 30% with respect to 1990s levels. This, along with the decline of European and North American gas reserves made many new LNG liquefaction and regasification projects competitive and six new countries started LNG imports between 1999 and 2005 (EIA, 2008).

The current outlook for the LNG market is not as optimistic as it was at the beginning of the 2000s. General construction costs and capital costs were more than 200% higher in 2007 than in 2003, and the strains in capital markets increased financing costs for many of the proposed new projects. Furthermore, the current economic crisis is likely to slow natural gas demand growth in the world, thus delaying the construction of new LNG exporting and importing facilities.

For the South American countries that have started, or plan to start importing LNG, the changing conditions in the global LNG market increase uncertainty of investment returns and supply reliability. To understand better how the changing conditions in global LNG markets affect market development and integration in South America, we ask where and at what prices can gas be imported.

To answer this question, we run a world LNG trade model developed by Olaya (2006). The first scenario is a 2010 scenario, with the currently built and expected new liquefaction capacity. This scenario represents the current conditions of supply because it is high-cost scenario. Then, we move to 2015, assuming costs return to previous 1990s levels and run the model again, this time adding the new plants we expected to be built and operating as of 2015. Finally, we expand the analysis to 2020, and assume all new proposed capacity has been built and it is operating. This is our long-term scenario, which intends to examine the market opportunities and competitive forces.

Before discussing the results and the model, in section 2, we discuss natural gas markets structure and trade in South America. In section 3 we describe the current operation of LNG markets and the possibilities for developing LNG projects in South American countries. Then, in sections 4 and 5 we briefly describe the model assumptions and data, while the model results are shown in Section 6. Finally, we present our conclusions in section 7.

## Natural gas markets and trade in South America

Total natural gas reserves in South American and Caribbean countries are relatively small compared to the global gas reserves. Together, South American countries have only 4.4% of the global proven natural gas reserves (BP, 2008). Nonetheless, as seen in Table 4, natural gas reserves in South America and the Caribbean are relatively abundant with respect to the regional consumption level. This, along with the production surpluses and deficits in different countries, indicates that market integration is a feasible alternative to satisfy growing demand for natural gas in the continent.

Table 4. 2007 Natural gas proven reserves, production and consumption in South American and Caribbean countries. Source: BP, 2008

| | 2007 | | | |
|---|---|---|---|---|
| | Reserves | Production | Consumption | Deficit / Surplus |
| Country | $10^9$ $m^3$ | $10^9$ $m^3$ | $10^9$ $m^3$ | $10^9$ $m^3$ |
| Argentina | 440 | 44.8 | 44.1 | +0.7 |
| Bolivia | 740 | 13.5 | | +10.5 |
| Brazil | 365 | 11.3 | 22.0 | -10.7 |
| Chile | | | 4.4 | -4.4 |
| Colombia | 125 | 7.7 | 7.7 | 0.0 |

| | | | | |
|---|---|---|---|---|
| Perú | 355 | 6.6 | 2.7 | +3.9 |
| Trinidad and Tobago | 480 | 39.0 | 28.5 | +10.5 |
| Venezuela | 5150 | 28.5 | 24.9 | +3.6 |

Source: British Petroleum (2008), Ministry of Energy and Mines – Peru, U.S. EIA.

Several pipelines already connect Argentina, Bolivia, Brazil and Chile, and a pipeline to connect Peru and Bolivia has been proposed. Interconnection of the Andean and Caribbean markets started with the construction of a pipeline connecting Venezuela and Colombia, which is expected to start operating by 2012. In addition, there are plans to build pipelines connecting Colombia and Ecuador, further advancing Andean energy integration. The southern cone markets and the Andean markets are not connected, and the long-delayed plans for building gas liquefaction facilities in Venezuela have not passed the planning stage.

The main pipeline flows in the continent are from Bolivia to Brazil and from Bolivia to Argentina (see Table 5). Exports from Bolivia, however, have suffered interruptions after Bolivia nationalized its hydrocarbons sector in 2006. Supply disruptions in Bolivia and in the depletion of Argentina's gas reserves reduced gas exports from Bolivia to Brazil and from Argentina to Chile during 2007. Although the supply disruptions discussed before had external causes, it is expected that the gap between supply and demand in countries such as Argentina and Chile continues increasing.

In the last years, there have been no significant reserves additions in Argentina and reserves discovered in Brazil in 2007 and 2008 are yet to be developed. The natural gas deficit in the southern cone is widening because investment to develop Bolivian reserves has not been adequate, while gas demand in Chile and Brazil continues growing. In the short term, therefore, it is unlikely that Bolivian gas production fills regional gas deficits. At the same time, production from the Camisea field in Perú is destined to liquefaction, and it is already contracted for exporting to Mexico (Garcia and Vasquez 2004).

To secure supply, the southern cone countries are looking for alternative gas sources. Chile expects to complete its first regasification terminal in 2009-10 to import gas from diverse sources. Argentina imported its first LNG cargo in 2008 using a dockside facility, and Brazil is following a similar strategy, and looking at Nigeria as the least-cost source (Santana et al., 2009).

LNG imports to South America face challenges related to the structure of the regional gas markets, the inflexibility of LNG markets, and the magnitude and duration of LNG investments.

The use of LNG for thermal power generation illustrates these challenges. As discussed by Barroso et al. (2005), the variability of hydro power generation in South America (which is caused by fluctuation in the hydrological cycles of the Andes) increases generation costs for the integrated LNG importers because LNG prices are higher for short-term orders.

Table 5. 2007 pipeline and maritime trade of natural gas in South America and the Caribbean

| 2007 Pipeline trade, $10^9$ cu.m | | | |
|---|---|---|---|
| | From: | | |
| To: | Bolivia | Others (L.A) | Trinidad and Tobago |
| Argentina | 1.85 | | - |
| Brazil | 9.88 | 0.12 | - |
| Chile | - | 2.38 | - |
| Others | - | 0.19 | - |
| 2007 LNG trade, $10^9$ cu.m | | | |
| Dominican Republic | - | - | 0.36 |
| Puerto Rico | - | - | 0.74 |

Source: Statistical review of World Energy (BP, 2008)

Argentina has the most advanced natural gas market of the region. Natural gas provides more than 40% of the total energy output in Argentina; this is the highest share of natural gas in the region. In Chile, natural gas share is only 7%, whereas in Brazil this share is around 9.4%. Residential sectors are the main consumers in Argentina, whereas in Chile and Brazil natural gas is mainly used for thermal generation. Natural gas in Brazil is also consumed in the transportation sector.

Brazil imports natural gas from Bolivia and Argentina because its domestic production does not satisfy demand. A pipeline built during the late 1990s transports the gas from Bolivia; this pipeline transported 24 million $m^3$ per day in 2006. Imports from Argentina are destined to the thermal generation sector and amounted 960000$m^3$/day in 2005 (ANP, 2006). After nationalization of the hydrocarbons industry in Bolivia, natural gas supply from Bolivia became uncertain, prompting Brazil to start the construction of two LNG import terminals in order to diversify its natural gas supply sources.

LNG market

Almost 30% of world gas consumption is traded internationally. About 1/3 of this international trade is LNG. LNG's share has been increasingly driven by tight natural gas markets and declining transportation and liquefaction costs.

High natural gas prices, high oil prices, environmental concerns, and desires for energy supply diversification have spurred increases in production and consumption of LNG worldwide. In 2003, nine liquefaction plants, with a total capacity of 37.9 million tons of LNG per year (tpy) (Drewry Shipping Consultants, 2003) were under construction; all of these plants were operating in 2007.

Liquefaction projects already under construction could add more than 48 million tons per year (tpy) to the current liquefaction capacity (158 million tpy) by 2010. At the same time, new regasification terminals are being built in Asia, Europe, North and South

America. Entry of new importers and exporters increases competition, changing market dynamics and the distribution of LNG flows and prices around the world.

In 2003, thirteen countries imported LNG; by 2007 this number had increased to 17 (BP, 2008). Atlantic markets (Europe and the U.S.) and Pacific markets (currently the East Asian countries of Japan, Korea and Taiwan) are the main destinations of LNG exports. The Atlantic and Pacific LNG markets differ in their dependence on LNG imports. Whereas LNG is almost the only source of natural gas for East Asian countries, European countries import pipeline gas from Norway, the Netherlands, Algeria and Russia, whereas the U.S. imports pipeline gas from Canada (DOE-EIA, 2004).

Twelve countries supplied LNG in 2003, with Indonesia and Malaysia accounting for nearly 40% of production (BP, 2004). By 2007, the number of suppliers had increased to 15 and the market share of Indonesia and Malaysia had decreased to 25% of global LNG exports (BP, 2008). Although the proximity of these two main producers to East Asia has offset their higher gas costs, lower transportation costs have allowed suppliers from West Africa, South America and the Middle East to increase their market share in all markets (Drewry Shipping Consultants, 2003).

The LNG industry is capital intensive and developing new liquefaction and regasification projects requires long-term planning and coordination between the host country and the exporting country. Historically, high transport costs encouraged LNG trade only in regional markets (Atlantic or Pacific), predominantly through bilateral long-term transactions, and LNG prices have been lower in the Atlantic than in the Pacific markets. To reduce the risk of investment and to secure financing in these markets, LNG exporters and importers signed long-term take-or-pay contracts which frequently prevented reselling and redirecting LNG cargoes. Consequently, arbitrage was limited.

The above model for LNG supply is changing. Now, nearly 9% of LNG is traded on the spot market. Excess transportation and liquefaction capacity and growth of world natural gas demand have promoted this increase in flexibility of LNG contracts and greater arbitrage. Although long-term contracts are likely to prevail, the increasing number of suppliers and higher market integration are likely to strengthen market forces and flexibility (Jensen, 2003).

Outlook for the LNG market

According to Jensen (Jensen, 2008), LNG demand growth in North America, the U.K, and Spain has been rapid, and the response of LNG supply to this growth has been slow. Expectations for demand growth along with tight capital markets, have contributed to increase costs and delay construction in many of the liquefaction and import projects currently under consideration. The outlook for the LNG market is then uncertain, and could greatly change depending on the supply and demand balance in the world gas market (Jensen, 2008).

Uncertainty in the LNG market is increased by the raise in energy prices observed from 2007 to 2008. The current financial crisis, along with geopolitical issues in exporting countries such as Bolivia, Venezuela, Nigeria, Iran and Russia also increase uncertainty in the LNG market.

Given the structure of natural gas markets, South American countries need a better understanding of their position in the global LNG market. As seen in the table, only Trinidad and Tobago exports natural gas to other continents while the other South American countries use their natural gas reserves in their domestic markets. Despite many proposals for energy integration policies, international trade in South America amounts to only 10% of the regional gas consumption (BP, 2008).

Table 6 shows some of the proposed import and export LNG projects in South America. The only liquefaction project already under construction is Camisea, in Peru, which will supply the import terminal of Baja California, México. As for the import plans, Chile expects to complete its first LNG terminal in 2009-10; supply for this terminal has been contracted with British Gas and will come from several Atlantic LNG sources.

Table 6. Planned LNG infrastructure in South America

| Name | Type | Capacity, million LNG ton per year: | Stage | Start year | PARTNERS |
|---|---|---|---|---|---|
| ARGENTINA | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Bahia Blanca GasPort | Dockside LNG Terminal | 2.1 | Operating | 2008 | Excelerate, YPF |
| Bahia Blanca | | | Proposed | | Enarsa, PDVSA |
| BRAZIL | | | | | |
| Pecem | Regasification vessel | 1.9 | Under Const. | 2009 | TAG |
| Guanabara Bay, Rio | Regasification vessel | 3.8 | Under Const. | 2009 | |
| CHILE | | | | | |
| Mejillones | LNG Terminal | 1.5 | Planning | 2011 | Suez Energy International, Codelco |
| GNL Quintero SA. | LNG Terminal | 2.5 | Planning | 2QTR 2009 | ENAP, Metrogas, BG Group plc, Endesa Chile |
| PERU | | | | | |
| Pampa Melchorita | LNG | 4.4 | Under Const. | 2010 | Hunt Oil, Repsol, SK CORP. |
| VENEZUELA | | | | | |
| Gran Mariscal de Ayacucho, Sucre | LNG | 4.7 | Planning | 2010 | --- |
| José Anzoátegui | LNG | 2.1 | Planning | -- | |

Sources: Oil and Gas Journal Worldwide Construction Update, 2008. Oil and Gas Journal, Mar 24, 2008.

If completed, the liquefaction plants in Venezuela would be a viable alternative to connect the Southern Cone markets with the Andean-Caribbean markets, increasing regional integration and diversifying natural gas supply.

In the next section (Section 4) we discuss our approach to modeling global LNG trade. Because uncertainty in the LNG market is high, the model explained in Section 4 finds flows and prices that indicate market forces and opportunities, and that should not be understood as forecasts.

## Modeling global LNG trade

The results and analysis in this paper are based on an update of a global LNG market model developed by Olaya (2006). This is a spatial price model that finds competitive equilibrium prices and quantities for the LNG market supply and demand nodes. The spatial price model for the LNG market differs from other models of world natural gas markets in that it is publicly accessible, modular and easily expandable. Besides increasing the understanding of the competitive forces in the world LNG market, Olaya's model indicates possible flows and suppliers.

A complete description of the model we use in this paper is found in (Olaya, Dahl and Newman, 2008). In the spatial price model for the LNG market, *S* profit-maximizing suppliers compete in *M* regional markets. Demand at each market is represented as a function of price with inverse demand function $P^M_m(X^M_m)$ where price for market *m* is a function of consumption ($X^M_m$). The cost function of each supplier *s*, $C_s(X^S_s)$, depends on supplier *s*'s wellhead price of gas ($P^S_s$) and on its production level ($X^S_s$).

Total costs for each supplier *s* depend on its production level ($X^S_s$) and on *s*'s wellhead price of gas ($P^S_s$) and liquefaction costs. Liquefaction costs for supplier *s* depend on operating costs for

existing trains and operating plus capital costs for new trains. $H_s$ is the number of trains for supplier *s*. The levelized capital cost per unit of LNG for train *h* of supplier *s* is $CL^K_{sh}$ and the operating cost per unit of LNG for train *h* of supplier *s* is $CL^{O}_{sh}$. Total gas liquefied for supplier *s* ($X^{S}_{s}$) is the sum of the gas liquefied in all trains for supplier *s*: $\sum_{h \in H_s} x_{sh}$.

Unit transport costs for existing ships include only operating costs, which are $CT^{O}_{sml}$ per unit between supplier *s* and regasification plants *l* at market *m*. Transport costs for new ships include operating and levelized capital cost ($CT^{K}_{sml}$) per unit between supplier *s* and regasification plant *l* at market *m*. Shipments of the liquefied gas from supplier *s* to plant *l* at market *m* are $x_{sml}$. Contracted shipments from supplier *s* to consumer *m* are represented as $x^{C}_{sm}$. Since most contracts seem to be CIF (cost, insurance and freight), these amounts are modeled as delivery amounts. LNG is liquefied, shipped in tankers and regasified at the end market. Since regasification is the lowest cost component of the supply chain, one unit cost (*CR*) per unit regasified.

The spatial competitive problem can be formulated as a maximization of ``social welfare'' which is the area under the demand curve minus transport and supply costs summed over all markets (Takayama, 1946). Using the notation above, the non linear problem is:

$$
\begin{aligned}
\max \sum_{m \in M} \int_{0}^{X^{M}_{m}} P^{M}_{m}(u)du - \sum_{s \in S} P^{S}_{s} X^{S}_{s} - \sum_{s \in S} \sum_{h \in H_S} (CL^{K}_{sh} + CL^{O}_{sh}) x_{sh} \\
- \sum_{m \in M} \sum_{l \in L_m} \sum_{s \in S} (CT^{K}_{sml} + CT^{O}_{sml}) x_{sml} - CR \sum_{m \in M} X^{M}_{m} \qquad (1)
\end{aligned}
$$

The function above is maximized, subject to liquefaction and import capacity constraints, as well as to flow-balance constraints, and contracts. The complete formulation can be found in (Olaya et al., 2008). The spatial price equilibrium problem is formulated as a non-linear program in AMPL 9.1 and solved with MINOS 5.5, using the cost and demand functions we describe in the following section and in Olaya, Dahl and Newman (2008).

Model inputs and data

Model inputs are developed from a wide variety of sources. For this paper, we expand the data set of Olaya et al. (2008), to include the new liquefaction and regasification projects that have been recently proposed. We use the same approach described in Olaya et al. (2008) to calculate costs based on investment and operating cost data from industry and academic sources, while we estimate demand function parameters based on estimates of natural gas demand elasticities and normalizing around LNG price and consumption.

We divide costs into liquefaction, transportation and regasification. Liquefaction and transportation costs are the largest components of total LNG cost (between 70 and 90% of the total); thus, their estimations are more detailed than the regasification cost estimation. We categorize total costs into operating and capital. We use operating costs to model trade with existing capital whereas total costs are needed for modeling new capital equipment.

We levelize capital costs to be the constant LNG price that would pay for all equity and debt over a 20 year period including taxes, operation and maintenance costs, and depreciation for each LNG train h for supplier s ($CL^K$). We update our capital expenditures (in constant 2003 dollars) reported by Greaker and Sagen (2004) with data from Oil and Gas Journal Construction Issues, LNG Observer and other industry news sources, to include capital costs for potential projects to be built between 2003 and 2015. We calculate unit operating costs ($CL^O$) in conjunction with levelized costs. A complete description of the procedure for calculating levelized and operating liquefaction and transportation costs is found in (Olaya et al., 2008).

Our demand projections are based on the annual energy outlook published by EIA (EIA, 2008). In its 2008 forecast, the EIA has reduced demand projections as well as the share of international trade in gas supply, thus reflecting the supply-side constraints observed during the 2000s.
Recent forecasts from the IEA show a similar trend to decrease gas demand forecasts and participation of international trade (Jensen, 2008). Table 7 shows the forecast for LNG demand reported by Jensen (2007), and which is based on EIA forecast.

Table 7. World LNG demand projections

| | $10^6$ $m^3$ per day | | | |
|---|---|---|---|---|
| | Actual | Base case | Base case | Base case |
| | 2005 | 2010 | 2015 | 2020 |
| Northeast Asia | 319 | 434 | 489 | 534 |
| China | 0 | 39 | 53 | 69 |
| India | 16 | 22 | 29 | 40 |
| Other | 0 | 3 | 5 | 6 |
| North America Pacific | 0 | 23 | 66 | 73 |
| Latin America Pacific | 0 | 9 | 12 | 14 |
| Total Pacific Basin | 335 | 532 | 668 | 750 |
| OECD Europe | 130 | 168 | 229 | 305 |
| North America Atlantic | 51 | 140 | 232 | 287 |
| Latin America Atlantic | 1 | 4 | 22 | 24 |
| Total Atlantic Basin | 182 | 312 | 483 | 616 |
| Total World | 517 | 843 | 1151 | 1367 |

Source: Jensen Associates, 2007

Model assumptions 2010

We use the demand forecast in Table 7 as the base for adjusting the parameters of the linear demand functions of the import nodes of the market model. To center these demand functions, we keep prices at the 2007 levels, and shift the demand curves out using the demand projections in Table 8, and adjusting the demand projections for South America using data from OLADE and other government sources. Table 8 summarizes the prices and quantities used to calculate the parameters of the demand functions shown in Table 9.

Table 8. LNG demand projections

| | Imports, Million LNG ton per year | | | Price, 2007 US$/Million BTU | | |
|---|---|---|---|---|---|---|
| | 2010 | 2015 | 2020 | 2010 | 2015 | 2020 |
| Argentina | 0.20 | 2.30 | 3.10 | 12.00 | 10.00 | 9.00 |
| Belgium | 3.60 | 4.28 | 5.13 | 6.42 | 6.42 | 6.42 |
| Brazil | 1.70 | 5.50 | 5.50 | 9.00 | 9.00 | 9.00 |
| Canada | 3.85 | 9.00 | 15.00 | 9.00 | 9.00 | 9.00 |
| Chile | 1.70 | 3.40 | 5.00 | 9.00 | 9.00 | 9.00 |
| China | 7.00 | 14.00 | 20.00 | 8.14 | 8.14 | 8.14 |
| Dominican Republic | 0.47 | 0.49 | 0.63 | 7.42 | 7.42 | 7.42 |
| France | 11.30 | 13.42 | 16.07 | 6.42 | 6.42 | 6.42 |
| Greece | 0.62 | 0.74 | 0.88 | 6.42 | 6.42 | 6.42 |
| India | 10.00 | 14.00 | 15.00 | 8.14 | 8.14 | 8.14 |
| Italy | 6.32 | 7.50 | 8.98 | 6.42 | 6.42 | 6.42 |
| Japan | 72.00 | 79.00 | 85.60 | 7.85 | 7.85 | 7.85 |
| Mexico | 2.47 | 2.62 | 2.62 | 7.42 | 7.42 | 7.42 |
| Netherlands | 0.00 | 3.40 | 6.80 | 9.00 | 9.00 | 9.00 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Portugal | 2.98 | 7.94 | 11.34 | 4.85 | 4.85 | 4.85 |
| Puerto Rico | 1.16 | 1.22 | 1.55 | 7.42 | 7.42 | 7.42 |
| Singapore | 0.00 | 1.50 | 3.00 | 9.00 | 9.00 | 9.00 |
| South Korea | 30.23 | 35.67 | 42.81 | 8.90 | 8.90 | 8.90 |
| Spain | 21.48 | 25.51 | 30.55 | 6.61 | 6.61 | 6.61 |
| Taiwan | 10.68 | 13.17 | 16.57 | 8.14 | 8.14 | 8.14 |
| Thailand | 0.00 | 0.65 | 1.30 | 9.00 | 9.00 | 9.00 |
| Turkey | 7.13 | 8.46 | 10.14 | 6.42 | 6.42 | 6.42 |
| U.K. | 13.98 | 16.60 | 19.88 | 6.05 | 6.05 | 6.05 |
| U.S.A. | 10.00 | 26.70 | 29.64 | 7.07 | 7.07 | 7.07 |

Sources: EIA(2008), BP(2008)

As can be seen in Table 8 below, we define 2010, 2015 and 2020 as the analysis years. These years correspond to the forecasts by EIA and other agencies and are the basis for creating possible scenarios for the evolution of LNG markets. We discuss such scenarios, and the model results in Section 6.

Table 9. Import capacity and parameters of the LNG demand functions: P = a - bQ

| | | Inverse demand functions P=a - b*Q, US$/$10^7$ million LNG ton per year | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 2010 | | | 2015 | | | 2020 | | |
| | Elasticity | a | b | Import capacity, Million LNG Ton per year | a | b | Import capacity, Million LNG Ton per year | a | b | Import capacity, Million LNG Ton per year |
| Argentina | -0.6 | 165.80 | 518.13 | 2.30 | 138.17 | 37.55 | 2.30 | 124.35 | 25.07 | 3.10 |
| Belgium | -0.6 | 88.70 | 15.38 | 6.80 | 88.70 | 12.95 | 6.80 | 88.70 | 10.81 | 6.80 |
| Brazil | -0.6 | 124.35 | 45.72 | 5.50 | 124.35 | 14.13 | 5.20 | 124.35 | 14.13 | 5.20 |
| Canada | -0.6 | 124.35 | 20.19 | 5.67 | 124.35 | 8.64 | 9.50 | 124.35 | 5.18 | 17.00 |
| Chile | -0.6 | 124.35 | 45.72 | 1.89 | 124.35 | 22.86 | 4.31 | 124.35 | 15.54 | 8.00 |
| China | -0.6 | 112.47 | 10.04 | 9.68 | 112.47 | 5.02 | 21.32 | 112.47 | 3.51 | 21.32 |
| Dominican Republic | -0.6 | 102.57 | 136.31 | 2.04 | 102.57 | 129.82 | 2.04 | 102.57 | 101.72 | 2.04 |
| France | -0.6 | 88.70 | 4.91 | 17.20 | 88.70 | 4.13 | 17.20 | 88.70 | 3.45 | 17.20 |
| Greece | -0.6 | 88.70 | 89.28 | 3.40 | 88.70 | 75.19 | 3.40 | 88.70 | 62.77 | 3.40 |
| India | -0.6 | 112.47 | 7.03 | 16.33 | 112.47 | 5.02 | 12.93 | 112.47 | 4.69 | 12.93 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Italy | -0.6 | 88.70 | 8.78 | 8.85 | 88.70 | 7.39 | 23.28 | 88.70 | 6.17 | 23.28 |
| Japan | -0.6 | 108.44 | 0.94 | 199.43 | 108.44 | 0.86 | 199.44 | 108.44 | 0.79 | 199.44 |
| Mexico | -0.6 | 102.57 | 25.95 | 13.99 | 102.57 | 24.48 | 23.89 | 102.57 | 24.48 | 23.89 |
| Netherlands | -0.6 | n.a | n.a | n.a | 124.35 | 22.86 | 6.00 | 124.35 | 11.43 | 12.00 |
| Portugal | -0.6 | 67.01 | 14.05 | 3.10 | 67.01 | 5.27 | 6.40 | 67.01 | 3.69 | 6.40 |
| Puerto Rico | -0.6 | 102.57 | 55.26 | 2.00 | 102.57 | 52.63 | 1.20 | 102.57 | 41.24 | 1.20 |
| Singapore | -0.6 | n.a | n.a | n.a | 124.35 | 51.81 | 3.00 | 124.35 | 25.91 | 3.00 |
| South Korea | -0.6 | 122.92 | 2.54 | 44.07 | 122.92 | 2.15 | 44.07 | 122.92 | 1.79 | 44.07 |
| Spain | -0.6 | 91.38 | 2.66 | 22.69 | 91.38 | 2.24 | 30.01 | 91.38 | 1.87 | 30.01 |
| Taiwan | -0.6 | 112.47 | 6.58 | 5.83 | 112.47 | 5.34 | 13.00 | 112.47 | 4.24 | 13.00 |
| Thailand | -0.6 | n.a | n.a | n.a | 124.35 | 119.57 | 5.00 | 124.35 | 59.78 | 5.00 |
| Turkey | -0.6 | 88.70 | 7.78 | 8.39 | 88.70 | 6.55 | 8.39 | 88.70 | 5.47 | 8.39 |
| UK | -0.6 | 83.59 | 3.74 | 10.96 | 83.59 | 3.15 | 46.04 | 83.59 | 2.63 | 46.04 |
| USA | -0.6 | 97.69 | 6.11 | 92.91 | 97.69 | 2.29 | 119.07 | 97.69 | 2.06 | 119.07 |

Evolution of LNG trade

To understand what are the possible sources and markets for LNG in South America, we analyze the evolution of LNG trade from 2010 to 2015 and 2020. First, for 2010, we assume a high cost scenario, with liquefaction and transportation costs 200% higher than in 2003. This 2010 scenario represents the current conditions of the LNG market, with tight capital markets and delayed expansions. Then, for 2015, we assume that supply costs return to 2003 levels, and that all the projects currently under construction or in planning / engineering stages, and scheduled to start operating by 2010, are completed and operating. Finally, for 2020, we assume that the remaining proposed projects are completed and operating. Table 10 summarizes the changes in supply and demand captured by the 2010, 2015 and 2020 scenarios.

Table 10. Changes on LNG supply and demand for 2010, 2015 and 2020

| Scenario | Total LNG demand | LNG liquefaction capacity | Increase in liquefaction capacity with respect to previous scenario | New importers | New exporters |
|---|---|---|---|---|---|
| | $10^6$ LNG Ton | $10^6$ LNG Ton | $10^6$ LNG Ton | | |
| 2010 | 219.67 | 275.40 | 52.60* | Argentina, Brazil, Canada, Chile | Peru, Russia, Yemen |
| 2015 | 298.95 | 330.76 | 40.70 | NetherlandsSingapore, Thailand | Angola, Venezuela |
| 2020 | 363.45 | 349.06 | 7.50 | | Iran |

*Increase with respect to 2007

LNG trade in 2010

We first run the model for 2010. Among the liquefaction plants scheduled for starting production during, or before 2010 are Camisea in Peru, Sakhalin 1 in Russia, and Bal-Haf in Yemen (Oil and Gas Journal Construction Update, 2008). These plants, along with scheduled capacity expansions in Qatar, Argelia, Australia and Indonesia, add nearly 53 Million LNG tons of liquefaction capacity to the capacity already installed by 2008. Again, to reflect the current constraints in capital and construction markets, we assume that liquefaction and transportation costs in 2010 are 200% higher than in 2003. Total projected LNG demand for 2010 is 219.67 millions of LNG tons; by 2010 Argentina, Brazil, Chile, and Canada are expected to have imported their first LNG cargoes.

The outstanding contracts are lower bounds on the modeled flows. These contracts limit the possible supplies to new importers that have not signed supply contracts yet. As a result, the South American countries that make short-term LNG transactions to satisfy seasonal peaks in electricity demand or to generate electricity during dry seasons, face LNG prices higher than the average.

Table 11 shows that, with the current contract distribution, Argentina and Brazil would import LNG from Nigeria, whereas Chile could import it from Peru, taking advantage of the low transportation costs. Peru, however, has already signed a supply agreement with Mexico, and it is likely that this contract allows shipments larger than the reported 2.84 Million of LNG tons. If Peru committed all of its Camisea's production to Mexico, then Chile would have to look for alternative sources, with much higher transportation costs, such as Trinidad and Tobago.

Table 12. Selected 2010 flows, Millions of LNG tons

| | From: | | | | |
|---|---|---|---|---|---|
| To: | Peru | Trinidad and Tobago | Nigeria | Argelia | Equatorial Guinea |
| Argentina | 0.00 | 0.00 | 0.23 | 0.00 | 0.00 |
| Belgium | 0.00 | 0.00 | 1.63 | 0.00 | 0.00 |
| Brazil | 0.00 | 1.89 | 0.00 | 0.00 | 0.00 |

| | | | | | |
|---|---|---|---|---|---|
| Canada | 0.00 | 4.44 | 0.13 | 0.00 | 0.00 |
| Chile | 1.12 | 0.00 | 0.00 | 0.00 | 0.00 |
| China | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| France | 0.00 | 0.00 | 0.39 | 6.70 | 0.00 |
| Greece | 0.00 | 0.00 | 0.00 | 0.51 | 0.00 |
| India | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Italy | 0.00 | 0.00 | 2.80 | 1.43 | 0.00 |
| Japan | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Mexico | 2.84 | 0.00 | 0.00 | 0.00 | 0.00 |
| Portugal | 0.00 | 0.00 | 2.49 | 0.00 | 0.11 |
| Puerto Rico | 0.00 | 1.22 | 0.00 | 0.00 | 0.00 |
| Dominican Rep. | 0.00 | 0.53 | 0.00 | 0.00 | 0.00 |
| South Korea | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Spain | 0.00 | 5.30 | 6.42 | 2.63 | 0.00 |
| Taiwan | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Turkey | 0.00 | 0.00 | 0.95 | 3.18 | 0.00 |
| UK | 0.00 | 0.00 | 1.80 | 11.77 | 0.00 |
| USA | 0.00 | 6.63 | 0.00 | 0.64 | 3.63 |

Table 13. Selected flows, Million of LNG ton

| To: | Year | From: Algeria | Angola | Egypt | Equatorial Guinea | Nigeria | Peru | Trinidad and Tobago | Venezuela | Yemen |
|---|---|---|---|---|---|---|---|---|---|---|
| Argentina | 2010 | 0.00 | 0.00 | 0.00 | 0.00 | 0.23 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 2015 | 0.00 | 0.00 | 0.00 | 0.37 | 2.06 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 2020 | 0.00 | 3.27 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| Brazil | 2010 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.89 | 0.00 | 0.00 |
| | 2015 | 0.00 | 5.00 | 0.00 | 0.00 | 0.40 | 0.00 | 0.00 | 0.00 | 0.00 |
| | 2020 | 0.00 | 1.73 | 0.00 | 0.37 | 3.29 | 0.00 | 0.00 | 0.00 | 0.00 |
| Canada | 2010 | 0.00 | 0.00 | 0.00 | 0.00 | 0.13 | 0.00 | 4.44 | 0.00 | 0.00 |
| | 2015 | 0.00 | 0.00 | 0.00 | 0.00 | 7.92 | 0.00 | 0.00 | 0.00 | 2.15 |
| | 2020 | 0.00 | 0.00 | 1.04 | 0.00 | 8.98 | 0.00 | 0.00 | 0.00 | 6.80 |
| Chile | 2010 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 1.12 | 0.00 | 0.00 | 0.00 |
| | 2015 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 4.06 | 0.00 | 0.00 | 0.00 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2020 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 5.51 | 0.00 | 0.00 | 0.00 |
| | 2010 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.84 | 0.00 | 0.00 | 0.00 |
| | 2015 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.84 | 0.00 | 0.00 | 0.00 |
| Mexico | 2020 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 2.84 | 0.00 | 0.00 | 0.00 |
| | 2010 | 0.64 | 0.00 | 0.00 | 3.63 | 0.00 | 0.00 | 6.63 | 0.00 | 0.00 |
| | 2015 | 0.64 | 0.00 | 0.00 | 3.63 | 4.89 | 1.50 | 13.89 | 3.75 | 0.00 |
| USA | 2020 | 0.64 | 0.00 | 0.00 | 3.63 | 3.01 | 0.06 | 13.89 | 6.38 | 0.00 |

LNG trade in 2015

We assume that, by 2015, costs return to their 2003 levels and new liquefaction trains in Algeria, Angola, Australia, Qatar, Peru (Pampa Melchorita) and Nigeria are starting production. These new trains add 40.70 Million LNG ton of capacity to the 2010 capacity, for a total liquefaction capacity of 330.76 million LNG ton per year. Again, this production capacity forecast is larger than the demand forecast of 298.95 Million LNG ton.

Among the new LNG importers in 2015 are the Netherlands, Singapore and Thailand, whose import terminals are currently under construction and expected to be completed between 2011-2012 (Oil and Gas Journal, 2008).

With new importers, excess liquefaction capacity is less than 10%, and average prices increase with respect to 2010, which is a high cost scenario. Trade-average prices in 2015 are $6.80/10^6$BTU; 5% higher than the $6.46/10^6$BTU average of 2010 (See Table 14). This price increase suggests that by 2015, the LNG market could absorb more liquefaction capacity than the 40.70 Million LNG ton we assumed are added between 2010 and 2015.

Table 14. Modeled prices and imports

| | 2010 | | 2015 | | 2020 | |
|---|---|---|---|---|---|---|
| Table. Imports and prices | Imports, Million LNG ton | Price, 2007 US$/Million BTU | Imports, Million LNG ton | Price, 2007 US$/Million BTU | Imports, Million LNG ton | Price, 2007 US$/Million BTU |
| Argentina | 0.22 | 9.94 | 2.30 | 9.96 | 3.10 | 8.97 |
| Belgium | 3.53 | 6.63 | 4.22 | 6.55 | 4.39 | 7.93 |
| Brazil | 1.84 | 7.70 | 5.20 | 9.78 | 5.20 | 9.78 |
| Canada | 4.43 | 6.72 | 9.50 | 8.14 | 15.83 | 8.14 |
| Chile | 1.09 | 7.56 | 4.00 | 6.32 | 5.42 | 7.70 |

| | | | | | | |
|---|---|---|---|---|---|---|
| China | 7.72 | 6.72 | 15.67 | 6.50 | 20.33 | 7.89 |
| Dominican Rep. | 0.52 | 6.07 | 0.53 | 6.41 | 0.61 | 7.82 |
| France | 11.61 | 6.10 | 13.62 | 6.23 | 14.27 | 7.59 |
| Greece | 0.66 | 5.74 | 0.76 | 6.06 | 0.80 | 7.41 |
| India | 12.31 | 4.99 | 12.93 | 9.14 | 12.93 | 9.98 |
| Italy | 6.65 | 5.83 | 7.69 | 6.12 | 8.08 | 7.47 |
| Japan | 77.95 | 6.74 | 86.96 | 6.51 | 85.18 | 7.88 |
| Mexico | 2.70 | 6.25 | 2.84 | 6.34 | 2.70 | 7.01 |
| Netherlands | | | 3.86 | 6.95 | 7.29 | 7.89 |
| Portugal | 2.49 | 6.16 | 6.40 | 6.39 | 6.40 | 8.34 |
| Puerto Rico | 1.20 | 6.97 | 1.20 | 7.58 | 1.20 | 10.21 |
| Singapore | | | 1.78 | 6.22 | 3.00 | 8.97 |
| South Korea | 34.55 | 6.75 | 41.36 | 6.51 | 44.07 | 8.43 |
| Spain | 22.44 | 6.10 | 26.32 | 6.24 | 27.73 | 7.61 |
| Taiwan | 12.06 | 6.36 | 13.00 | 8.29 | 13.00 | 11.03 |
| Thailand | | | 0.76 | 6.50 | 1.43 | 7.51 |
| Turkey | 7.53 | 5.80 | 8.39 | 6.49 | 8.39 | 8.23 |
| UK | 13.19 | 6.60 | 15.76 | 6.53 | 16.15 | 7.91 |
| USA | 10.46 | 6.50 | 27.22 | 6.82 | 26.63 | 8.24 |
| Total | 235.15 | | 312.27 | | 334.13 | |
| Average | | 6.46 | | 6.80 | | 8.22 |

Because the new liquefaction capacity in Peru is not contracted, in the 2015 scenario, Chile can import from its least-cost supplier (Peru). The U.S.A. imports from Venezuela, Trinidad and Tobago, Equatorial Guinea and Nigeria while Canada imports from Trinidad and Tobago, Yemen and Nigeria. Nigeria and Angola are the main sources of LNG for Brazil, and Nigeria is also the main source of Argentina's imports, as can be seen in Table 13.

LNG trade in 2020

Iran is the only new exporter in our 2020 Scenario. Venezuela expands its liquefaction capacity, and the total expansion of liquefaction capacity with respect to 2015 is 7.5 Million of LNG ton per year. In this scenario, there are no new importers, and total demand grows from 298.95 to 363.45 Million of LNG tons per year.

By 2020, the supply and demand balance in the global LNG market is tighter than in 2015, and the market absorbs all the new liquefaction capacity. Because liquefaction capacity is less than the total potential demand, trade-average prices in 2020 increase by more than 20% with respect to 2010.

The South American suppliers increase their production in the 2020 scenarios. Capacity expansions in Peru (Camisea 2) support exports to Chile, Mexico and the U.S.A., while expansions in Venezuela (José Anzoátegui LNG plant) contribute to increase exports from Venezuela to the Caribbean (Puerto Rico and Dominican Republic) and to the U.S.A. In this scenario, Trinidad and Tobago does not expand its liquefaction capacity, and it continues trading in the Atlantic markets: Spain, the U.S.A and the Caribbean.

As in the 2015 scenario, Chile imports from Peru, while Argentina and Brazil import from Africa: Angola, and Nigeria. Canada, and the U.S.A increase their imports from Nigeria, too, because LNG from Trinidad and Tobago is exported to other Atlantic markets, like Spain.

Conclusions

Results from the LNG trade model described above indicate that the opportunities for the new suppliers in South America and the rest of the world are good. The North American market, with its declining reserves seems a natural destination for LNG produced in Peru, Venezuela and Trinidad and Tobago. As a result, in the three scenarios analyzed, Brazil and Argentina imported LNG from other Atlantic sources, such as Angola and Nigeria. Imports from Peru are the least cost supply for Chile. The availability of LNG supply from Peru, however, depends on what contract agreements are made for the planned expansion of Camisea liquefaction plant.

Although LNG imports contribute to diversify gas supply, reducing the exposure to the regional supply disruptions, these imports also increase costs for the South American consumers. LNG prices are formed in global markets, and they reflect the global supply and demand imbalances. Whereas in 2007 Brazil contracted pipeline imports from Bolivia at \$ 4.30/$10^6$BTU (AFP, 2007), modeled prices for LNG imports in 2010 are \$7.7/$10^6$BTU and they could increase above \$9/$10^6$BTU in 2015 and 2020 scenarios. High gas prices, however, could not be sustainable in the region, since most demand growth in the region is associated with power generation.

Despite the uncertainty of the expansion of LNG supply, and despite downward revisions of projections of natural gas demand, the results suggest that the global LNG markets will continue growing and could absorb all of the new liquefaction capacity proposed as of 2008. The construction of new liquefaction plants in Europe, South America, Africa and Asia and Australia is expected to reduce transport costs and supply risks, since it diversifies supplies. For the importing countries, this expansion of LNG supply is expected to increase competition in the market and to contribute to higher flexibility of LNG supply.

For the long-term, the expansion of LNG markets signals opportunities for developing the natural gas resources in Bolivia and Venezuela and for strengthening regional pipeline trade. LNG trade in South America can play an important role in complementing the regional pipeline trade and integration by providing new markets for the produced gas and by increasing diversification of importer's supply.

## References


EIA (2008). International energy outlook. Forecasts to 2025. Available at http://www.eia.doe.gov/oiaf/forecasting.html.

Olaya, Y. (2006). World LNG trade model. Ph. D. thesis, Colorado School of Mines, Golden, Colorado.

BP (2004). Statistical review of world energy 2004. Available: http://www.bp.com.

BP (2008). Statistical review of world energy 2008. Available: http://www.bp.com.

Garcia, R. and A. Vasquez (2004). *La Industria del Gas Natural en el Perú*. Working Paper N° 1. Office of Economic Research, OSINERGMIN – Peru.

SantAna de Mello, Paulo Henrique; Jannuzzi, Gilberto De Martino; ValdirBajay, Sergio. (2009). "Developing competition while building up the infrastructure of the Brazilian gas industry". *Energy Policy* 37: 308–317

Takayama, A. (1946). Analytical Methods in Economics. Ann Arbor, Michigan: The University of Michigan Press.

Hartley, P. and D. L. Brito (2007). “Expectations and the Evolving World Gas Market.” *The Energy Journal* 28 (1): 1–24.

Hartley, P. and K. Medlock (2005). The Baker Institute World Gas Trade Model. Available: http://www.rice.edu/energy/research/ electricity/index.html.

DOE-EIA (2004). U.S. LNG Markets and Uses: June 2004 Update. Update of the Energy Information Administration’s January 2003 report U.S. LNG Markets and Uses. Available: http://www.eia.doe.gov/pub/oil gas/natural gas/feature articles /2004/lng/lng2004.pdf.

Drewry Shipping Consultants (2003). The Drewry annual LNG shipping market review and forecast 2002.

Oil and Gas Journal Worldwide Construction Update (2008). http://www.gasandoil.com/goc/news/ntl81691.htm

Oil and Gas Journal, Mar. 24 2008. Pecem LNG regas terminal in Brazil approved.
http://www.ogj.com/articles/article_display.cfm?ARTICLE_ID=323847&p=7.

Olaya, Y., Dahl, C., Newman, A. (2008). Filling the Gap in United States Liquefied Natural Gas Demand. Working paper

Mathias, M.C., Szklo A. (2007). “Lessons learned from Brazilian natural gas industry reform” *Energy Policy* 35: 6478–6490

Bondorevsky, D. Petrecolla, D. (2000) The structure of natural gas markets in Argentina and antitrust issues in regional energy integration / Diego Bondorevsky, Diego Petrecolla. p.cm. Sustainable Development Department Technical papers series ; IFM-131

California Energy Commission. (2007). The Outlook For Global Trade In Liquefied Natural Gas Projections To The Year 2020 Prepared By: Jensen Associates Aug-07 CEC-200-2007-017

Jensen, James T. (2008) Special Report: Global LNG Trade To 2020 Marked By Uncertainty.

Oil & Gas Journal, Volume 106, issue 8 (February 25, 2008)

Barroso, Luiz Augusto; Hammons, Thomas J; Rudnick, Hugh (2005) . Integrated Natural Gas-Electricity Resource Adequacy Planning. In Latin America. *Oil, Gas & Energy Law Intelligence*. Vol. 3 - issue 2, June 2005. www.gasandoil.com/ogel/

AFP (2007). Brazil to pay 3 - 4 percent more for rich Bolivian gas Feb 15, 2007 http://www.france24.com/france24Public/en/archives/news/americas/20070216-Bolivia-Brazil.php

Authors' short resumes

Dr. Yris Olaya Morales holds a B.Sc. degree in Petroleum Engineering and a Ph.D. in Mineral Economics from Colorado School of Mines, U.S.A. She is currently assistant professor at the Universidad Nacional de Colombia and conducts research on energy markets.

Arturo Vasquez Cordano holds a B.Sc. degree in Economics, a M.Sc. degree in Mineral Economics, and is currently a Mineral Economics Ph.D. candidate at Colorado School of Mines, U.S.A. He has worked for the Peruvian government and conducted research on energy economics and economic regulation.

Dr. Carol Dahl holds a Ph.D. in Economics from the University of Minnesota, U.S.A. She is currently the director of the joint IFP-CSM masters program in Energy Economics. Professor Dahl works at Colorado School of Mines, where she conducts research on analysis and modeling of energy markets and energy policies.

# 32. Relative Efficiency and Performance in the Integrated Oil & Gas Industry

**Roberto Pougy Ferreira da Cunha, Edmar Luiz Fagundes de Almeida**

Institute of Economics, Federal University of Rio de Janeiro

Avenida Pasteur 250 sala 123 – Urca, 22295-900 - Rio de Janeiro, RJ Brazil

Phone: +55 21 3873-5269, Fax: +55 21 2541-8148, robertocunha@ie.ufrj.br

Keywords: Integrated Oil & Gas Industry Efficiency, Data Envelopment Analysis

Abstract: The scope of this project is to investigate the relationship between efficiency and performance in the integrated oil & gas industry (majors). We propose the estimation of regression models to explain the relative performances of selected companies in terms of their relative efficiencies. We expect to find out that, against intuition, in this industry more efficiency weakly leads to more profitability, while its relative size and investment strategy would play a much bigger part; a possible reason is the large differences in the profitability of upstream projects. The access to highly profitable projects in the upstream is expected to be an important performance determinant. The proposed method is to build the efficiency measure through data envelopment analysis (DEA), for it provides a non-parametric technique for measuring the relative efficiency between several decision-making units. Data for this study was obtained from the past 5 fiscal years (2003-07) files submitted to the U.S. Securities and Exchange Commission (SEC). Additional data was obtained from the investor's relation section of each company's website.

## 1. Introduction

The integrated oil and gas industry has long been known as portraying a very peculiar market structure: reduced number of giant sized companies operating under opaque and ill defined costs, production determined by geology, influencing exploration, production and transportation operating costs; producers preferences for guaranteed markets, high prices to recover investment costs, a tendency to desire vertical integration and consumer preference for long term security of supply (Hawdon, 2003). With all these eccentricities, it is only fair to inquire whether or not this industry displays the expected characteristics of familiar market structures such as oligopolies.

In order to reach our goal, we propose the adoption of the Data Envelopment Analysis (DEA) method to measure the productive efficiencies of selected publicly traded companies in their exploration and production activities. DEA is a non-parametric method that establishes relative efficiencies in a sample of observed productive practices, first by determining the best practice and then by measuring all the others against the best one. After establishing the efficiency rank, we propose a regression model to establish the relationship between being relatively more efficient relatively more profitable.

Our hypothesis is that, under so many adverse structural conditions, efficiency is a weak determinant of overall performance. We are explicitly interested in establishing the manner in which overall relative productive efficiency and relative performance correlate under these several specificities. Possible grounds for our hypothesis are the disparity in the profitability of upstream projects, the most profitable ones being only accessible to the biggest players. The access to these highly profitable projects is expected to be an important performance determinant.

The paper is divided as follows: section II describes the adopted DEA methodology; section III depicts the adopted variables, overall adopted modeling specifications and the utilized data; section IV displays the results and section V elaborates our conclusions over the findings.

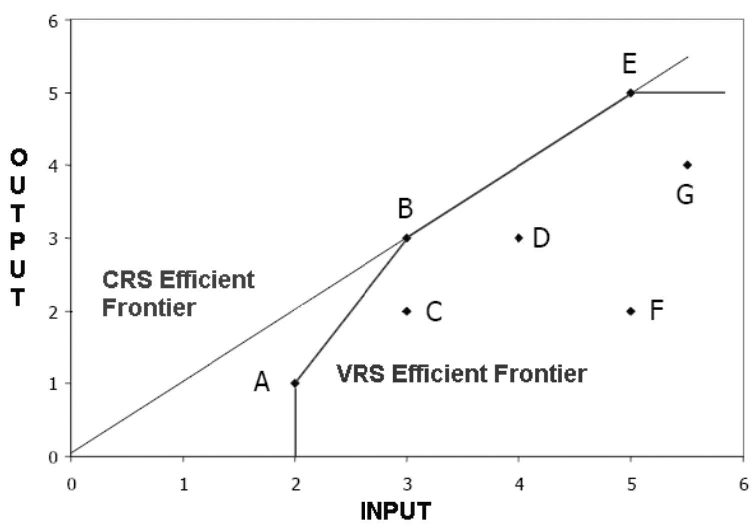
## 2. Measuring efficiency through the DEA approach

The Data Envelopment Analysis technique provides efficiency measures as a relative norm calculated in terms of a pre-determined best practice. This best-practice is established in terms of observed productivity, hence determining an efficient frontier, that can be either a constant returns to scale one (CRS) or a variable returns to scale one (VRS). The best practice decision making unit (DMU) has the efficiency rank of 1, the inefficient ones are ranked proportionally to their distance to the frontier.

In a simple 1-input, 1-output framework, the productivity concept strictly means the ratio between the total output and the total input quantities. With multiple inputs and outputs, productivity takes on the meaning of the ratio between a weighted average of the outputs' quantities and a weighted average of the inputs' quantities.

Thus, the best-practice DMU in the first framework will simply be the one with the highest productivity and the CRS efficient frontier will be the straight line through the origin with slope equal to the best-practices' productivity. The VRS efficient frontier is graphically represented by line segments, in the input-output space, connecting the best-practices at different levels of inputs and outputs. Figure 1 illustrates the two concepts of efficient frontier in a 1-input, 1-output space.

Figure 1



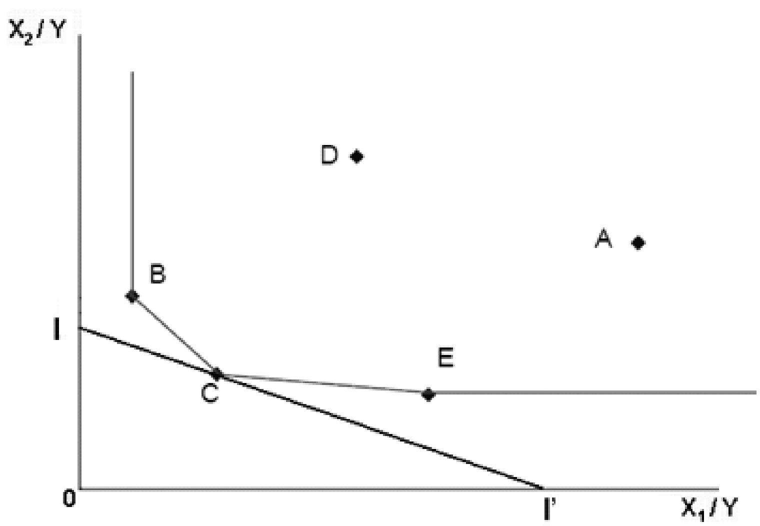

DEA models can also be either input or output oriented. The DEA measure for the inefficiency is a ratio between the distance from a DMU to the efficient frontier and, its distance to either the horizontal or the vertical axis, depending on a adopted *orientation*. The input oriented approach measures efficiency as the horizontal distance from the practice to the frontier, over the total distance between the practice and the vertical axis. The output oriented approach measures efficiency as the vertical distance between the practice and the efficient frontier, normalized by the overall distance between the frontier and the horizontal axis.

DEA frameworks also depict the concept of overall productive efficiency into technical and allocative efficiency (Ramos-Real et al, 2008). The former is strictly concerned with the relationship between inputs' and outputs' quantities, in the sense that an efficient firm should achieve either maximum outputs for a given quantity of inputs or, alternatively, minimum use of inputs for a given amount of outputs. For only regarding quantities, it fails to devote attention to its prices. Ergo, allocative efficiency compares alternative technically efficient positions in terms of inputs or outputs relative prices.

Figure 2 depicts the difference between technical and allocative efficiency. The example considers a production activity where firms A to E produce one output Y using two inputs $X_1$ and $X_2$. Each axis displays the amount of inputs used per unit of output produced.

From the efficiency point of view, it is natural to consider DMUs which use together fewer of both inputs to get one unit of output as more efficient. We therefore identify the line connecting B, C, E as the efficient frontier. DEA does not discuss the trade-offs between these DMUs.

Figure 2




Note that not for any DMU on the frontier it is possible to improve the productivity of one input without decreasing the productivity of the other. The I-I' line displays the relative price between inputs $X_1$ and $X_2$ at hypothetical market prices. Allocative efficiency means that the DMU is on the efficient frontier and minimizes total cost given these prices, which in the context of Figure 2 means that the unit's position is intersected by the closest line to the origin that is parallel to I-I', the case of DMU C.

Consensual advantages of the DEA approach in the literature are that it requires minimal assumptions regarding the structure of production and that it places no restrictions regarding the functional form of the relation between inputs and outputs. A main disadvantage is that the greater the number of restrictions placed, the higher the measured efficiencies will be (Hawdon, 2003). Most importantly, the higher the number of inputs and outputs considered, the higher the likelihood of an increased number of units on the efficient frontier. At the limit, if we consider a larger number of inputs and outputs than of DMUs and years of observation, all units could be considered efficient, which is disserving to our purposes. The solution to this problem is presented in the form of a large dataset, either as an increased number of DMUs and/or many years of observations.

## 3. Data and model choice

Applied Data Envelopment Analysis is backed by a very well established and mature literature, developed concurrently with the technique itself within the last 30 years. Directly related to energy economics, just to cite a few, Ramos-Real et al. (2003) applied DEA to assess the productive efficiency of Brazilian gas distribution companies; Hawdon (2003) assesses the productive efficiency of gas exporting countries, Thompson (1996) applies a variant of the original DEA apparatus, with assurance regions as boundaries for the optimization problems, to measure the efficiency of American oil and gas companies.

One recurrent aspect within the analyzed literature is the choice of non-financial inputs and outputs, that is, measured in physical quantities. The main gain is to avoid problems arisen from the differences between the DMUs, such as accounting principles, countries they operate, economic environments, etc. The literature explicitly suggests that the adopted variables should be broad, of very simple and straight forward definition to avoid said difficulties, but also to avoid an excessive number of input variables that would reduce the precision of the estimates and increase the amount of units on the efficient frontier.

From here, we proceed to adopt as a proxy for the capital input the amount of crude oil and gas reserves available at the previous year-end. It is straight forward that to be more productive a company should produce more oil and gas per amount of barrels of oil or cubic feet of gas on reserves. The complex issue of revisions in proved reserves is not analyzed here.

As per the labor input, we adopt the total number of employees. Even though we are only trying to assess the productive efficiency in the upstream activities, the total number of employees is a proxy, given data availability, as it is unintuitive that a company would have completely different productive efficiencies, relative to its competitors, in different sections of the oil and gas chain. In other words, there is no apparent reason to expect that the least labor productive company in the upstream is the most productive company in the downstream.

The outputs adopted were the year's total production of crude oil (MMbbls) and natural gas (Bcf) from its respective current proved reserves.

Regarding the DEA parameters choice, in the case of oil and gas exploration and production, we considered that the output oriented with variables returns to scale was more adequate. It makes little, if any, sense to suggest that, to increase efficiency, any of the companies should reduce their current reserve levels while maintaining the same production level. Moreover, it is suggested by the literature that the variable returns to scale (VRS) approach is best fitted for oligopolistic markets, as interactive behavior is present; whereas the constant returns to scale (CRS) is best fitted for nearly perfectly competitive markets.

The dataset consisted of 5 years of observations of the oil and gas reserves disclosures of 14 companies available in SEC forms 10-K and 20-F, depending on whether or not the company is U.S. based. Thereupon, we have a dataset magnitude of 70 observations for each input and output (DMU times years of observation).

Considering the relative small size of the dataset, the full DEA efficiency model – 3 inputs and 2 outputs – was likely to find most DMUs in the efficiency frontier. Henceforward, we decided to construct two control models with less inputs and outputs, more specifically, by reducing the bigger model into a oil-only and a gas-only model. Table 1 outlines the variables in each model.

Still taking into consideration the dataset's reduced magnitude, we sought to adapt the efficiency variables and the performance variables into rank variables before proceeding to the regression models. The basis for that decision was to avoid possible biases and inconsistencies still present from the reduced dataset and the broad proxy adopted for

Table 1

| DEA models: inputs and outputs | Model 1 | Model 2 | Model 3 |
|---|---|---|---|
| | Oil-only | Gas-only | Full Spec. |
| Outputs | | | |
| Total Oil Production | X | | X |
| Total Gas Production | | X | X |
| Inputs | | | |
| Total number of employees | X | X | X |
| Total Oil Reserves, previous year-end | X | | X |
| Total Gas Reserves, previous year-end | | X | X |

the labor input, just as well exchange rates choices and accounting principles adopted by each company. The idea is that these proxies might dim the efficiency and performance estimates, but since equally present to all companies, should not interfere with the relative positions, i.e., the ranks.

After establishing the efficiency ranks, we move on to confront it to a performance rank. Profitability was chosen as a measure of the overall business performance. It is the ratio of a firm's profits by what created them, such as, gross sales revenue, amount invested in the business, asset base, etc (Lumby, 1991). We adopted the broadest possible measure, attained by dividing the company's net income by the company's total revenues for the year of 2007. Table 2 provides the profitability rank for the selected companies.

Table 2

| Company Name | Net income | Total Revenues | Profitability | Rank |
|---|---|---|---|---|
| PetroChina Company Limited | 21,327.32 | 122,287.70 | 17.44% | 1 |
| Petroleo Brasileiro S.A. | 13,138.00 | 87,735.00 | 14.97% | 2 |
| Eni S.p.A. | 12,889.62 | 114,402.62 | 11.27% | 3 |
| Exxon Mobil Corporation | 40,610.00 | 404,552.00 | 10.04% | 4 |
| Total S.A. | 16,725.42 | 175,532.79 | 9.53% | 5 |
| Royal Dutch Shell plc | 31,331.00 | 355,782.00 | 8.81% | 6 |
| Chevron Corporation | 18,688.00 | 220,904.00 | 8.46% | 7 |
| StatoilHydro ASA | 6,345.77 | 75,112.47 | 8.45% | 8 |
| BP plc | 20,845.00 | 291,438.00 | 7.15% | 9 |
| ConocoPhillips | 11,891.00 | 194,495.00 | 6.11% | 10 |
| Marathon Oil Corporation | 3,956.00 | 65,207.00 | 6.07% | 11 |
| Amerada Hess Corporation | 1,832.00 | 31,924.00 | 5.74% | 12 |
| Repsol YPF S.A. | 4,104.69 | 71,744.12 | 5.72% | 13 |
| China Petroleum & Chemical Corporation | 8,279.47 | 176,444.27 | 4.69% | 14 |

4. Results

Table 3 displays the VRS-Output Oriented-DEA total efficiency (VRS te) estimates. The CRS te estimates, returns of scale (RoS) and Malmquist indexes are provided for productivity evolution assessment. The far right column ranks the results.

Table 3

| Model 1 - Inputs: Employees, Oilres(-1); Ouputs: OilProd | | | | | | | |
|---|---|---|---|---|---|---|---|
| Company Name | CRS te | VRS te | RoS | Malmquist Index Decomp. | | | Rank |
| | | | | Eff. Chg | Tech. Chg | Tfpch | |
| Amerada Hess Corporation | 0.852 | 1 | irs | 0.966 | 1.031 | 0.996 | 1 |
| BP plc | 0.561 | 0.915 | drs | 1.041 | 0.998 | 1.039 | 8 |
| Chevron Corporation | 0.931 | 1 | drs | 0.963 | 0.999 | 0.962 | 1 |
| China Petroleum & Chemical Corporation | 0.562 | 0.605 | drs | 0.987 | 1.035 | 1.021 | 14 |
| ConocoPhillips | 0.627 | 0.751 | drs | 1.124 | 0.986 | 1.108 | 11 |
| Eni S.p.A. | 0.65 | 0.709 | drs | 1.003 | 1.027 | 1.030 | 13 |
| Exxon Mobil Corporation | 0.629 | 1 | drs | 0.990 | 1.017 | 1.007 | 1 |
| Marathon Oil Corporation | 0.889 | 1 | irs | 0.921 | 1.035 | 0.953 | 1 |
| PetroChina Company Limited | 0.488 | 0.948 | drs | 0.971 | 1.035 | 1.005 | 7 |
| Petroleo Brasileiro S.A. | 0.848 | 0.910 | drs | 0.955 | 0.995 | 0.950 | 9 |
| Repsol YPF S.A. | 0.765 | 0.771 | drs | 1.069 | 1.029 | 1.100 | 10 |
| Royal Dutch Shell plc | 0.883 | 1 | drs | 1.022 | 1.029 | 1.052 | 1 |
| StatoilHydro ASA | 1 | 1 | - | 1 | 1.007 | 1.007 | 1 |
| Total S.A. | 0.577 | 0.730 | drs | 0.977 | 1.032 | 1.008 | 12 |

| Model 2 - Inputs: Employees, Gasres(-1); Ouputs: GasProd | | | | | | | |
|---|---|---|---|---|---|---|---|
| Company Name | CRS te | VRS te | RoS | Malmquist Index Decomp. | | | Rank |
| | | | | Eff. Chg | Tech. Chg | Tfpch | |
| Amerada Hess Corporation | 1 | 1 | - | 0.930 | 1.009 | 0.938 | 1 |
| BP plc | 0.841 | 0.987 | drs | 0.966 | 1.055 | 1.019 | 7 |
| Chevron Corporation | 0.864 | 0.870 | irs | 0.975 | 1.023 | 0.998 | 9 |
| China Petroleum & Chemical Corporation | 0.395 | 0.446 | drs | 1.177 | 0.978 | 1.151 | 13 |
| ConocoPhillips | 0.975 | 1 | irs | 1.006 | 1.089 | 1.096 | 1 |
| Eni S.p.A. | 0.584 | 0.674 | drs | 1.036 | 1.041 | 1.078 | 11 |
| Exxon Mobil Corporation | 1 | 1 | - | 0.922 | 1.034 | 0.952 | 1 |
| Marathon Oil Corporation | 0.918 | 1 | drs | 0.933 | 0.985 | 0.918 | 1 |
| PetroChina Company Limited | 0.162 | 0.279 | drs | 1.094 | 0.978 | 1.070 | 14 |
| Petroleo Brasileiro S.A. | 0.496 | 0.602 | drs | 0.991 | 1.018 | 1.009 | 12 |
| Repsol YPF S.A. | 0.957 | 0.980 | irs | 1.011 | 1.082 | 1.093 | 8 |
| Royal Dutch Shell plc | 0.797 | 0.988 | drs | 0.964 | 1.012 | 0.976 | 6 |
| StatoilHydro ASA | 0.979 | 1 | irs | 0.949 | 1.134 | 1.076 | 1 |
| Total S.A. | 0.645 | 0.839 | drs | 0.966 | 1.001 | 0.966 | 10 |

| Model 3 - Inputs: Employees, Oilres(-1), Gasres(-1) - Ouputs: OilProd, GasProd | | | | | | | |
|---|---|---|---|---|---|---|---|
| Company Name | CRS te | VRS te | RoS | Malmquist Index Decomp. | | | Rank |
| | | | | Eff. Chg | Tech. Chg | Tfpch | |
| Amerada Hess Corporation | 1 | 1 | - | 1.000 | 0.958 | 0.958 | 1 |
| BP plc | 0.857 | 0.989 | drs | 0.997 | 1.021 | 1.017 | 11 |
| Chevron Corporation | 1 | 1 | irs | 1.000 | 0.970 | 0.970 | 1 |
| China Petroleum & Chemical Corporation | 1 | 1 | drs | 1.000 | 1.068 | 1.068 | 1 |
| ConocoPhillips | 0.976 | 1 | irs | 1.006 | 1.054 | 1.061 | 1 |
| Eni S.p.A. | 0.729 | 0.805 | drs | 1.019 | 1.031 | 1.050 | 14 |
| Exxon Mobil Corporation | 1 | 1 | - | 0.969 | 1.003 | 0.972 | 1 |
| Marathon Oil Corporation | 1 | 1 | drs | 0.934 | 0.980 | 0.916 | 1 |
| PetroChina Company Limited | 0.549 | 0.965 | drs | 0.994 | 0.998 | 0.992 | 13 |
| Petroleo Brasileiro S.A. | 1 | 1 | drs | 1.000 | 0.971 | 0.971 | 1 |
| Repsol YPF S.A. | 1 | 1 | irs | 1.000 | 1.111 | 1.111 | 1 |
| Royal Dutch Shell plc | 1 | 1 | drs | 0.990 | 1.049 | 1.039 | 1 |
| StatoilHydro ASA | 1 | 1 | irs | 1 | 1.019 | 1.019 | 1 |
| Total S.A. | 0.68 | 0.972 | drs | 1.011 | 0.960 | 0.970 | 12 |

As we expected, the reduced dataset led DEA to attribute the efficient score (of 1) to 10 out of 14 DMU's. The control models are more informative efficiencywise. The method placed 6 and 5 companies on the efficient frontier for the oil-only and gas-only control models, respectively.

Companies that attained the score of 1 on the 3 models were considered to be super-efficient, those being Amerada Hess, ExxonMobil, Marathon and StatoilHydro. Companies either oil-only efficient or gas-only efficient were Royal Dutch Shell, Chevron and ConocoPhillips. Repsol YPF, Petrobras and China Petroleum were only placed on the efficient frontier by the generalized model. Absolutely inneficient companies, those not on the frontier in any model, were British Petroleum, PetroChina, Eni S.p.a. and Total S.A.

Table 4 summarizes the data panel with the 4 ranks for the OLS regressions and provides the Spearman rank correlation between each model's rank and the profitability rank. Confirming our hypothesis, every correlation was found to be negative.

Table 4

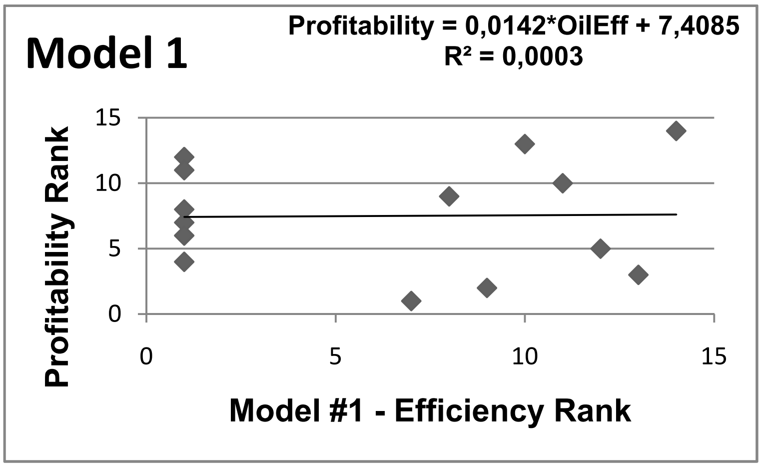
| Company Name | Oil-only Eff. Rank | Gas-only Eff. Rank | Full Spec. Eff. Rank | Profitability Rank |
|---|---|---|---|---|
| Amerada Hess Corporation | 1 | 1 | 1 | 12 |
| BP plc | 8 | 7 | 11 | 9 |
| Chevron Corporation | 1 | 9 | 1 | 7 |
| China Petroleum & Chemical Corporation | 14 | 13 | 1 | 14 |
| ConocoPhillips | 11 | 1 | 1 | 10 |
| Eni S.p.A. | 13 | 11 | 14 | 3 |
| Exxon Mobil Corporation | 1 | 1 | 1 | 4 |
| Marathon Oil Corporation | 1 | 1 | 1 | 11 |
| PetroChina Company Limited | 7 | 14 | 13 | 1 |
| Petroleo Brasileiro S.A. | 9 | 12 | 1 | 2 |
| Repsol YPF S.A. | 10 | 8 | 1 | 13 |
| Royal Dutch Shell plc | 1 | 6 | 1 | 6 |
| StatoilHydro ASA | 1 | 1 | 1 | 8 |
| Total S.A. | 12 | 10 | 12 | 5 |
| Spearman Rank Correlation (relative to the Profitability Rank) | -0.29 | -0.65 | -1.31 | |

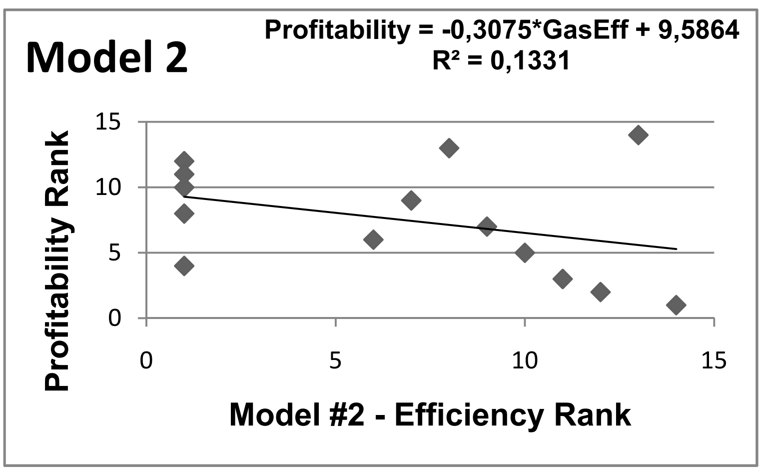
Table 5 and Figure 3 summarize the OLS regressions' estimates.

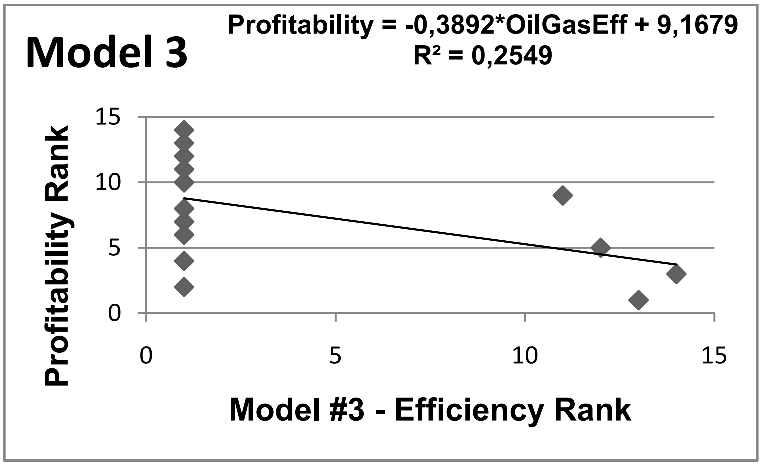
Table 5

| Model | $\beta_0$ | $\beta_1$ | $R^2$ |
|---|---|---|---|
| Profitability Rank = β0 + β1*OilEff Rank | 7.4085 | 0.0142 | 0.0003 |
| Profitability Rank = β0 + β1*GasEff Rank | 9.5864 | -0.3075 | 0.1331 |
| Profitability Rank = β0 + β1*Full Spec Rank | 9.1679 | -0.3892 | 0.2549 |

Figure 3






The graphs should be interpreted as follows. The more to the right a DMU is, the less efficient it is. The higher it is in the vertical axis, the less profitable it is. Hence a negative value of $\beta_1$ means that the more inefficient (higher efficiency rank), the more profitable (smaller profitability rank) within the sample.

In the Oil-only model (nb. 1), the 8 inefficient companies are evenly divided among the profitability rank. On that account we attained the $\beta_1$ estimate close to zero. On the Gas-only model (nb. 2), within the 50% most profitable companies, only one is efficient (ExxonMobil). Thus we have a bigger negative slope estimate $\beta_1$. The full specification model (nb. 3), in turn, confirmed our hypothesis. Even though our DEA procedures placed 10 companies as efficient, those companies were not the most profitable ones. In fact, 3 out of 4 inefficient companies rank top 5 in profitability.

5. Conclusions

In this paper we assessed the relationship between relative efficiency and relative profitability for a sample of 14 integrated oil and gas companies. The numbers revealed that relative efficiency is a weak determinant of relative profitability, as evidenced by the estimated Spearman rank correlations and the slope coefficients of the OLS regressions.

It is important to keep in mind that a known causality relationship between variables can be verified by regression models, but an estimated slope is not sufficient to infer a causality relationship, being an indication of statistical correlation within the data. This is the case in our results. Despite the estimated slopes, it is still true that efficiency contributes to better profitability and overall performance. However, the reduced regression model indicates us that we are missing other variables in the regression, a situation known in econometrics to introduce a bias in our estimator of $\beta_1$. That means in our case that the true impact from efficiency is so reduced that in the absence of the true causers it actually seems to work in the opposite direction.

All in all, we are comfortable to assert that being relatively more efficient than its competitors, that is, attaining better performances given its inputs amounts, is not the key factor when trying to establish the most successful companies.

## 6. References

Lumby, S., 1991. “Investment Appraisal and Financing Decisions”. Chapman & Hall, 4th edition, London.

Coelli, T. 1996. “A guide to DEAP Version 2.1 A Data Envelopment Analysis Program”. Centre for Efficiency and Productivity Analysis, University of Queensland.

Cooper, W.W., Seiford, L.M., Tone, K., 2007. “Data Envelopment Analysis. A Comprehensive Text with Models, Applications, References and DEA-Solver Software”. Springer Science+Business Media, LLC, New York.

Hawdon, D., 2003. “Efficiency, performance and regulation of the international gás industry – a bootstrap DEA approach”. Energy Policy Issue 31, pp. 1167-1178.

Ramos-Real F., Iootty M., Tovar de la Fe B., Almeida E., Pinto Jr. H. 2008. “The evolution and main determinants of productivity in Brazilian electricity distribution: an empirical analysis”. Fundacion de Estudios de Economia Aplicada, Documento de Trabajo 2008-41, Madrid.

Thompson, R.G., Dharmapala, P.S., Rothenberg, L.J. and Thrall, R.M., 1996. “DEA/AR efficiency and profitability of 14 major oil companies in U.S. exploration and production”. Computers Ops. Res. Vol 23. No. 4, pp. 357-373.

# 33. The Changing Brazilian Natural Gas Regulatory Framework: A Veto Player Analysis

**Leonardo Sobreira*, Edmar Almeida*, Felipe Dias****

*Institute of Economics, Federal University of Rio de Janeiro (UFRJ)

** Brazilian Petroleum Institute (IBP)

Institute of Economics, Federal University of Rio de Janeiro

250 Pasteur Avenue, Room 123, Urca, Rio de Janeiro, RJ, Brazil,

Zip Code: 22.295-900

Phone: (0xx55 21) 3873-5269/ Fax: (0xx55 21) 2541-8148 / leovantol@yahoo.com.br

Key Words: Natural Gas Regulation, Negotiation Process, Veto Player

Abstract: The vast majority of actors in the domestic natural gas industry – (NGI) have the perception that its regulatory framework is inadequate to address the specificities of this sector, in particular, the challenges of how to promote policies to encourage competition in the upstream simultaneously to investments in the downstream. The consensus that the NGI´s regulatory framework is inadequate was not enough to ensure a necessary consensus in the Brazilian Congress regarding the necessary changes that should be introduced in the new gas law. It is worth noting that this experience contrasts with the definition of a new regulatory framework for the electricity sector. The new electricity law was approved only two years after the president Lula da Silva was elected. This discrepancy between the legislative process in the gas and electricity sector raises the question of why the negotiating process on the natural gas sector has been so difficult. More specifically, which are the factors that are obstructing the approval of the new gas bill in Brazilian political arena?

This paper proposes to tackle this question by analyzing of the negotiation process for the new gas law in Brazil. The analysis will be based on institutional economic theory, taking as focus the model of Veto Players, as developed by Glachant (2002), Perez (2004) and Tsebelis (2002). Our vision is that there are veto players along the natural gas chain, which are trying to establish alliances policies, in order to ensure that the new gas law will provide their own interests, even if they are not the natural gas industry interest as a whole. The paper examines which are the positions of the main players of this industry within the process of negotiation. This analysis allows us to show which players have benefited and which have not in the gas law approved in December 2008. Our view is that there are inconsistencies in both the former legal framework and on the new gas law approved. The analysis of how main players have influenced the legislative process will help to explain why the new gas law proposal has failed to solve important inconsistencies for the natural gas regulation in Brazil.

## Introduction

Brazilian natural gas regulatory framework was under questioning by almost all stakeholders, including the government. Since 2004, there was a general perception that the former oil and gas law (Law 9478/97) was not adequate for all the segments. The law was designed to open the upstream activities and did not tackle the challenges of opening downstream segments, especially for the natural gas market.

Since 2007, Brazil started to face an increasing shortage of natural gas. In addition, political turmoil in Bolivia and Argentinean energy crisis have reduced the country´s importing alternatives. These problems have driven the congress to discuss a new legislation for natural gas in Brazil. After almost 4 years of discussion and negotiation, the congress has approved a final version of the new law in December of 2008.

The objective of this paper is to analyze how the negotiations for changing the NGI´s regulatory framework took place and try to explain the main remaining inconsistencies of the new gas regulation. This paper will try to point out the main remaining challenges for regulatory good practices in Brazil. The first part of the paper presents the theoretical framework that supports our analysis of the negotiation process towards a new gas law. The analysis is based on Institutional Economic Theory, specifically on the Veto Players Model (Glachant, 2002; Perez, 2004; and Tsebelis, 2002). The second part will address the current context of the Brazilian natural gas industry, focusing the main objectives of the energy policy and the structure of the industry. The third section analyzes the evolution of the regulatory framework in Brazil, trying to show the inconsistencies and its impacts on the investment along the gas chain. Finally, the last part of the paper analyzes the legislation process the resulted in the approval of a new law, focusing on how the veto players have blocked the necessary changes for reducing the inconsistencies of the NGI regulatory framework. A particular attention will be given to the reasons why we still face those inconsistencies.

1 — The Veto Players model

According to Tsebelis (2002), veto players are individual or collective actors, which the agreement is needed in order to achieve the necessary consensus to change the current policies of the country. The veto players model has been used in several empirical work[112] to explain the reform process in the infrastructure sectors around the world. The development of this theoretical framework was related to an effort to explain why is so difficult to replicate success experiences of reforming the network industries such as American and British experiences. This research agenda has tried to show the role of the country´s institutional environment and specific players in defining what are the limits of what can be changed and the depth of changes in the current *status quo*.

McCubbins, Noll & Weingast (1987) shows that we cannot restrict the policy-making process to a mere relationship between the Executive and Legislative powers. Different actors interact through a political game, involving conflicts, negotiations and interests. Dixit (1996) emphasizes that are multiple actors, each one with a single set of goals, interacts in the public policy definition and implementation. Each player has different incentives and conditions to influence the reform process.

Glachant (2002) shows that there are different ways to combine the market structure with institutional framework in the network industries reforms, which would ensure a socially and economically desirable changes. It is also important to note that changing the institutional framework is *path dependence* process, since institutions depends on the historical setting through which it was developed. In addition, it is relevant to mention that non-economic variables strongly influence decision making in each country.

As the traditional regulatory analytical approach couldn't adequately explain many reform experiences, Spiller started a research agenda in the early 90s applying institutional analysis based on North (1991) and Williamson (1985 and

---

[112] As a example, we can quote the following works: (i) Roxo (2005); (ii) Gehlbach & Malesky (2008); (iii) Scartascini, Stein & Tommasi (2008).

1996). This approach wanted to explain the conditions, which ensured the credibility of the reforms. According to spiller credibility is crucial to guarantee stable commitments between the parties involved in the regulation. In Spiller model, stability depends on how the four regulatory devices[113] are applied in the country's political system[114]. Spiller model tested the stability of each regulation device in the various political systems[115], showing a different degree of stability and credibility in reforms processes. The initial model of Spiller (based on the identification of points of veto) has explained various reform processes satisfactorily. However, it failed to explain the performance of the reform process in several countries.

According to Perez's (2004), Spiller model lacks a set *ex post* actions capable of taking account of both non-anticipated events. It is vital to consider the evolution of interactions between the different dimensions[116] of the regulatory environment, which are under a continuous process of change that can affect the shape of the regulatory environment and the allocation of power inside it. Perez (2004) has proposed the improvement of the original model of Spiller through the introduction of a new concept of credibility in reform in network industries: the seeking of ensuring the stability of commitments *versus* the permission to the evolution of the game's rules, giving space to the adoption of flexibility, avoiding simultaneously opportunistic actions. This will allow the regulatory contract remains in line with the evolution the institutional environment. This is crucial to the attraction of investments, since the reform is a continuous learning process. It is necessary to ensure that the mistakes made during the development of rules

---

[113] The regulatory devices considered by Spiller (1998) are: (i) Specific legislation, (ii) Presidential Decrees, (iii) concession or license contracts, and (iv) Administrative procedures.

[114] They are: (i) the North American system of Presidential *check and balance* (there is a strict separation of the Executive, Legislative and Judicial powers, each one with veto power), (ii) Weak bicameral (kind of deterioration of the bicameral system, leading to the proximity of the veto power of the Legislative Chambers), and (iii) the Parliamentary System (the Executive and Legislative powers are concentrated and controlled by a single political party, getting closer these two veto players).

[115] According to the Spiller model (1998), regulatory devices are stable if: (i) the concession contracts (or licenses), as administrative procedures in presidential political systems, (ii) the administrative procedures in presidential or parliamentary systems that adopt the weak bicameral model, and exclusively the concession contract (or licensing) in parliamentary systems.

[116] It should extend the understanding of the credibility definition, to cover the interrelationship of the following dimensions: (i) macro (the State, and the Executive, Legislative and Judicial powers), (ii) intermediary (the regulatory agencies), and (iii) micro (regulated firms).

and the choice of the governance structure to be adopted can be corrected (Bicalho & Pinto Jr., 2004; Glachant, 2002 and Perez, 2004).

This Veto Players model can be applied to analyze how the reform proposals are developed, negotiated and approved within the political arena. One advantage of this analytical approach is the fact that it doesn't require a deep knowledge of the different types of existing political systems. The reform process is the result of a political decision making, according to the institutional and governance specificities of each country. To evaluate the path traced by the reforms of the existing *status quo*, as well as its speed in the political arena, it should be noted the veto players' position and characteristics, who can be: constitutional, partisans or informally ones (Tsebelis, 2002).

The analyze of a veto players' require to check how they are positioned into the political arena, in order to safeguard their interests into the power game, defining who are the players that have – effectively – both the veto power in the decision making process and the ability to determine what's going to be the political agenda. The player who has the power agenda[117] should elaborate proposals to the other veto players that must be feasible to be accepted. Finally, a higher number of veto players tend to increase the difficulty of negotiation (Tsebelis, 2002).

In the next sections, it'll be examined the Brazilian reform experience in the gas sector, in the light of the model of veto players, emphasizing the negotiating process through a new legal framework for this sector.

2 - Industrial Organization and Market Context in the Brazilian Gas Industry

Even though Brazil decided to end Petrobras's legal monopoly in the gas production and commercialization in 1997, the market structure is still very concentrated on Petrobras. The company is still responsible for almost all domestic production and gas imports. There are very few independent gas producers operating in Brazil, although about 60 companies have acquired oil and gas exploration rights. Independent gas producers have decided to sell their production to Petrobras, instead of trying to access the market. These companies have encountered important obstacles to directly sell their gas production.

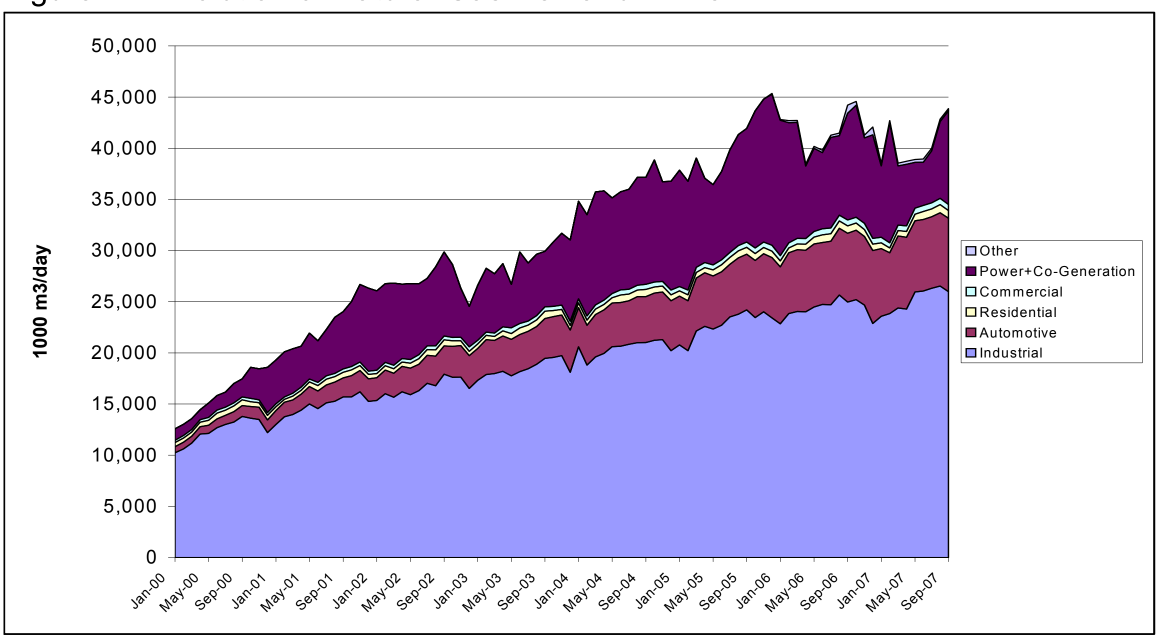
---

[117] Often, the agenda power is played by an actor collective with preferences, which are not clearly defined, and so it's difficult to predict the set of policies that can replace the existing *status quo* (Tsebelis, 2002).

One of the most important obstacles for the reduction of market concentration in Brazil is Petrobras' cross participation along the gas chain. The company is not only the largest producer, but it controls over 90% of the gas transportation capacity since most of the domestic pipelines belong to Petrobras. In addition, Petrobras has participation in 20 of the 27 gas distribution companies operating in Brazil. Therefore, Petrobras can determine the gas procurement's strategy of most of the distribution companies operating in Brazil.

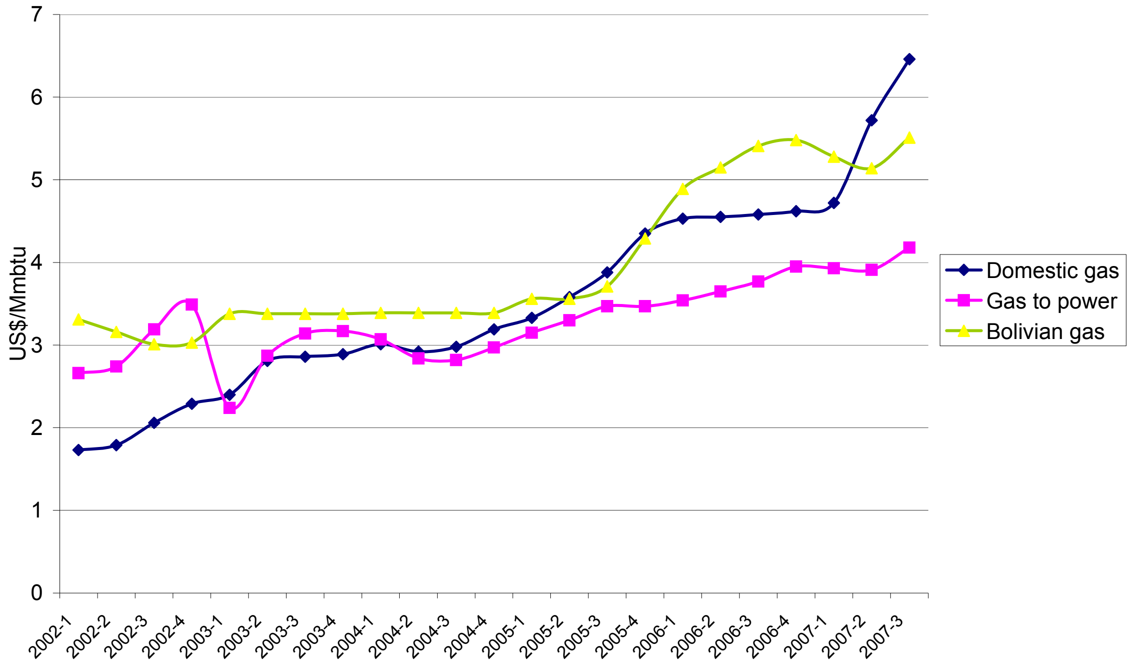
Brazilian natural gas industry has experienced a rapid development in the last 10 years, with gas demand growing at an average of 12% per year in this period. This demand growth was the result of replacing oil products demand in the industrial sector; the conversion of about 1.3 million vehicles from gasoline into CNG; and the development of thermal power plants to complement hydro generation. This rapid development has been jeopardized by a gas supply shortage after 2005 (see figure 1). The gas supply problem is raising a number of questions about the ability of current regulatory framework to attract private investments.

Figure 1 – Evolution of Natural Gas Demand in Brazil.




Since the start of gas shortage in 2005, thermal power plants are disputing gas supply with other market segments. Petrobras has been responsible to arbitrate the dispute over gas supply. In order to accommodate these two market segments Petrobras has managed gas market by: i) Increase in the gas prices (figure 2); ii) managing its own consumption; and promoting interruptible gas contracts. In order to reduce the supply shortage Petrobras made gas upstream investments a priority[118]. In addition, the company is investing in two regasification terminals in order to import LNG. To guarantee Bolivian gas supply, Petrobras has agreed to resume its investments in the Bolivian upstream[119].

Figure 2 – Evolution of Natural Gas Prices at the City-gates in Brazil




S

3

Natural gas regulatory framework in Brazil was defined by the law 9478 approved in 1997. This law has created a regulatory body for oil and gas sector, the National Regulatory Agency for Petroleum and Gas - ANP. ANP is an independent regulatory institution directed by a collegiate board, formed by one General Director and four Directors, all appointed by the President and approved by the Senate ANP. They have a fix mandate of 4 years each.

---

[118] In 2006, Brazilian government has created a program to induce the reduction of Brazilian dependence on Bolivian gas (Plangas). As a result Petrobras committed itself to a plan to increase gas supply in the South and Southeast regions from 24 million m³/d to 55 million m³/d by the end of 2010.

[119] Petrobras had decided to freeze its investments in Bolivia since the political turmoil in 2005 and the gas nationalization of 2006.

The role of ANP in the natural gas sector is restricted to the upstream and the transportation segment. Gas distribution is regulated by the States directly or through states regulatory agencies. Therefore, each state has the autonomy to define the policy and regulatory framework concerning gas distribution.

According to the 9478 law, the upstream investments in Brazil are subject to open competition. ANP is responsible for organizing exploratory bidding rounds. All qualified domestic and foreign companies can participate in the exploratory bidding rounds. Similarly, there is no restriction for the investments in the gas transportation segment. Every interested company can apply for an authorization license. Transportation capacity in new pipelines should be offered through open-season process where all shippers should have equal opportunity to participate. The pipeline operator is also required to offer open access to the gas pipelines.

According to 9478 law, ANP is not in charge of defining the gas transportation tariffs. These tariffs are negotiated between the transportation company and the shippers. ANP should only approve the negotiated tariffs. Nevertheless, ANP has defined some methodology for tariffs calculation according to the type of transportation service.

The 9478 law does not empower ANP to enforce changes in the structure of the industry. As far as the competition is concerned, ANP is responsible to notify the Administrative Council for Promotion of Competition – CADE, in charge of promoting competition, the problems of this nature. The lack of power to deal with competition problems and the fact that the distribution segment is out of reach of ANP responsibility led to a situation where very little have been done since 1997 to promote competition in the BGI.

Since 2004, a wide consensus has been formed in Brazil that the 9478 law was not adequate to attract private investments and promote competition in the BGI. Important aspects of the industry dynamics has not been regulated by the 9478 law. This law was oriented to open the upstream activities, especially for oil production. Specific aspects of the gas downstream have been ignored, such as pipeline system operation regulation, open access regulation and tariffs.

In order to build a new gas law, three projects were proposed to the National Congress. The first, authored by Senator Rodolpho Tourinho from the Social Democratic Party (PSDB) was proposed to the Senate in 2004. This proposal has suffered an important influence of the private companies BGI, and aimed at creating conditions for increasing competition in the natural gas supply in Brazil. In the same year, a bill was proposed in the Chamber of Deputies by Deputy Luciano Zica from the government's party (PT) aiming to compete with

Tourinho's proposal. The proposal of Deputy Zica provided little changes in the *status quo*.

In 2006, the federal government sent a draft law alternative to the Chamber of Deputies, the 6673 bill. It was a government attempt to use its agenda power, assuming the conduction of the debate on the gas law. Basically, the Executive's bill proposal has emphasized the gas transportation segment. Main aspects of the law proposal were: (i) changing access rules according to the network maturity; (ii) the natural monopoly characteristics of the transportation and distribution of natural gas, (iii) the establishment of rules for the secondary market for natural gas; (v) the National Energy Policy Council (CNPE) should be responsible for establishing priorities for natural gas consumption in situations supply shortage. Finally, it is important to mention that the government proposal has emphasized the role of government in promoting the gas policy.

In 2007, a Special Commission was formed in the Chamber of Deputies to prepare a new gas law proposal to unify and replace all three concurrent gas law projects in the congress. The three proposals were unified and new proposal was submitted to the congress in August 2007. Since then a long period of negotiation took place in the political arena. This proposal was approved by congress only in December 2008.

3.1 – Main regulatory Changes of the New Gas Law

After 4 years of tough negotiations Brazilian congress has reached a consensus over a new gas law. The negotiations for the new gas law have resulted in few significant changes as far as the 9478 gas law was concerned. The new law changes were focused on the gas transportation segment and backbone of 9478 law has been maintained. For instance, the distribution segment remained out of the scope of the Federal Gas regulation. This means that only state governments can propose any change in the distribution monopoly over the end-market; current industry structure remained unchanged, and Petrobras continues to be the dominant player in the gas production and imports, with no restrictions to cross participation in the gas chain. Even though Petrobras is practically the sole gas supplier, the company remained free to decide de gas pricing policy in Brazil.

As mentioned main change in the new gas law concerns the transportation segment. Under the 9478 law, transportation pipelines required authorizations licenses given by the ANP. In the authorization contracts, pipeline companies assume all economic risks involved in the project and are free to fix the transportation tariffs. The new gas law determines that new pipelines will receive a 30 years concession contracts. These contracts will be allocated in a competition process where investors will dispute the opportunity to invest in the pipeline[120]. These contracts give ANP the right to fix the tariffs. ANP will organize an open season process to determine the demand for transportation services for each pipeline expansion/construction. Once the demand is determined, ANP will organize the bid for selecting the investor. The bid winner will be the investor that requires the lowest annual revenue and therefore smaller tariffs.

The proposal also allows new pipelines to be built under current authorizations licenses. Therefore, these licenses will be restricted to pipeline for importing natural gas or a pipeline to be used by a specific consumer.

According to the new law, open access to transportation pipelines shall be ensured only after a period of exclusivity. During the exclusivity period only initial shippers that bought transportation capacity in the open season process can use the capacity available capacity in the pipeline[121]. The period of access exclusivity in the current transportation pipelines is 10 years, counted from the start of commercial operation. In the case of new pipelines the Ministry of Mines and Energy will fix the exclusivity period.

Once the concession contract ended, the goods and equipments, linked to the transport activity will be reversed to the Union, upon payment of fair and prior compensation in money to the concessionary. Operators will have to keep providing services until they were replaced by others or the gas pipeline is deactivate, and the operation tariffs, during this transition period, will be set by the ANP.

---

[120] The new gas law establishes rules and mandatory terms for concession contracts, and also for the biddings, including: (i) the description of the transport pipeline's route, object of the concession, (ii) the point of injection and delivery; (iii) the transportation capacity projected and criteria used for its determination. The selection of the investor in the project will be done through a bidding process organized by ANP. The rules of access in the pipeline should be transparent as well as the rules to be employed to resolve disputes. It was also determined the establishment of a emergency and contingency plan, in order to avoid facts and circumstances that may interrupt the transport services.

[121] The initial shipper is defined as: "the one whose hiring of transport capacity has enabled or contributed to enable the construction of the pipeline, in whole or in part."

Aiming to conciliate the interests of large gas consumers with the need to respect the States monopoly in the gas distribution, the new gas law has innovated through the creation of the following actors in BGI: the free consumer[122], the auto producer[123], and self-importer[124]. These definitions aimed at reduce obstacles for large energy-intensive companies to have access to natural gas. Now, in case the local distribution company lack the necessary resources to build the infrastructure for gas distribution, large consumers have the possibility to directly invest in the required infrastructure to procure natural gas[125].

The new gas law requires the National Council of Energetic Policy (CNPE) to establish guidelines for the natural gas use as raw material in the industrial productive processes, through the regulation of specific criterias and conditions, to its efficient use and compatible with domestic and foreign markets.

The import and export activities will be subject to authorization, following the CNPE's guidelines. The activity of natural gas storage in geological formations will be exercised by means of concession, preceded by bidding process. The other forms of storage shall be carried out through authorization contracts.

The MME will be responsible to plan and propose new projects or expansion of existing pipelines. MME will also determine key aspects of the new pipeline projects such as which type of license should be used (authorization or concession); the public sector participation in the investment through Public Private Partnership; the use of public resources for financing or subsidize the project in order to make viable projects considered of relevant public interest.

3.2 – The New Gas Law: Remaining Inconsistencies

The use of natural gas can represent an important differential in terms of competitiveness for industrial companies, and thus for the country. The

---

[122] Free consumer: natural gas consumer, who under the terms of the state law, has the option to purchase natural gas from any agent producer, importer or trader."

[123] Auto producers: natural gas explorer and producer agent that uses all or part of its production as raw material or fuel in their industrial plants;

[124] Self importer: authorized agent to promote natural gas import, who uses all or part of the imported product as a raw material or fuel in their industrial plants.

[125] These players will be authorized to build gas pipelines for their specific use if they sign authorization contracts with the state distributor, attributing to the latter, its operation and maintenance. Similarly to what happens in the federal sphere, this infrastructure will be incorporated into the state's assets by means of a public utilities declaration, and through fair and prior compensation, when it'll be completely used.

advantages of using natural gas added to the environmental restrictions to the use of coal and fuel oil represent strong incentives to its industrial use.

The natural gas development potential in Brazil conducts us to two central issues. First, the definition of a domestic price policy is essential to guarantee the expansion of natural gas consumption, especially in the industrial and power generation sectors. In a context of lack of competition in the supply side, the gas price is fixed by Petrobras with no transparent methodology. It has generated a major conflict along the natural gas chain, which also involves the local governments.

State governments have pushed Petrobras to offer low cost natural gas to promote industrial and power generation development. A usual argument used is that the associated gas opportunity cost at the wellhead is close to zero[126]. Thus, end consumers and the local governments criticize the use of international prices for the domestic natural gas production, especially for the associated gas.

Another major source of conflict in the gas chain is related to the state regulation. The natural gas market development depends on the regulatory conciliation between the expansion of the local distribution infrastructure and the emergence of competitive forces. The resolution of issues concerning open access and commercial by-pass, and the new contractual arrangements for the gas commercialization are, thus, crucial for the expansion of the distribution infrastructure, and to assure the development of new markets.

Today, there are two distinct categories of concession contracts in the natural gas distribution activity in Brazil. The first model of contract refers to the one used by state enterprises. Although, the activity of regulating the distribution service is exclusive of each state government, there is a standard contract for the distribution of state companies.

The second category is based on private companies, which is more diverse than the first group. These contracts regulate the distribution companies' activities in the state of Rio de Janeiro[127] and Sao Paulo[128], but it is important to note that there are some differences between them. However, the existence of common characteristics to both concessions types allows us to put them into a single category.

---

[126] The cost of associated gas production is under the whole investment cost, except for the pipeline infrastructure . In other words, the oil production should guarantee the return on the investment, including the natural gas extraction.

[127] Ceg and Ceg Rio

[128] Comgas, Gás Brasiliano and SPS Gás Natural

The analysis and comparison of the incentive structure of the two groups allows identifying important regulatory shortcomings with regard to stimulate investment, the quality of services and the development of competitive forces, mainly in the group of state owned enterprises. Thus, the resolution of "regulatory bottlenecks" in the segment of natural gas distribution is an important key issue to be settled.

From the beginning of the gas supply crisis in 2005, there was a dispute between the electricity sector and the gas distributors over the priority of additional gas supply. The electricity market is characterized by a high growth rate and an installed capacity of electricity generation in the country of about 100 GW. In this scenario, if the expansion of the power sector is concentrated on gas, large amounts of natural gas may be consumed in the electric sector, reducing the supply to meet the industrial demand.

Finally, a growing source of conflict is the increasing need to flexibility the gas demand, in order to reduce costs and meet the power generation needs. A crucial feature to be considered in this sector is the great uncertainty regarding the future gas demand. The installed capacity of gas-fired thermoelectric generation has been growing, but this capacity function as an insurance hydroelectric generation. Therefore, the thermal dispatch occurs only during periods of low hydraulicity.

Pinto Jr. et alli (2007, p.284) highlights the following characteristics of the Brazilian NGI that result in a high cost for the supply flexibility. They are:

There’s no storage capacity developed outside the own storage capacity of the pipelines.

About 75% of national production comes from associated gas fields. Thus, in the case of change in the gas production with the objective to take account of the need for flexibility of the thermal generation sector, it would have impacts on the oil production.

Almost all associated gas production and 60% of non-associated gas production come from offshore reservoirs. Even the recently discovered gas reserves in the Santos Basin, despite being non-associated gas, have a high opportunity cost in terms of the expressive investment cost needed to develop these offshore reservoirs, and the liquids from gas, which wouldn’t be produced during periods of reduction of production.

The current production of onshore non-associated gas is located, basically, in the Amazon Region isolated system[129], without the possibility to offset the change in the Brazil's Northeast or Mid-South gas demand,

The variation in the gas supply imported from Bolivia also has a high opportunity cost, given the great distance of the consumption centers in Brazil.

Therefore, it is desirable to add flexibility at the demand side. It would lead to a more efficient system and lower the overall cost to gas consumers. In this sense, an important challenge to the natural gas regulatory framework is to guarantee the legal conditions to allow for market based solutions towards more flexibility and lower risk to investments.

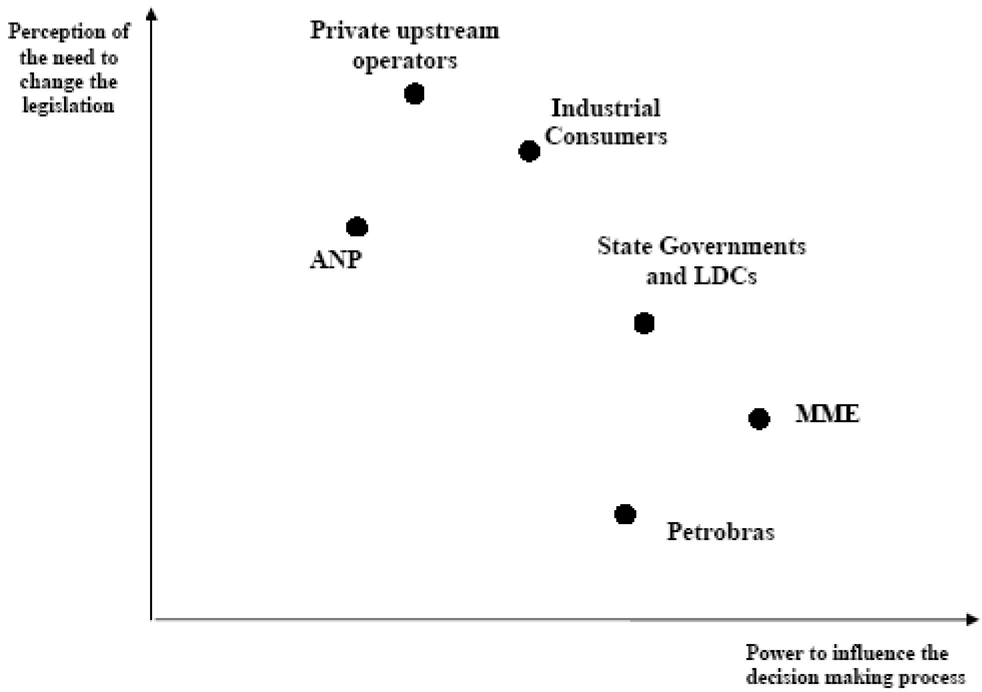
4 – Veto Players and Barriers Towards Best Practices in Brazilian NGI

The negotiation process in the reform of the Brazilian NGI involve 6 main players or group of players: 1) the Federal Government represented by the Ministry of Mines and Energy, 2) Petrobras; 3) State Governments and/or local distribution companies (LDC); 4) National Oil and Gas Regulation – ANP; 5) Large industrial gas consumers; 6) and private upstream operators. Figure 3 shows that each of these players have different level of power to interfere in the decision making process and different perception of the need to change gas regulatory framework. One important characteristic of case of Brazilian NGI was the fact that players more committed to the reform were those with less power to interfere in the decision making process. This was the main reason why the negotiation process took so long to reach a consensus.

From the 6 players, we can consider that 3 have been Veto Players: Petrobras, MME and State governments and LDC. These players have been able to avoid any significant regulatory change that could harm their interests, by establishing pre-conditions for the negotiation process. The result was not only a lengthy negotiation process but a new law with few significant changes on the regulatory framework.

[129] According to the National Operator of the Electric System, there is a plan to integrate the whole Amazon Region to the National Integrated System (SIN) by the end of 2010.

Figure 3 – Main Players in the Brazilian Natural Gas Industry




Source: Own elaboration

As it is summarized in table 1, the main players involved in the negotiation process for the new law had very different objectives. The federal government main objective in the negotiation process was in increase its ability to interfere in the sector dynamics. President Lula cabinet has always expressed its discomfort to the fact that the MME has had a reduced role in the gas sector to the benefit of ANP and Petrobras. Therefore, the government has tried to increase its ability to influence the sector dynamics. The government has tried to give MME a central role in planning the expansion of the gas transportation pipeline and formatting the business model for new investments in the sector. MME was an important winner in the negotiation process since a central expansion planning was approved, giving the MME the power to define new pipeline routes and the ability to support new investment with public funds (subsidies).

Petrobras was the only of these players that was contrary to changing the 9478 law. Its director for natural gas has expressed several times that changing the law was unnecessary. Petrobras has sustained that Brazilian NGI was at its infancy and any change aiming at promoting competition in the downstream would create obstacles for new investments in the sector. Petrobras was clearly at a defensive position fearing the threats that a new law could create to its dominant position. Once the legislative process started Petrobras has been very active in defending its interest. One of its most important objectives in the negotiation has been to guarantee the by-pass of gas distribution companies in case of its own gas consumption. Petrobras is by far the largest natural gas consumer in Brazil. Petrobras consumes about 30% of all natural gas in Brazil in its platforms, refineries and industrial plants[130]. Several state governments and distribution companies have been questioning the fact that Petrobras does not pay anything for the distribution companies, when it directly supplies gas for its own plants. The new gas law has clarified this situation. The gas supplied to oil refineries and Petrobras' fertilizer plants was considered out of the distribution monopoly. The same applies to the gas consumed in the platforms.

Another important objective of Petrobras was to avoid the adoption of a compulsory open access to its infrastructure of gathering pipelines. Petrobras owns the totality of the 2,500 kms of gathering pipelines in Brazil (mainly offshore). If other gas producers were able to have access to this infrastructure they would be able to directly negotiate with distribution companies and large free consumers instead of selling their gas to Petrobras. The law explicitly excludes all gathering pipelines and pipelines that transport gas between processing plants and refineries from the opens access requirements.

Since 2004, ANP has been very active in supporting the government and the congress on the necessary changes on the 9478 law. The agency has contracted international consulting companies to identify weaknesses of the Brazilian gas regulatory framework. This diagnosis has been presented to the government the other players. The main objective of ANP was to increase its regulatory power and ability to accomplish with the mandate of promoting competition in the downstream. More specifically ANP has identified the need to change the regulatory contract of the transportation segment. The authorizations required in the 9478 law did not allow ANP to regulate the open access to the pipelines. ANP did not manage to increase its regulatory power. Nevertheless, the authorization contracts were replaced by concession contracts, with gas tariffs being decided in a competitive bidding process organized by ANP.

State governments were able to maintain their monopoly power over the gas distribution segment. The monopoly over the end gas market allowed increasing the value of the distribution companies. In addition, by controlling the regulation over gas distribution, state governments maintained an instrument for industrial

---

[130] This number does not counter gas consumed in thermal power plants and industrial plants, such as petrochemicals, where Petrobras has a stake.

policies. Nevertheless, states remained very depend on Petrobras regarding the natural gas supply.

Large gas consumers did not manage to increase the level of competition in the natural gas supply. The access of new suppliers to the network remained very difficult and their status as consumers continue to depend on the state level regulation. Nevertheless, large consumers gained the possibility to directly import natural gas, limiting Petrobras and distribution companies' market power. Finally, the private upstream operators have obtained very limited gains in the new law. Their main objective was to reduce barriers to entry in the downstream segment. The difficulties to access the end market remained very important, given Petrobras' market power. The only gain for private operators was the creation of auto-producer player. According to the new law, gas producers can consume their production in their own industrial plants (for instance thermal power plants or petrochemical plants). In this case, they should pay distribution companies for operating and maintaining the pipelines liking the gas processing plant and the industrial plant.

Table 1 - Main players in the Negotiation of the New Natural Gas Law in Brazil

| | MME | Petrobras | ANP | State Governments/LDCs | Large Consumers | Private upstre operators |
|---|---|---|---|---|---|---|
| Main Objectives | Strengthen and amplify the planning and intervention power | Maintain its market power and dominant position | Amplify its regulatory power and increase competition<br>Open access to the downstream | Maintain distribution monopoly<br>Increase upstream competition | Increase competition in the entire chain | Reduce e barriers |
| Positions at the negotiation process | Tried to guarantee a central role in NGI planning investment dynamics | Tried to avoid big regulatory changes<br>Tried to ensure distribution by-pass for its own gas consumption<br>Tried to avoid open access to the gathering pipelines infrastructure | Tried to establish a concessions regime in transportation<br>Tried to increase its role on tariff regulation in transportation<br>Tried to increase its enforcement power | Tried to avoid physical and commercial by pass of the distribution companies; | Tried to create tariff regulation in transportation<br>Tried to increase open access to the network<br>Tried to implement physical and commercial by pass of the distribution companies | Tried to incre open access the network<br>Tried implement physical a commercial pass of distribution companies |
| Profits | Planning the sector expansion | Few changes in regulatory | Concessions regime for new | Maintenance of distribution monopoly | Possibility to commercially by- | Possibility commercially |

| | | | | | | |
|---|---|---|---|---|---|---|
| | Ability to determine investment in the transportation segment | framework<br>Permanence of dominant position<br>Ability to by-pass distribution companies in case of self consumption | pipelines | | pass distribution companies in case of gas imports for own consumption | pass distribu companies case of consumption |
| Losses | Not relevant | Not relevant | Enforcement remained low<br>Absence of tools to stimulate competition | By-pass of distribution companies in case of self consumption | Lack of competition | no reduction entry barriers |

Source: Own Elaboration

5 - Conclusions

This paper has analyzed the evolution of Brazilian natural gas regulatory framework and has tried to explain why it has been so difficult to reach a political consensus on the new gas law. The paper has shown that although vast majority of players had the perception that the former regulatory framework was inadequate to promote the development of Brazilian GNI, very few changes have been introduced in the new gas law.

In order to explain why the negotiating process has been so difficult, the paper has applied the analytical framework of the institutional economics theory, focusing Veto Players model. We have identified 6 main players or group of players in the negotiation of the new gas law: 1) the Federal Government represented by the Ministry of Mines and Energy, 2) Petrobras; 3) State Governments and/or local distribution companies; 4) National Oil and Gas Regulation – ANP; 5) Large industrial gas consumers; 6) and private upstream operators. The paper has shown that three of these players can be considered Veto Players. These veto players were able to preserve their interest in the negotiation process, reducing the scope for changing the regulatory framework.

The paper has also shown that the veto players were those less committed with reforming the *status quo*. The players more committed to the reform (ANP, large gas consumers and private operators) did not have power to define the negotiation agenda and to act as Veto Players. As a consequence, the new gas law has been approved after 4 years of intense negotiation, with very few gains for the large gas consumers and private gas upstream operators. Therefore, the level of competition in Brazilian NGI tends to remain very low in the years to come.

The paper has shown that there are several inconsistencies the new gas law approved, as far the development of Brazilian NGI is concerned. One of the most important is the potential conflict between the agents over current natural gas pricing policy. Considering the absence of competition, Petrobras market power tends to be questioned by the other players, resulting in a significant level of conflicts. The asymmetry between federal and state gas regulation is another potential source of regulatory conflicts in the NGI. Finally, there are some driving forces for increasing the competition in the downstream segment: increasing the competition in the upstream; and the need to flexibility in natural gas demand, in order to accommodate the fluctuation of thermal power plants gas demand. These driving forces will be a future source of tensions for the current NGI regulatory framework. Therefore, we believe the remaining inconsistencies tend to jeopardize the stability of the current regulatory framework.

6 – References

ALMEIDA, E. (2004) “Mercado de Gás Natural no Cone Sul”. Grupo de Economia da Energia, Instituto de Economia, UFRJ: Rio de Janeiro.

ALMEIDA, E. e PINTO Jr., H. (2005 )“Evolução da Indústria de Gás Natural: Modelos de Regulação e Lições para o Caso Brasileiro”. Rio de Janeiro, october.

AUSTVIK, O. G. (2003) Norwegian Natural Gas. Liberalization of the European Market. Oslo.

BICALHO, R et alli (2007). *Ensaios Sobre Política Energética*. Editora Interciência, Rio de Janeiro.

BICALHO, R.; PINTO JR., H.. (2004) “Novo Modelo Institucional do Setor Elétrico”. Infopetro Boletim Infopetro, Jan., 2004. Available at <http://www.ie.ufrj.br/infopetro>. Accessed on November, 2008.

BRAZIL. (2008a) *Coletânea de Legislação Administrativa e Constituição Federal*. 8ª edition. Ed. Revista dos Tribunais São Paulo,

BRAZIL. (1993) Federal Law nº. 8.666 of June 21st, 1993 with its following changes. Available at: <www.senado.gov.br>. Access on November.

BRAZIL. (1997) Federal Law nº. 9.478 of August 6th, 1997. Available at: <www.senado.gov.br>. Access from May, 2008 to January, 2009.

BRAZIL. (2006a) Senate Bill n.° 6.666 of February 22nd, 2006 with its following changes. Available at: <www.senado.gov.br>. Access from June, 2008 to January, 2009

BRAZIL. (2006b)Chamber Bill n.° 6.673 of March 7th, 2006 with its following changes. Available at: <www.camara.gov.br>. Access from June, 2008 to January, 2009.

BRAZIL. (2007a) Chamber Bill n.° 334 of April 3rd, 2007 with its following changes. Available at: <www.camara.gov.br>. Access from June, 2008 to January.

BRAZIL. (2007b) Senate Bill n.° 90 of November 15th, 2007 and its following changes. Available at: <www.senado.gov.br>. Access from June, 2008 to January, 2009.

DIXIT, A. (1996). The Making of Economic Policy: A Transaction Cost Politics Perspective. MIT Press, Cambridge, MA.

GEHLBACH, S., MALESKY, E. J. (2007). ”The Role of Veto Players in Economic Reform”. Paper prepared for presentation at the 2007 annual meeting of the International Society for New Institutional Economics. Available at

<www.isnie.org/assets/files/papers2007/gehlbach.pdf> Accessed on December 12th, 2008.

GLACHANT, J. M. e BROUSSEAU, E. (2002) “Contract Economics and the Renewal of Economics”. In Glachant J. M.; Brousseau E. (orgs.) The Economics of Contracts: Theories and Applications. New York, EUA: Cambridge University Press, 28 pp.

GLACHANT, J. M; DUBOIS U.; PEREZ Y. (2008 ). “Deregulating with no regulator: Is Germany electricity transmission regime institutionally correct?” ADIS research centre, University of Paris XI. Available at: <www.grjm.net>. Access on November.

MCCUBBINS, M. D; NOLL R., et al. (1987). “Structure and Process, Politics and Policy: Administrative Arrangements and Political Control of Agencies”. Virginia Law Review, v. 75, n.2, p 431-482,

NORTH, D. C. (1991). “Institutions”. Journal of Economic Perspectives, v. 5, n. 1, p. 97-112, Jan. 1991.

____________. *Institutions, institutional change and economic performance*. Cambridge: Cambridge University Press, 1990.

NORTH, Douglass C. (1992). Transaction Costs, Institutions, and Economic Performance. San Francisco: ICS Press.

PEREZ, Y. (2004 ) “Credibiltiy as trade-off in network industries”. University of Paris XI, Working Paper GRJM ADIS, , 19 pp. Available at: <www.grjm.net>. Accessed on October, 2008.

PETROBRÁS (2008). *Plano de Negócios 2008-2012.* Petrobrás, 2007. Available at: <www.petrobras.com.br>. Accessed on December.

PINTO Jr. H., et alli (2007). Economia da Energia: Fundamentos Econômicos, Evolução Histórica e Organização Industrial. Campus Press, Rio de Janeiro.

Roxo, L. F. (2005). *A Credibilidade das Reformas: Uma Análise do Setor Elétrico Brasileiro.* Tese de Mestrado (M.Sc. in Economics), Institute of Economics, Federal University of Rio de Janeiro, Rio de Janeiro, 169 pp.

SCARTASCINI, C.; Stein, E. H. & Tommasi, M. (2008). “Veto Players, Intertemporal Interactions and Policy Adaptability: How Do Political Institutions Work?”, RES Working Paper 4593, Inter-American Development Bank (BID), Research Department, August, 2008, 48 pp. Available at: <www.iadb.org>. Access on November.

SPILLER, P.T. (1996 ) “A Positive Political Theory of Regulatory Instruments: Contracts, Administrative Law or Regulatory Specificity?”, USC Law Review v.69, n.2, pp. 477-515.

SPILLER, P.T..; BERGARA, M. & HENISZ, W. "Political Institutions and Electric Utility Performance: A Cross Nation Analysis", California Management Review v.40, n.2 (Winter, 1998), pp. 18-35.

TSEBELIS, G. (1997). "Processo Decisório em Sistemas Políticos: Veto Players no Presidencialismo, Parlamentarismo, Multicameralismo, e Pluripartidarismo". Revista Brasileira de Ciências Sociais, São Paulo, v.12, n.34, June, pp. 89-117.

TSEBELIS, G. (2002). *Veto Players: How Political Institutions Work.* Princeton., New Jersey: Princeton University Press.

WILLIAMSON, O. E. (1985). *The Economic Institutions of Capitalism*. New York: The Free Press.

__________________. (1996). *The Mechanism of Governance*. New York: Oxford University Press.

# 34. The Rig Market: Economic Issues and Implications on Oil Companies Strategies

**Raul Ramos Timponi**

Masters student at The Federal University of Rio de Janeiro (UFRJ),

Institute of Economics

Av. Pasteur, nº. 250 Room 123

Rio de Janeiro, RJ - CEP: 22290-240

+55 21 38735257

raultimponi@ie.ufrj.br

Key words: Rig market; Transaction costs; Vertical integration.

Abstract: Integration, in different levels of the oil supply chain, has been discussed in the literature since the sixties, first motivated by antitrust studies. Many reasons are pointed out to justify why structural changes have been taking place. Although drilling activity is not vertically integrated, reasoning why brings us interesting insights for further discussions, and rigs, as one of the main inputs in the upstream stage of exploration and production in the petroleum industry, deserve our consideration. In a context where the importance of deepwater drilling is increasing, some crucial changes in the rigs market structure are worth of notice. This paper intends to show what these changes are, how they are closely related and, finally, bring together all these aspects to analyze the strategies used by oil companies when drilling their wheels. Based on a transaction cost analysis, described by Williamson (1985), alternative strategies for the future are suggested.

## 1.- Introduction

Integration in different levels of the oil supply chain has been discussed in the literature since the sixties, first motivated by antitrust studies by Teece (1976). Despite the fact that he found few reasons to believe that the industry is oligopolistic in nature, concrete historical facts showed us that concentration and vertical integration in the oil industry have always been widespread characteristics.

The upstream segment went through many changes since the seventies, from the large prevalence of major oil companies highly integrated and concentrated to powerful National Oil Companies, widely controlling the upstream sector. Nowadays, after a long restructuring process, oil companies are expanding again and even integrating some levels of the supply chain into their activities.

This article intends to focus on the exploration phase, more specifically in the drilling stage. Drilling service is usually outsourced and, consequently, it is not vertically integrated in the oil companies' activities. The answer why is not as simple, although it helps us find out what are the possible conflicts and tensions involved in drilling services. Considering some particularities of the rig market, we will show, based on a transaction costs framework, how this market can deeply affect oil companies' strategies and performance and how negative effects could be mitigated. This concern is frequent in the literature, as seen in Osmundsen, et al. (2008): "combined with a substantial increase in contract length, scarcity of rigs has prompted a number of discussions over possible changes in contractual and organizational patterns for drilling on the NCS".

Following this introductory section, we review vertical integration in oil industry, in a historical and conceptual approach. In the third section, first we characterize drilling rigs and try to show the intrinsic aspects of the rig market, as its cyclicality, revenue patterns and concentration. Then, in section 4, drilling contracts are briefly discussed before we introduce Transaction Cost Theory, first described by Williamson (1985). From this, we analyze risks and losses taken by oil companies in drilling activities, suggesting alternative strategies for the future. Finally, we conclude in the last section.

## 2.- Vertical integration in the oil industry

When the oil industry started some 145 years ago, producers, refiners and marketers[131] were not identical. In that context, refiners were the centerpiece: the operations involved were bigger and more complex than the preceding and subsequent phases of the whole oil industry. Historically, it is from refining that the

[131] This term describes all the transport, distribution and commercialization segments of the oil supply chain.

industry came towards concentration and, therefore, integration. Integration here will be defined as “a process of linking units – or levels – which are or were originally independent of one other” (Frankel, 1953). In other words, the existence of integration depends on “whether there is in fact one oil industry or whether there are different industries – crude oil production, refining, distribution, with transport functions interposed between each of two of these phases” (Frankel, 1953).

The history of integration in the oil industry started with John D. Rockefeller. In the beginning of his long journey through this industry, he was first and foremost a refiner who obtained great success in becoming bigger and better. Crude oil producers have always had the problem of finding oil. After that, investment and profit came easily. The producers who failed to find oil ended in bankruptcy, concentrating this segment in few hands. In this environment, we observed the refiner (mainly the big enterprise Standard Oil) starting to establish retail outlets, going into distribution, taking advantage of knowing that the habit of a consumer can be counted upon with greater certitude than the wholesaler who is willing to switch more rapidly according to prices and terms (Al-Moneff, 1998).

The oil industry was concentrated in such a manner that, before 1973, the seven major companies known as the Seven Sisters, controlled 70% of the total oil produced in the world (Al-Moneef, 1998). They controlled production, transport, refining, distribution and marketing networks. Vertical integration was, until the early seventies, a key factor in the effective monopoly power of the oil majors, and the growth of the industry. During the seventies, we observed a change in the structure of the oil market: price decisions changed from the companies to the oil producing countries governments, that is, from an oligopolistic market to a cartel one, leading to changes in the oil industry. National Oil Companies (NOCs), thus, started to control most of the world reserves and crude production (upstream) while major oil companies focused on controlling the downstream sector (refining and marketing). Vertical and horizontal characteristics of Multinational Oil Companies (MOCs) were affected, in something like a disintegration process.

In the eighties, these companies went through a process of restructuring where mergers, acquisitions and development of new areas took place. After a period of administered oil prices (1975-1985), we moved to a system of market related prices. MOCs lost their initial vertically and horizontally integrated structures and were forced to restructure in the upstream and downstream. Just after the second oil shock, with high prices, they tried to reposition themselves in the upstream by developing new areas, engaging in reserve acquisitions as well as exploring and developing in non-OPEC areas. In the same way NOCs attempted a vertical integration through the construction of refineries aiming exportation and purchasing distribution facilities. As suggested by Al-Moneef (1998), “OPEC countries were able to increase the refined products component of their total petroleum exports from 6 per cent in 1976 to 19 per cent in 1996". It is interesting that this new process of integration has had the NOCs as important players instead of major oil companies.

However, since the 90's we have been observing another inflexion point in this 70's and 80's trend: significant flexibilization and liberalization on the monopoly of NOCs and the constant growth of major oil companies (even more concentrated than the 70's).

It is widely known that the oil industry came atop of the list in terms of degree of vertical integration. But, why has integration always been a present key factor in oil industry? Generally, "integration of several phases of industry or, conversely, the state of their independence is a function of the unit of operation in each phase" (Frankel, 1953). This means that if a stage of the total production chain has lots of units competing for supply and especially if all stages do quite the same thing, there is little incentive to integrate preceding or subsequent phases, because each operator will have a feeling of safety. This can change if on any level the unit of operation becomes big in comparison with the competitors of the same stage and the respective customers and suppliers. So, "branching out into the subsequent (or previous) phase is more often a method of safeguarding a position than one of adventure or lust for power" (Frankel, 1953). It is closely related with the drilling activity, as we will see later.

The degree of vertical integration is not necessarily positively related with the level of efficiency of companies. As we will discuss latter, integration brings the guarantee of supply for integration in lower levels of the productive chain and market assurance in higher levels of the productive chain, among other benefits. However, it also brings costs as managerial diseconomies, non-specialization of production, uncertainty on supply, etc.[132] Summarizing, "it seems that firms will decide to integrate for reasons related to the market structure, the characteristics of technology, the stage of maturity of the industry, and firm-specific factors" (Barrera-Rey, 1995). It is easy to imagine that most of these aspects are frequently present in the oil industry and that is why integration, historically, is so important.

In this background, another pertinent definition would be: "a firm will be vertically integrated if it incorporates two single production processes in which either: (1) the entire output of the 'upstream' process is employed as yurt or all the quantity of one intermediate input into the 'downstream' process, or (2) the entire quantity of one intermediate input into the 'downstream' process is obtained from part or all of the output of the 'upstream' process" (Barrera-Rey, 1995 apud Perry ,

[132] Depending on the approach (theory of the firm, the theory of contracts and the theory of markets), different costs and benefits are emphasized.

1989, pp. 185). Therefore, drilling activities could be considered vertically positioned in the exploration stage, as it anticipates other subsequent phases of exploration, like completion. We will see during this article that oil companies outsource drilling activities, not integrating them in the oil supply chain. Therefore, rethinking the question 'why drilling activities are not vertically integrated' will give us relevant economic aspects of the relationship (generally reduced in contracts) between oil companies and drilling contractors.

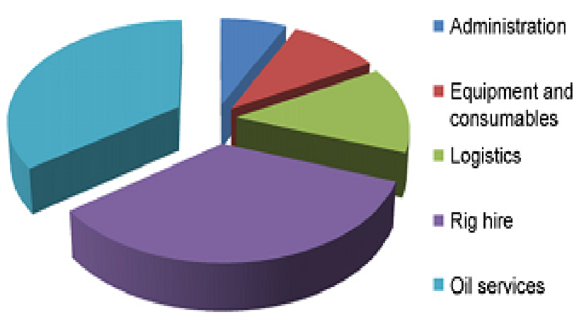
## 3.- The drilling rigs market

In this section, we first show the most important types of rigs and the current relevance of deepwater drilling units. After that we point out three important aspects of the rig market which are a source of tension for oil companies due to their dependence on rigs for their exploration activities.

During drilling stage, oil companies use rigs intensively. Actually, in the Norwegian Continental Shelf (NCS), rigs hiring represent more than one third of total drilling costs, as Figure 1 indicates. This is one of the most important assets through the supply chain and deserves considerable attention.

Figure 1

Typical composition of drilling costs on the NCS




Source: Osmundsen, et al. (2008)

In this section, we first show the most important types of rigs and the current relevance of deepwater drilling units. After that we point out three important aspects of the rig market which bring some tension for oil companies due to their dependence on rigs for their exploration activities.

### Rigs

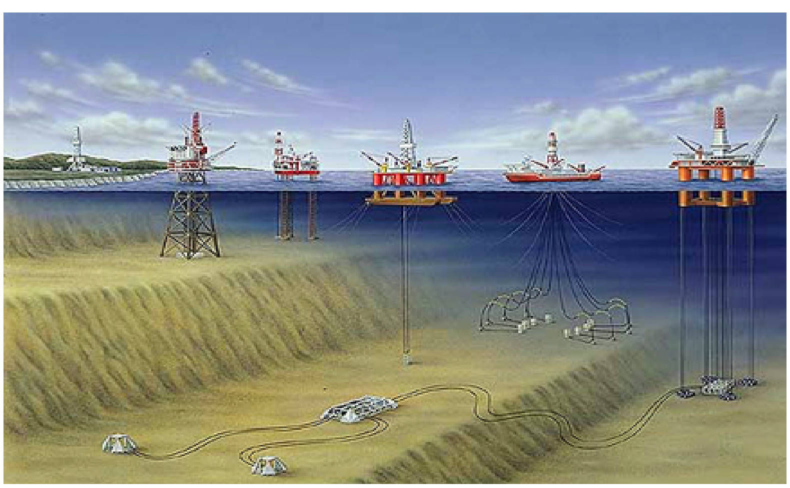
Onshore rigs were the pioneers, being very similar among them. One important difficulty was how to get to the place to be drilled. Due to geographic changes in new discoveries, there was a need to develop more sophisticated rigs for offshore activities, and not just onshore put into structures. Thereafter, this industry developed a range of options according to the specificity of the well to be drilled in the sea. There are two main types: one with the BOP (Blowout Preventer) on the surface and the ones with the BOP underwater.

The first group includes fixed platforms, jackups, submersibles and tension legs, being used for low depths, achieving at maximum water layers of up to 300 meters. Jackups are widely used because they guarantee considerable stability to its structure. A notable advantage would be its great mobility, since it is made up of mobile platforms, transported by towers or by self propulsion. The tension legs can be used also in the development phase of exploratory fields.

The second group, also called floaters, includes semi-submersibles and drillships, both widely used in the recent years. The semis, as they are known, are floating units which have an anchor system or are dynamically positioned to avoid excessive movement due to ocean waves. They present great mobility and because of that, they are preferred to drill wells. The ones with dynamic positioned system can drill to a depth up to 5000 meters. Drillships are designed exclusively for deepwater drilling activities and also have a security system underwater and a dynamic positioning system. Their most notable advantages are: high storage capacity, wide range of drilling depth, and they do not need services or support boats during operation. Along with jackups and semi-submersibles, drillships belong to the most relevant and used group of the offshore drilling fleet in the oil industry.

Figure 2

Types of rigs



Left to right: onshore platform; fixed platform; jackup rig; semi-submersible;

drillship; tension leg platform.

Nowadays, the rig fleet sums more than 3500 rigs all around the world, as we can see on Table 1. The majority is designated for onshore drilling, located mainly on the Mexican Gulf. Besides that, the offshore rigs are important due the fact that since the seventies, around 80% of the new oil and gas reserves are offshore. The last "big one" inland reserve was discovered more than 35 years ago.[133]

Table 1

Worldwide rig count (onshore and offshore)

| 2008 | Latin America | Europe | Africa | Middle East | Far East | Total Foreign | Canada | U.S. | Total World |
|---|---|---|---|---|---|---|---|---|---|
| Jan | 365 | 93 | 68 | 275 | 252 | 1053 | 494 | 1749 | 3296 |
| Feb | 373 | 81 | 58 | 272 | 248 | 1032 | 620 | 1765 | 3417 |
| Mar | 380 | 100 | 70 | 269 | 235 | 1054 | 408 | 1797 | 3259 |
| Apr | 380 | 93 | 73 | 279 | 249 | 1074 | 106 | 1829 | 3009 |
| May | 367 | 101 | 66 | 278 | 263 | 1075 | 135 | 1863 | 3073 |
| Jun | 398 | 97 | 65 | 277 | 265 | 1102 | 266 | 1901 | 3269 |
| Jul | 379 | 107 | 63 | 280 | 263 | 1092 | 412 | 1932 | 3436 |
| Aug | 382 | 97 | 62 | 289 | 257 | 1087 | 449 | 1987 | 3523 |
| Sep | 398 | 99 | 68 | 291 | 252 | 1108 | 435 | 2014 | 3557 |
| Oct | 403 | 101 | 60 | 288 | 244 | 1096 | 446 | 1976 | 3518 |
| Nov | 397 | 107 | 59 | 280 | 253 | 1096 | 417 | 1935 | 3448 |
| Dec | 389 | 101 | 67 | 279 | 242 | 1078 | 361 | 1782 | 3221 |
| Avg. | 384 | 98 | 65 | 280 | 252 | 1079 | 379 | 1878 | 3336 |

Source: Baker Hughes Rig Counts

Looking at the numbers, we can clearly notice that there is a trend in deepwater drilling in the whole offshore industry. As an example, Petrobras has today 33 rigs in drilling activity: 25 are semi-submersibles, 6 drillships and 2 jackups.[134] The RS Platou Report (2008) confirms this trend, pointing out that oil and gas companies are demanding more floating vessels (semis and drillships) than jackups. Even in the new building market, it is clear that drillships for deepwater drilling are becoming the centerpiece. According to Simmons & Company International (a consultant of the rig industry), in 2007, orders for floating units increased 40% against 20% of jackups.

Technological improvements in the rig industry ultimately focus on the possibility of longer drilling wells (including multilaterals), even if it declines efficiency in drilling, measured by meters drilled per day (Osmundsen, et al., 2008). Deepwater wells are more demanding, but qualitatively better. There are other possible reasons to explain lower efficiency, such as ageing of the rig fleet,

[133] Simmons & Company International (a financial consultant of the rig industry).
[134] Rigzone.com (September/2008).

sub-optimal maintenance, and low quality drilling personnel, among others, that should be investigated in detail.[135]

Concentration, cyclicality and revenue

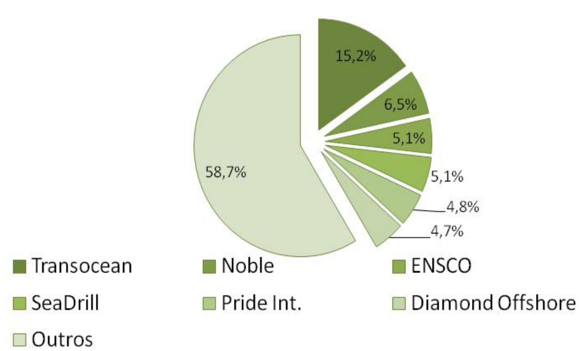
The rig market influences directly and indirectly the business of an oil company. However, this market is also influenced by many other factors, such as oil price, revenue rate, capacity of the shipyards, number of rigs in maintenance, effective offer and availability of rigs, etc (Rosenblatt and Fernandes, 2006). From these characteristics, we focus on three economic aspects of this market considered as the most relevant: concentration, cyclicality and supply expansion mechanisms (revenue pattern).

According to Corts and Singh (2004), just a small number of National Oil Companies own and operate their own offshore rigs. “All other firms, including all the majors, contract for the services of drilling rigs with independent driller contractors”. Through previous years we’ve been noticing an increasing concentration in this market, evaluated by the quantity and market shares of all existing drilling contractors. According to Inikori, et al. (2001), this trend is verified by the combination of two factors: a slowdown on revenues in the last two decades and the high quantity of inactive rigs due to maintenance stops and ageing fleet. In this context, low profitability has contributed to acquisitions and fusions in the last years. The last relevant one occurred in the end of 2007, when Transocean, the leader company, bought Global SantaFe.

Nowadays, we can affirm with confidence that the rig market is concentrated in a few firms. Considering the total offshore fleet, 6 firms have a market share of almost 40%, as seen on Figure 3. Considering just rigs designated to deepwater drill – more than 3000 m – 3 firms control more than 75% of the market (Figure 4).

Figure 3

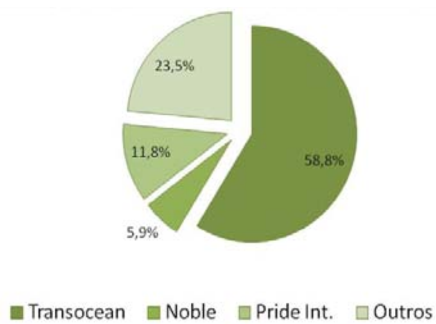
Market share in the rig market – Total fleet in current utilization




[135] For more technological approaches in offshore drilling, see Managi, et al. (2005) and Managi, et al. (2004).

Figure 4

Market share in the rig market – Deepwater rigs in current utilization




Source: Rigzone.com (October/2008)

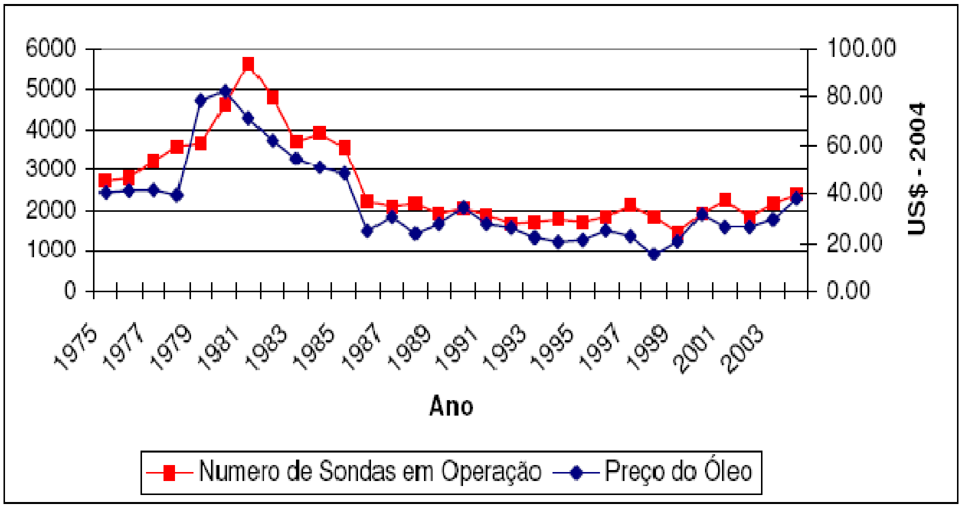
Another interesting and relevant characteristic of the rig market is its cyclicality pattern. This industry is capital intensive, mainly if we look at offshore units, where a rig can cost more than 400 million dollars. Once it is built, it is crucial to rent it for a reasonable day rate in order to generate the cash flow necessary to the initial investment. Since being idle represents a big cost, when the utilization rate drops to low levels, we observe a relative competitive ambient where the operators can take advantages, bargaining for cheap day rates. However, as the fixed cost begins to dilute through the periods and the demand to increase we observe a turning point: high day rates allow drillers to increase prices, mainly if we are passing through an intensive exploration effort period, with elevated oil prices[136], as we can see on Figure 5. In this new framework, drillers can accumulate capital and get prepared for a new cycle of revenue, going back to the first moment when we had high utilization rates.

Figure 5

Oil price (Brent, based on 2004 prices) vs. Active rigs

---

[136] In fact, as seen in Rosenblatt and Fernandes (2006), argue that oil prices influence considerably rigs demand. That's why high prices turn viable more E&P projects, thus drilling more exploratory fields. There is a consensus that rig demands respond to oil prices changes approximately one year lagged.

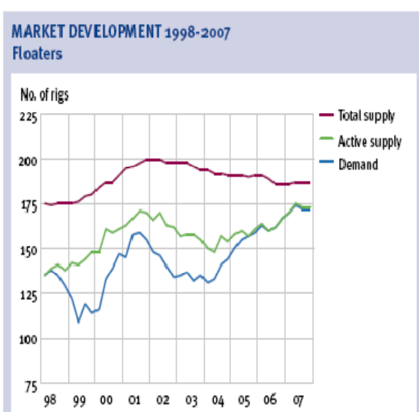


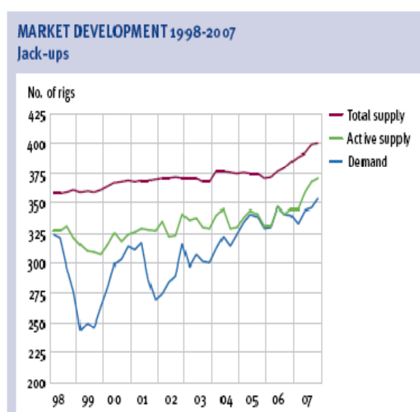

Source: Rosenblatt and Fernandes (2006)

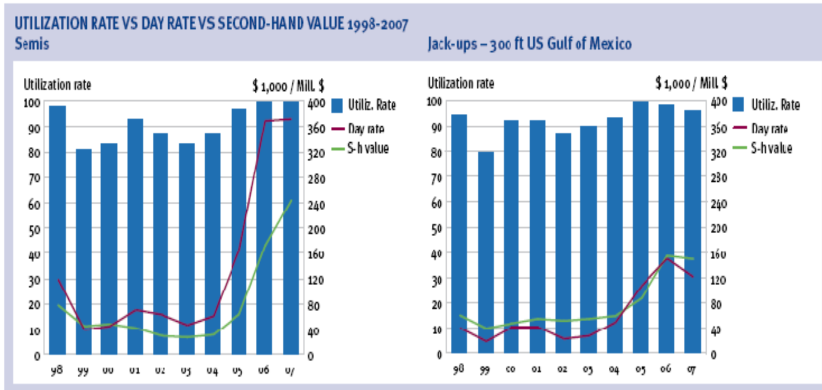
In general, the revenue pattern occurs this way, but other aspects can change or even intensify this dynamics. The current market structure, more concentrated, speeds up the low phase of the cycle and increase its peak duration and higher utilization rates. At the moment, as seen on Figure 6, the offshore drilling market is passing through a peak of a cycle started in 2005. The last time such a utilization rate in the rig industry was observed (Figure 7), there was a boom in the offshore new-building market (Simmons, 2002).

Figure 6

Active rig supply (excluding the ones in maintenance) vs Demand (2005 cycle)



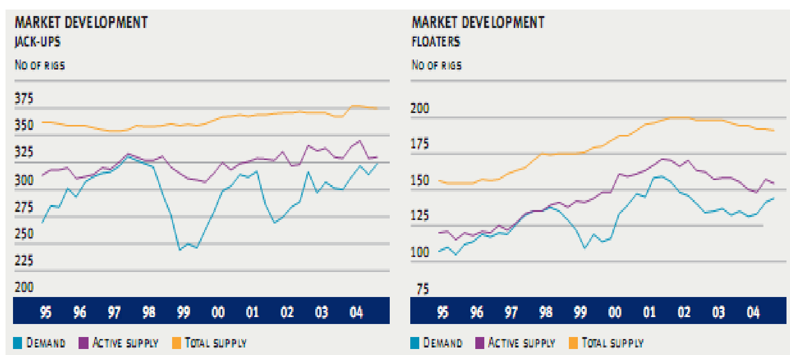



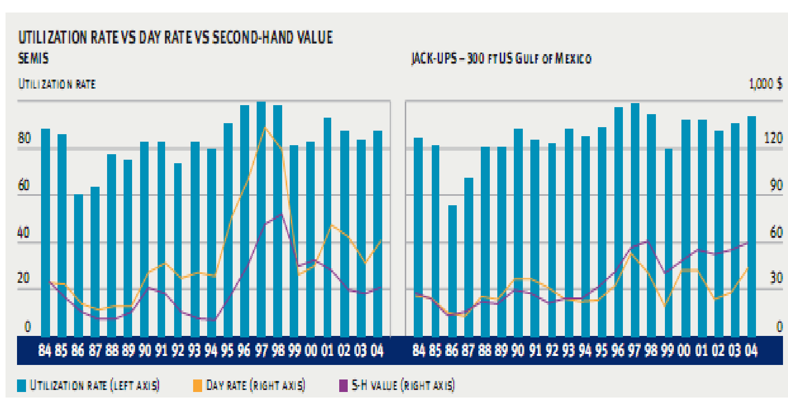



Source: RS Platou Offshore Report – 2008

Figure 7

Active rig supply (excluding the ones in maintenance) vs Demand (1996 cycle)




Source: RS Platou Offshore Report – 2005

All the aspects discussed above prove how complex is the revenue business. Building a new drilling unit, besides being a crucial decision to the investor, is a very complex project. It is widely limited by the number of shipyards available; the project is more specific than a standard vessel, as it requires shipyards with certain abilities and know-how to deal with, and to have access to a large number of raw material. It is not surprising that the deadlines are often postponed and cost analyses underestimated. In numbers, in 2007 were spent more than 10 billion dollars with revenues in the offshore market, as seen below.

Table 2

Revenue costs (2005-07)

| | 2007 | | 2006 | | 2005 | |
|---|---|---|---|---|---|---|
| | $ | % | $ | % | $ | % |
| Revenues | $ 10,428.2 | 100.0% | $ 9,027.4 | 100.0% | $ 7,185.5 | 100.0% |
| Cost of revenues | 6,845.6 | 65.6% | 5,876.4 | 65.1% | 5,023.7 | 69.9% |
| Research and engineering | 372.0 | 3.6% | 338.9 | 3.8% | 299.6 | 4.2% |
| Marketing, general and administrative | 932.8 | 8.9% | 877.8 | 9.7% | 628.8 | 8.8% |

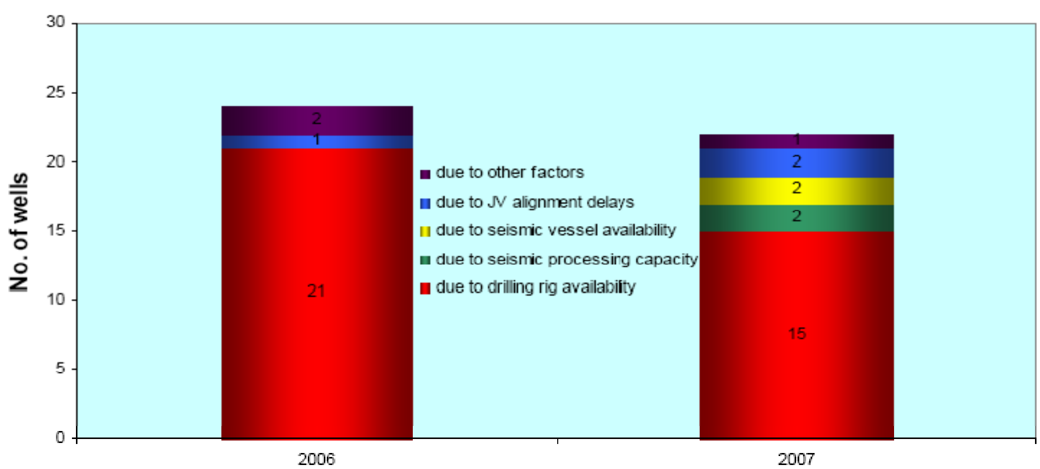
Source: Simmons & Company International

4.- Drilling contracts analysis

The actual rig market design turns this asset into a relevant restriction to exploration activities of its operator. As an example, during the last 2 years in the UK, the main restriction in exploration and evaluation of new wells were due to drilling rig availability restrictions (Figure 8).

Figure 8

Restrictions on exploration and evaluation activities in the UK




Source: Exploration and Appraisal Activity Survey 2007 (UK Offshore Oil & Gas Industry Association).

Such a restriction can bring significant loss and increases in costs for oil companies, even more if the turning of the whole oil industry into deepwater drilling is considered. Consequently, it is recommended that firms revise their strategies related to the drilling activity in order to find better solutions and contract designs that benefit themselves and mitigate risks and uncertainties involved.

In this section we will first point the different kinds of drilling contracts in respect to the exploration activities. After that we will define and justify our method of analysis – transaction costs – and use it to evaluate current strategies, suggesting alternative ones.

## Drilling contracts

Exploration and production companies contract with drilling contractors following two standard contract forms: day-rate and turnkey. Firms formulate exploration and development plans and decide which of the planned projects should be drilled under each type of contract, solicit bids from drilling contractors and evaluate these bids based on certain considerations, as prices, rig capabilities, safety record, etc.

In the first contract form, the drilling contractor provides a staffed and functional rig for a previously defined period, in exchange for which it receives a daily payment (day rate). Generally, the contract specifies some goals to be met by both agents to avoid penalties (such as downtime). The whole process is monitored and managed by two workers: one representing the oil company and the other representing the driller. In sum: “in this setting, the drilling contractor is but one of many equipment and labor providers retained by the oil company to complete the project” (Jablonowski and Kleit, 2006). This is the most popular kind of contract, governing the drilling of more than 80% of Gulf of Mexico’s wells (Corts and Singh, 2004) and 80-95% of all wells drilled during the 90’s (Jablonowski and Kleit, 2006).

In the turnkey option, an E&P company pays a fixed price for a well drilled according to previous specifications. In this situation, the turnkey company contracts a driller and takes on the responsibility for all technical, engineering, staff, and logistics aspects, managing the entire process. It is important to notice that the structure of the contract will be quite similar (day rates), varying just the fact that now oil companies do not contract drillers directly. Although the turnkey company does not bear the risk of a “dry hole”, it assumes all financial risk for cost overruns and delays in the completion of the well. Moomjian (1999) also finds that turnkey contracts and the ones that take meters drilled as a basis for remuneration are rarely used in offshore drilling, the opposite occurring on land, where these contracts are used in certain circumstances.

## Transaction costs approach

There are, in related literature, many articles[137] that build contracts analyses on general contract and incentives theory (known as agency theory), mainly based on Lafont and Tirole's literature. However, we intend to base our analysis on Transaction Costs Theory (TCT)[138], using the same analytic choice taken in Jablonowski and Kleit (2006). This choice is mostly justified by the fact that this approach gives the deserved importance to intrinsic uncertainty of any economic environment and to the specificity of assets, two notable characteristics of the upstream segment. Besides that, it gives the possibility to analyze ex-ante (before the contract decision had been taken) economic transactions, allowing us to compare buying a market solution or the integration of the firm's activities. As seen in the first section, in oil industry, vertical integration really matters. Thus, TCT approach should be more appropriate. In the next paragraphs we introduce the Transaction Cost Theory and afterwards we will interpret drilling contract issues under this view.

Economic transactions, between suppliers and firms, employees and their managers, etc are the starting point of TCT. Transactions, which can be seen as contracts, usually produce significantly transaction costs that will affect the form of a firms' economic organization. In other words, the ideal governance structure to coordinate economic agents. The market (buy) is not the only structure in which the economic transactions can be performed; the internalization (make) of an activity, productive or organizational, by the hierarchical structure of the firm is another option, in addition to hybrid forms.

So it is fundamental that transaction costs are not negligible. According to Williamson (1985), this occurs when two behavioral conditions are observed: bounded rationality and opportunistic behavior. The first one recovers approaches from Simon (1959,1978), where agents are exposed to the unpredictability of future contingencies given their cognitive and reckoning limitations, leading to the selection of sub-optimal allocations. The opportunism is linked to the existence of incomplete information. From this, players can act not only chasing their self-interest, but pursuing it with malice, trying to take advantage of any new situation during the contracted period. Finally, we can still introduce uncertainty as an element that completes the set of factors which determine the difficulty and the costs of an economic transaction.

The transactions costs in a more contractual approach can be divided in:

---

[137] See, for example, Osmundsen et al. (2006) and Osmundsen et al. (2008).

[138] For general views, see Williamson (1981) and Williamson (1985). For its contractual approach, see Williamson (1991) and Williamson (2002).

Ex-ante costs: related to the elaboration and negotiation of the terms of the contract, describing, in the best possible way, future contingencies and safeguard mechanisms;

Ex-post costs: closely linked to divergences regarding contractual clauses, the monitoring activity and renegotiation of the contract in face of changes in the initial context.

Choosing the most appropriate governance (market, hierarchy or hybrid) for each transaction is intimately linked to the capacity that one or another has to deal with unexpected changes of the decisive parameters of the contract. Even more important is the level of assets specificity involved in such transactions, i.e., how much these assets are specific to the considered economic transaction and how difficult using it in some other alternative activity would be.

After this brief review of TCT, we can now touch the object of study so far developed in the article, i.e., drilling activity. From the point of view of an oil company, we notice that this economic activity – and the contracts involved in its transaction – does not have negligible transaction costs. What makes it true is the fact that: i) drilling involves bounded rationality due to inexistence of total reliable information, to cognitive limitation in the sense of interpreting seismic analysis, etc and predicting all future contingences; ii) opportunistic behavior can be observed, for example, when turnkey companies take advantage of a heated market, finalizing quickly their contracts without regard for the quality of services; or even when drilling contractors speculate about the future oil price and revenue need in order to distort their day rates. Uncertainty is widespread in this activity, evident in the future oil price and on questions like how many days are needed to hire a rig to drill a well satisfactory. These are just random examples that show how transaction costs in that context are not negligible whatever the governance structure is adopted by the firm.

Analysis and perspectives

The results presented by Jablonowski and Kleit (2006), point out the need to weigh the several aspects involved in 'make' or 'buy' decisions. In this case 'make' occurs when an oil company itself sets up a contract with a drilling contractor and 'buy' means to contract a turnkey firm. Know-how and efficiency in the activities of exploration, tracking and uncertainty costs and, of course, cost of hiring should be weighted before choosing the best governance structure. Econometric analysis and evidence in the Gulf of Mexico lead the authors to conclude that "the optimal industry structure would remain a mix of internal and turnkey drilling, but in reverse proportions to approximately the current shares."

In addition to this approach, where vertical integration means to directly hire drilling rig and the solution 'buy' means a contract with a turnkey firm, we believe that in the current context of relevant changes in the rig market structure, the possibility of verticalization may be given a new thought.

As discussed throughout the essay, several characteristics are potentially damaging to oil companies. An oligopolistic market, a reprimanded supply with extremely slow adjustments due to the difficulties of renewing, both technical and speculative, the cyclic character that has been following a pattern of elevations and abiding peaks with exorbitant day rates. Beyond that, a fundamental point here is the strong amplification of the specificity or rigs. Consensually we have major seek for assets related to deepwater drilling, due to the shortage of shallow water reservoirs. This way, drillships and semis, assets that are becoming even more specific to drilling are indispensable on big oil companies' routines. Give in to shipyards' capacity, to the interest of rigs' owners in fleet renewing, on the exhibit of exorbitant prices of lease, on the possibility of long waits on provision of assets for exploration of wells, sounds to us, in the whole, risks that firms already concerned with the volatility of oil prices and with unsuccessful "dry wheels" do not wish to incur.

Above are listed transaction costs (ex-ante and ex-post) that oil companies would incur when dealing with a drilling contractor. Another option under TCT would be to vertically integrate this economic transaction (drill a wheel), which can be interpreted in many different forms. Total integration – build its own rig to take absolute control of the drilling activity – does not seems to be reasonable. In fact, other transaction costs would come to light: limited rationality in time delivery and lack of know-how relative to the rig industry, for example; or, opportunistic behavior of the shipyard using materials with specifications that are not as stringent as those specified in the contract would be some more negative aspects of this governance structure.

So, imagine somewhat like a hybrid option where oil companies buy rigs in partnership with shipyards. These would bring mutual benefits through sharing of transactions costs in an uncertain environment. Joint-ventures with drilling contractors should also mitigate the difficulty of renewal, in one hand, and the lack of know- how ordering rigs, in the other hand. This view is shared by some authors, like Carter and Ghilselin (2003), who suggest that rig operators and contractors, working together to develop an integrated industry, will increase the efficiency and incorporation of new technology and contracting more effective procedures.

That is the main point: coordination and paternities between those players (oil companies, driller contractors and shipyards) should bring more benefits than costs. This argument is reinforced, as we have seen, by particularities of the oil industry, such as its high vertical integration degree and also current rig market structural characteristics and constraints.

We have already observed some oil companies, like Petrobras, taking some actions in this direction. Strategies such as guaranteeing previously rig demand for a long period in order to incentive offshore buildings by shipyards, are clever ones that probably are going to be more and more common in oil industry's future.

## 5.- Conclusions

This essay considers many relevant aspects of oil industry, rig markets, drilling activity and contracts, showing how several of them are closely related. The idea is to link the concept of vertical integration, structural problems of the rig market that bring risk and insecurity to oil companies drilling activities and finally the transaction cost theory all together. Then, under TCT, we can point out alternative governance structures and new strategies for oil companies in order to mitigate their exposition to the market.

A lot of attention to the rig market was given because we believe that this is one of the main strategic assets in the whole upstream segment. Its characteristics were also pointed out as they can considerably affect oil companies' performance. The uncertainty intrinsic to this whole environment was focused too. It brings intangible aspects that complicate even more the decision regarding the best contract design in drilling activities.

To give a definitive solution to the optimal governance structure (make, buy or hybrid) that oil companies should adopt when drilling is not part of this article's objectives. The main objective is to map the discussion in the literature and describe the multiple variables involved, contributing to the discussion about which governance is more efficient. Concluding our qualitative approach: the fundamental question is how specific rigs are to drilling activities and, from here, study (and even try to measure it) the transactions cost in each case.

As market structures can deeply affect the performance of firms, further sophisticated and modelled studies in this direction are necessary and can really be decisive in oil companies' future.

## 6.- References

Al-Moneff, M. A. (1998). "Vertical integration strategies of the National Oil Companies". *The Developing Economies*, vol. 2, (28), pp. 203-22.

BakerHughes.com. Access in 02/01/2009: http://investor.shareholder.com/bhi/rig_counts/rc_index.cfm

Barrera-Rey, F. (1995). “The Effects of Vertical Integration on Oil Company Performance”. Working Paper nº. 21, Oxford Institute for Energy Studies.

Beng, C. (2006). “Delivering Results in a Booming Rig Market”. ISEAS Energy Forum, presentation on 31 may 2006.

Carter, S., Ghiselin, R. (2003). “Bringing efficiency to the offshore rig contracting business”. *Society of Petroleum Engineers*, (79894).

Corts, K. (2000). “Turnkey Contracts as a Response to Incentive Problems: Evidence from the Offshore Drilling Industry”. Working paper, Harvard University.

Corts, K. S. and Singh, J. (2004). “The Effect of Repeated Interaction on Contract Choice: Evidence from Offshore Drilling”, Journal *of Law, Economics, and Organization*, vol. 20, (1), pp. 230-60.

Exploration and Appraisal Activity Survey by Oil & Gas UK, 2006/07. Available at: http://www.oilandgasuk.co.uk/issues/operations/exploration_apprai

sal_activitysurvey.pdf

Frankel, P. H. (1953). “Integration in the Oil Industry”. *The Journal of Industrial Economics*, vol. 1, (3), pp. 202-211.

Inikori, et al. (2001). “The Responsiveness of Global E&P Industry to Changes in Petroleum Prices: Evidence From 1960 - 2000”. *Society of Petroleum Engineers*, (68587).

Jablonowski, C., Kliet, A. (2006). “Transaction costs and risks preferences: modeling governance in offshore drilling”. *Society of Petroleum Engineers*, (101936).

Kupfer, D., Hasenclever, L. (2002). *Economia Industrial: Fundamentos Teóricos e Práticas no Brasil*. 9ª ed. Campus: Rio de Janeiro.

Managi, S. et al. (2005). “Technological change and petroleum exploration in the Gulf of Mexico”. *Journal of Environmental Economics and Management*, (33), 619-632.

Managi, S. et. al. (2004). “Technological change and depletion in offshore oil and gas”. *Journal of Environmental Economics and Management*, (47), 388-409.

Moomjian, C.A. (1999). “Contractual insurance and risk allocation in the offshore drilling industry”. *Drilling Contractor*, January/February, March/April and May/June.

Osmundsen, P. et al. (2006). “Design of drilling contracts - Economic incentives and safety issues”. *Energy Policy*, (34), 2324-29.

Osmundsen, P. et al. (2008). “Drilling contracts and incentives”. *Energy Policy*, (36), pp. 3138-44.

Pondé, J. (2000). “Processos de Seleção, Custos de Transação e a Evolução das Instituições Empresariais”. Tese (Doutorado em Ciência Econômica) - Universidade Estadual de Campinas. Orientador: Mario L. Possas.

Rigzone.com. Access in October/2008: http://www.rigzone.com/

Rosenblatt, L., Fernandes, A. (2006). “Aplicação de Dinâmica de Sistemas ao estudo do comportamento das taxas diárias de aluguel de sondas de perfuração offshore”. Projeto de Iniciação Científica (Graduando em Engenharia de Petróleo) - Universidade Federal do Rio de Janeiro, Agência Nacional do Petróleo. Orientador: Virgilio Jose Martins Ferreira Filho.

Simmons, R. (2002). “Offshore rig market could be on verge of recovery”. *Drilling Contractor*, May/June.

Simon, H. (1959). “Theories of decision making in economics and behavioral science”. *American Economic Review*, (49), pp. 253-58.

Simon, H. (1978). “Rationality as process and as product of thought”. *American Economic Review*, (68), pp. 1-16.

Teece, D.J. (1976). "Vertical integration in the US oil industry", in E.J. Mitchell (ed.) Vertical Integration in the Oil Industry, American Enterprise Institute: Washington, D.C.

Teece, D.J. (1980). “Economies of Scope and the Scope of the Enterprise”. *Journal of Economic Behaviour and Organization*, (1), pp. 233-47.

The Platou Report by R.S. Platou Shipbrokers, 2005 and 2008. Available at: http://www.platou.com/loadfileservlet/loadfiledb?id=Fri+Mar+11+12%3A27%3A19+CET+2005EDITOR&key=ThePlatouReport-2005.pdf and http://www.platou.com/loadfileservlet/loadfiledb?id=1205311719484PUBLISHER&key=1205499801725

Thomas, E. (2001). *Fundamentos de engenharia de petróleo*. Interciência: Rio de Janeiro.

Williamson, O. E. (1981). “The Economics of Organization: The Transaction Cost Approach”, *The American Journal of Sociology*, vol. 87, (3), pp. 548-77.

Williamson, O. E. (1985). *The Economic Institution of Capitalism*. Free Press: New York.

Williamson, O. E. (1991). “Comparative economic organization: the analysis of discrete structural alternatives”. *Administrative Science Quarterly*, (36).

Williamson, O. E. (2002). “The Theory of the Firm as Governance Structure: From Choice to Contract”. *The Journal of Economic Perspectives*, vol. 16, (3), pp. 171-95.

# 35. Industrial Energy Balance Towards Energy Usage Optimization

**Johanna Amaya-Leal and Cristian Cárdenas-Lailhacar**

Dept. of Industrial and Systems Engineering, University of Florida

303 Weil Hall, P.O. Box 116595, Gainesville, FL 32611. U.S.A.

Phone: (352) 392-1464 , Fax: (352) 392-1464

E-mail: cardenas@ise.ufl.edu

Keywords: Energy, Efficiency, Optimization

Today's high energy (all sources) cost, and sometimes scarce availability, has made energy one of the most important topics in engineering, economics, politics and even countries development. Not to mention its intrinsic correlation with the environment. Nowadays, and around the world, this issue is gaining more momentum due to the fact that the discussion is about how to find the best way to use energy, minimizing costs, and reduce waste. New technologies, renewable energy sources and its applications have seen a dramatic growth in development. Day after day, industries are seeking energy savings projects, to reduce consumption, operational and manufacturing costs, without jeopardizing neither the quantity nor the quality of the manufactured products.

In this work, we show some initial steps on the development of a tool that will help industry become more energy efficient, while satisfying their own production constraints. We consider energy, together with its efficient usage and associated cost, the starting points of our work. From the energy management, and its optimization perspective, it is necessary to identify initial energy consumption conditions. From an n-dimensional energy equipment usage space, this is the region where the optimal energy usage (solution) will become the global optimum. We start by analyzing the energy bills, then we balance the current energy consumption of all equipment in the plant. Then we create a mathematical representation of the major users of it, that we call “descriptors”. These descriptors, for demand, energy, and cost, associated with the equipment, account for most of the electric energy usage in the facility. Finally, we present some preliminary results and draw some conclusions.

# 36. Demand Side Response in Hydro-Dominated Electricity Systems

**Bart Van Campen**

The Energy Centre, University of Auckland Business School

Economics Department; OGG-Building – Room 6.79

Private Bag 92019, Auckland New Zealand

Tel: +64.(0)9.3737599 xtn 89557

Fax: +64.(0)9.3737427

Email: b.vancampen@auckland.ac.nz

Keywords: hydro-electricity markets, demand response, smart metering

Abstract:

Significant literature has been created on the benefits and possibilities of increased demand side response in electricity markets around the world. Most of this work has focused on thermal-dominated electricity markets. Although the economic principles of demand side response in hydro-dominated are the same, the different characteristics of the pricing signals (less intense short term peaks) and time horizons (medium-term: month or annual scale drought related scarcity peaks) create quite a different set of investment, technical and behavioural responses. Little work has been done in this area. This work presents a preliminary, qualitative comparison of hydro crises in New Zealand and Norway. It also explores the potential of modern smart metering to aid medium-term response to hydro crises.

## Introduction

This paper presents a preliminary analysis of 2 hydro crises in the New Zealand Electricity Market and the demand side response in these crises.

First a general description of the New Zealand electricity system is given and its institutional developments to a liberalized New Zealand Electricity Market (NZEM). Chapter 3 gives an overview of dry year events and overall response in the past. Chapter 4 and 5 focus at the 2 most serious events in the last decade: 2001 and 2008. Finally a preliminary, qualitative comparison is made with the 2002/2003 crisis in Norway as described by Von der Fehr (2005) and some potential lessons are explored for New Zealand, especially in the light of advances in residential smart metering.

In later versions of this paper additional cases (Chile) and more quantitative analysis will be added.

Brief description of the New Zealand electricity system

New Zealand is a small (4 million inhabitants), remote country with a hydro-dominated electricity system that – due to its remoteness – is not interconnected with any other electricity systems. It consists of 2 systems in the North and the South Island linked by HVDC-cable. Due to its length and the distance between the main load centres (North Island: Auckland) and the main hydro-lakes (South Island), the 'stringiness' of the transmission system[139] provides significant bottlenecks/constraints at times.

Generation

Traditionally New Zealand was a country with more than 70% hydro generation capacity. Since the 1970s and the coming online of major gas fields, hydro's share of the capacity has dropped to 59% (2007). Total annual production is around 42,000 GWh (see table 1).[140] Hydro inflows vary significantly from year-to-year (range of ca. 4,500 GWh between wet and dry years) and through the year. Due to limited storage capacity (ca. 10% or 6 weeks of total annual consumption), dry conditions can occur and disappear rapidly and wholesale prices can be very volatile on the medium term scale.

Table 1

| Electricity Generation by Fuel Type (2007) | | | |
|---|---|---|---|
| Fuel Type | GWh | PJ | % of Total Generation |
| Hydro | 23,283 | 83.8 | 54.9 |
| Gas[1] | 11,199 | 40.3 | 26.4 |
| Geothermal | 3,272 | 11.8 | 7.7 |
| Coal[1] | 2,921 | 10.5 | 6.9 |
| Oil | 1 | 0.0 | 0.0 |

[139] 17,334 km high voltage transmission line; 77,680 km distribution lines
[140] Transmission& Distribution losses are significant, around 7.5% or 3,200 GWh pa

| | | | |
|---|---|---|---|
| Wind | 928 | 3.3 | 2.2 |
| Others[2] | 771 | 2.8 | 1.8 |
| TOTAL | 42,374 | 152.5 | 100 |

[1] Includes output of cogeneration plants for these fuel types.

[2] Includes (co)generation from biogas, waste heat and wood

Source: MED-EnergyDataFiles June 2008

Since the 2003 downward revision of Maui gas reserves, the future, long term gas supply in New Zealand has become less secure, despite significant smaller finds. This has among others resulted in the 4 times 250 MW gas-fired Huntly power station near Auckland, switching to coal; as well as the need (in August-2004) for the government to (partially) underwrite the risk in the gas contract to a new 400 MW CCGT near Auckland (E3P). Gs exploration has intensified, but future, major gas finds in New Zealand are unclear, adding to the investment uncertainty for new capacity. LNG and CNG is considered. The previous (labour) government had introduced a 10-year ban on new thermal generation, an Emissions Trading Scheme (ETS) and an ambitious goal of 90% renewable in the electricity sector by 2025. The new (national) government that came to power in November 2008 has scrapped the thermal ban, is reviewing the ETS, but has supported the goal of 90% renewable by 2025. The main, new renewable sources in New Zealand that are developed at present are wind and geothermal energy, potentially marine energy in the further future.

Demand

New Zealand has a significant primary industrial (metals, pulp&paper) and agricultural sector dairy, meat), which is the largest consuming sector at ca. 44% of annual consumption (see table 2); followed by the residential sector at 33%. Use by the commercial sector is relatively small at 23% reflecting the shape of New Zealand’s economy.

Table 2

Consumption by Sector for 2007 March Year

| Sector | GWh | PJ | % of Total Consumption |
|---|---|---|---|
| Residential | 12,731 | 45.8 | 33.0 |
| Industrial | 16,825 | 60.6 | 43.6 |
| Commercial | 8,990 | 32.4 | 23.3 |
| TOTAL[1] | 38,545 | 138.8 | 100 |

[1] Total consumption shown does not include on-site cogeneration consumption of about 1 TWh.

Source: MED-EnergyDataFiles June 2008

The consumption peak is in the winter due to electric hot water and space heating. This coincides with a reduction in inflows in the major Southern lakes due to snow fall. Most of the consumption is located in the North Island, while 40% of the generation capacity is in the South Island.[141] Also the largest hydro storage lakes (70% of national storage capacity) are on the South Island and all major thermal capacity is on the North Island.

## Reforms & institutions[142]

The reform process in New Zealand's electricity sector started in the 1980s and in 1986 the first step was taken to transfer the Ministry's of Energy's responsibilities to the Electricity Corporation of New Zealand as a State Owned Enterprise (SOE) for the generation and transmission; and to Electricity Supply Authorities for the retailing and distribution of electricity. Gradually ECNZ was further split up into transmission and separate generation companies. On 1 October 1996 – on the splitting up and creation of Contact Energy as a competitor of ECNZ - the wholesale market started fully trading.[143] Further splitting up and privatisation of generation assets, as well as separation from lines (distribution network) companies[144] from their retailing activities (1998), created 5 main vertically

[141] South Island generation capacity used to be 2/3rds of the national generation capacity, but in the past decades all major capacity additions have been on the North Island, near the main load centre Auckland.
[142] Largely based on Evans (2005)
[143] Since 1 March 2004 NZEM is run as a compulsory, 'gross' pool..

[144] 28 distribution network lines companies exist in New Zealand

integrated generator-retailers: Meridian, Genesis, Mighty River Power (SOEs), Trustpower and Contact (private). Initially regulation relied on 'light-handed' general Commerce regulation and self-governance. After dry winter power 'crises' in 2001 and 2003 and failure of the sector to gain support for proposed, improved self-governance arrangements, the Electricity and Gas Industries Bill was introduced in 2003, making widespread changes to earlier reforms and the Electricity Commission was established as an independent government entity to centralize industry governance and regulation and among others improve dry year security. This resulted among others in the commissioning of a 155 MW 'dry year' reserve diesel generator (Whirinaki) on the East Coast of the North Island.

Metering, retailing and price responsiveness

As described above, households make up ca. 33% of national demand[145] and until recently all were provided with 'simple' electromagnetic meters, most of them one-tariff, i.e. no potential to differentiate between day and night tariffs either. Also large part of the smaller commercial connections still own simple meters. The total amount of 'simple' meters is estimated at ca. 2 million (ca. 50% of demand – source: SKM, (2005)). Almost all of these connections are provided with simple Fixed Price Variable Volume contracts (i.e. 'standard' incumbent contracts whose prices are changed once a year), providing no monetary incentives to reduce demand in times of hydro scarcity.

There are an estimated 10,000 TOU-meters in New Zealand. Many of the smaller connections of this type have chosen for contracts with fixed Time-of-Use pricing (48 half hour, but fixed prices plus sometimes a seasonal component), providing some incentives to shift loads away from (average) peaks, but no incentive for adapting behaviour to high spot prices in case of hydro scarcity. One of the complaints of end-users in NZEM is that with 240 pricing nodes in New Zealand, it is often difficult to get CFD-offers from retailers on the exact off-take node the consumer is on, leaving (sometimes significant) transmission constraint risk with the end-consumer. Instead retailers seem to prefer to offer more standard 'fixed price variable volume' contracts.

Some of the major metals, dairy and pulp&paper industrials do expose (part of) their load to spot the spot market, but details are confidential and strategies seem to regularly change. These industrials often respond significantly to extended

[145] In urban areas like Auckland (NZ's largest city with 1.2 million inhabitants), the residential share grows to 46.5%

periods of high (average) spot prices by cutting back on production. In total only an estimated 15% of New Zealand's national load is exposed to wholesale prices (source: SKM (2005)).

Hot water boiler control

Majority of residential consumers have electric hot water boilers with remote controls. Hot water boiler control can achieve up to 30% peak demand reduction (at an estimated 1,000 MW, this gives ca. 300 MW of peak lowering - Source: Nair (2008)). Until the splitting up and creation of the NZ Electricity Market (NZEM), the hot water boiler relays were more centrally controlled in case of power hydro shortages (eg in 1992 drought). These days consumer contracts usually provide for electricity supply to hot water cylinders to be cut only for a maximum number of hours per day (generally 5). Most hot water cylinder relays are controlled by the lines distribution companies (28 throughout New Zealand), that use them mainly to control distribution network peaks and sometimes to bid into the reserves market. Their use in the wholesale market (short & medium term) is very limited. Some distributors have made arrangements with the incumbent retailer on their network to control hot water load at their request outside network peak times, but in general retailers do not have such arrangements in place. Several industry observers have commented that the boiler control systems are in decline and need significant investment to maintain and improve performance. This would still provide one of the most cost-effective ways to improved (residential) demand side response in New Zealand, but barriers exist (eg distribution of benefits among consumers, retailers and lines companies). The Electricity Commission has indicated that, despite above-mentioned contractual limitations on hot water boiler (ripple) control, that in case of emergency it will use its powers to increase ripple control beyond contractual hours to prevent blackouts. Extended use of hot water cylinder control (12-16 hours per day) is estimated to reduce system energy demand by 2% (source: EC (2005)). Since 2001 this has not been necessary.

Dry year events and management in New Zealand

Hydro shortages or dry years are not new to New Zealand. Table 3 shows some of these events and the demand management necessary.

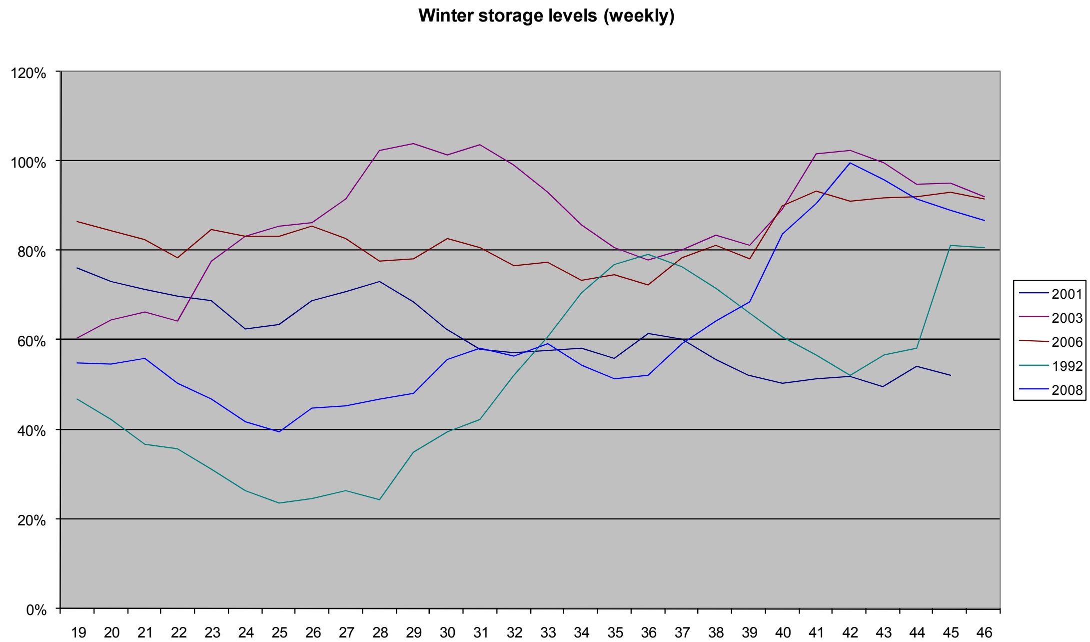
Table 3

| Dry year events and demand Side Management in New Zealand | |
|---|---|
| Period | Demand-side response |
| 1942 | Use of space heaters and radiators prohibited during peak hours between May and August in North Island |
| 1943 | Space heating was controlled further, and so too were indoor and outdoor lighting |
| 1946 | 20% power cuts imposed in the North Island |
| 1947 | 30% power cuts imposed in the South Island |
| 1958 | 15% power cuts imposed in the North Island |
| 1973 | Supply Authorities were requested to save up to 6%. Broadcasting hours were reduced. Water heating ripple control was increased and in some areas there were daily blackouts. |
| 1974, 1975, 1976, 1977 | Government requested ‘voluntary’ savings |
| 1992 | Large public savings campaign. Water heating ripple control was generally used for 18 hours/day. Some street lighting was cut. Comalco closed one of its 3 pot lines (ca. 5% of national demand) |

Source: Appendix 3, Electricity Shortage Review Committee (1992) cited in NZEM (2001)

This paper is mainly focused at more recent hydro shortages, especially those since the New Zealand Electricity Market was operational in 1996. The most recent event before that was in 1992. Figure 1 shows the relative weekly hydro storage levels (compared to the 30 yr-mean for that time of the year) to make a rough comparison of the seriousness of the events possible.

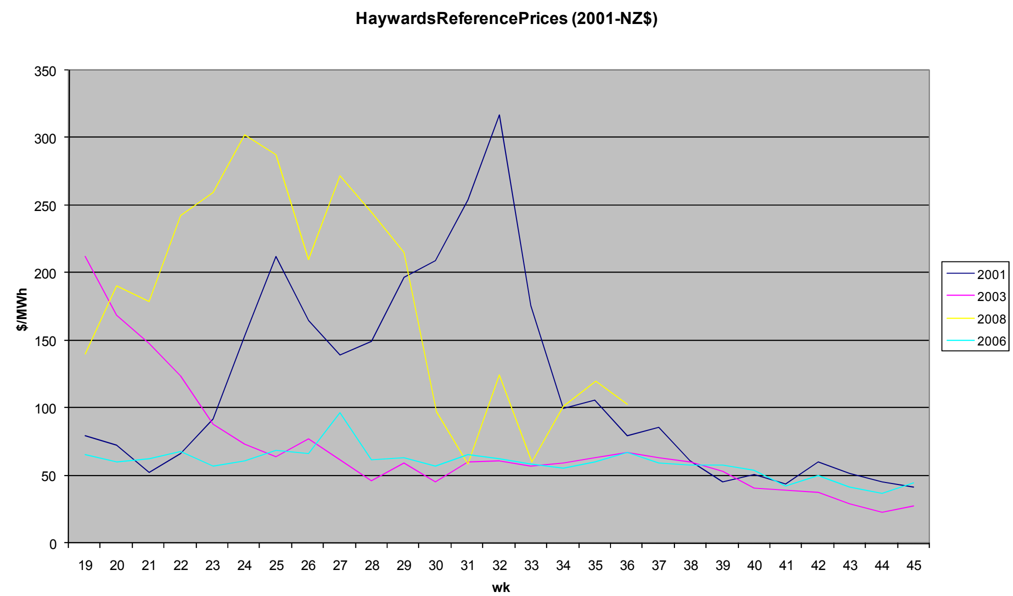
Figure 1




Source: M-Co (2008), EnergyLink (2008)

The 2003 and 2006-events both started as potential dry winter 'crises' with low lake levels going into winter and a period of low inflows, but enough rain arrived to avert the need for serious (demand side) actions and are sometimes labelled 'hydro scares'. 1992, 2001 and 2008 were more serious 'hydro crises' and required more serious interventions. In none of the years since the opening of the NZEM involuntary rationing has been was necessary.

Figure 2



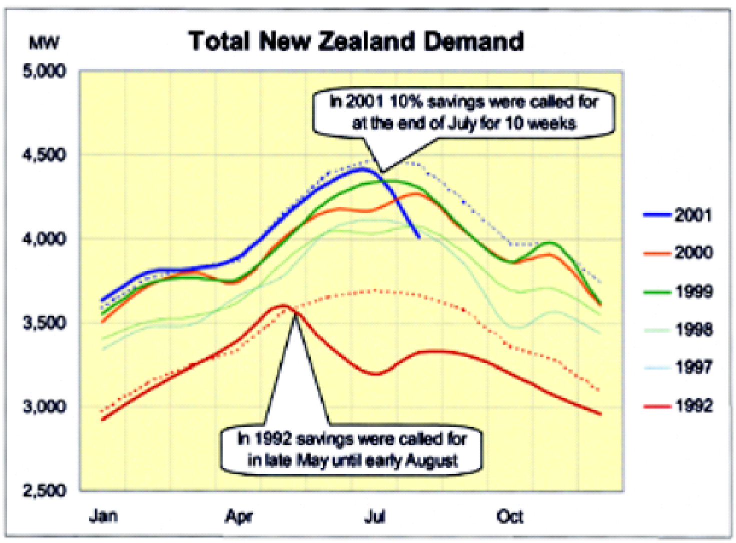

Source: EC-CDS (2008)

Figure 2 shows the impact on NZEM wholesale prices (Haywards reference node in the South of the North Island) of the 4 events since 1996. As the 2001 and 2008 events were the severest, we'll focus on these events.

The 2001 hydro crisis

2001 started off with above average lake levels in January, but turned out to be the driest year of the 70 years on record at the time in terms of cumulative inflow in the first 9 months of the year (1 Jan -1 August). The situation was aggravated by the TCC thermal power station (380 MW, gas-fired) being out from half March to late April[146]. Demand was also significantly higher than expected: a combination of increased overall demand (3-4%), peaking with an early cold snap resulted in demand levels reaching peak levels in June 2001 (see figure 3).

Figure 3




Source: NZEM (2001)

In the first week of June the government publicly declared a 'modest' hydro supply risk. The electricity industry started demand initiatives such as increased ripple control, industrial buy back and advertisement campaigns by the individual retail companies.[147] At the end of July government publicly announces a 'moderate' hydro supply risk and calls together electricity stakeholders for weekly meetings. Transmission security is relaxed in a number of areas and government announces

[146] Causing a loss of ca. 8,500 MWh thermal electricity production per day, i.e. in the order of 300 GWh thermal production over the outage period

[147] One retail company also started a rebate campaign for residential consumers for reducing consumption compared to the same period the year before, claiming to reach 60% of their residential consumers and saving 50 GWh.

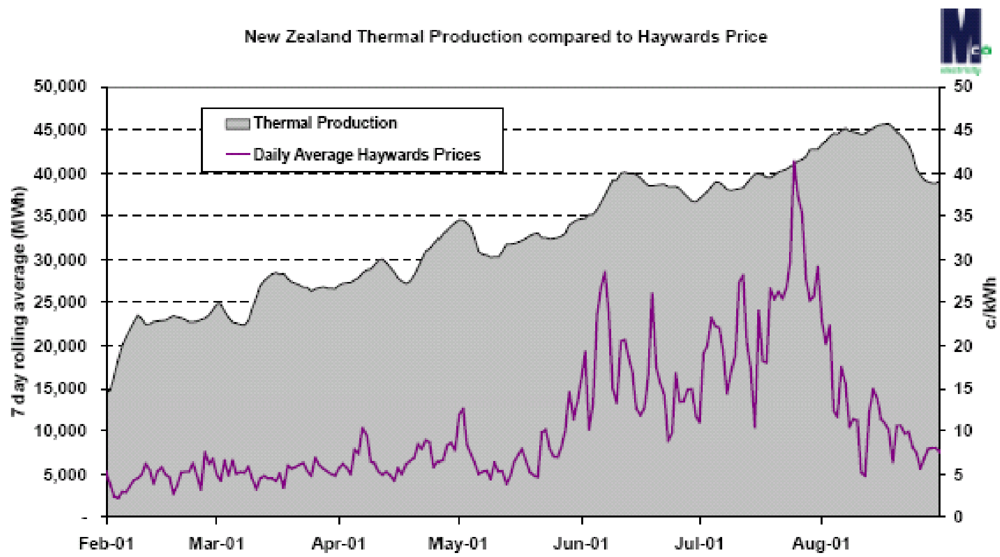
an electricity savings campaign with a target of 10% savings for 10 weeks and 15% for the public sector.

By the second half of August lake levels started to stabilize, demand was dropping and thermal generation reached full capacity. With the end of winter in sight spot prices fell below NZ$ 100 per MWh and on the 10th of September the Minister of Energy announced that the risk of an electricity crisis had diminished and called the weekly stakeholder meetings to end and for the conservation campaign to be eased. The government also announced the Terms of Reference for a Review of the winter events.

## Post 2001 Winter Review

One much debated aspect of the 2001 hydro crisis was whether thermal generators were employed fast enough or whether there were indications of holding back capacity. At the beginning of winter (May-June) it was clear hydro storage had fallen to historically low levels for that time of year. This should have resulted in spot prices rising sufficiently to induce all the reserve thermal plant to run and take market share away from the hydro generators, thereby conserving hydro storage. In fact, the thermal plant on the system did not run at capacity until July 2001. It is not clear why this delay occurred. Transmission constraints may have contributed: half June actions were taken to relax transmission constraints and end of July further relaxation took place. Thermal generation peaked at the beginning of August (see figure 4).

Figure 4




Source: NZEM (2001)

The 2001 'hydro crisis' initiated a government review of the self-regulated electricity market. The 2003 'hydro scare' reinforced the felt need for reforms, and when the sector itself couldn't agree on reforms, the Electricity Commission was created in 2003. Since then it has developed several versions of winter security-of-supply policies.

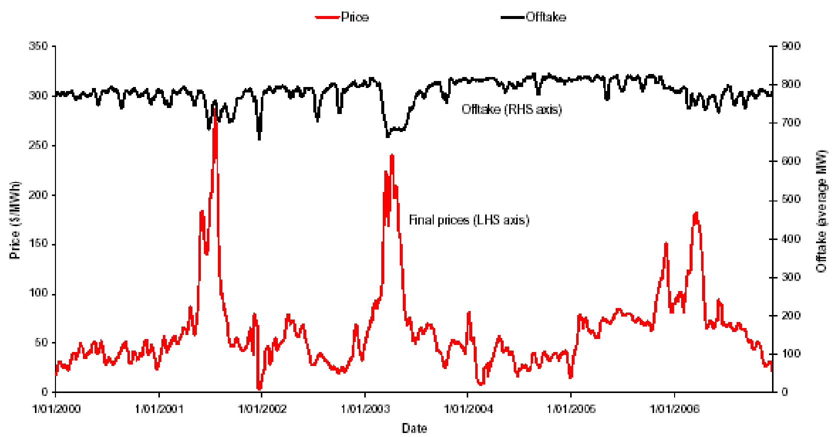
Indications of Demand Side Response

Although no overall overview or analysis exists of industrial demand response in 2001, anecdotal evidence and partial analysis of some of the largest industrial users indicated demand reductions in the range of 5-6% with peaks of 10% or higher (see figure 5)

Figure 5

Medium-term Demand response by 3 major industrials

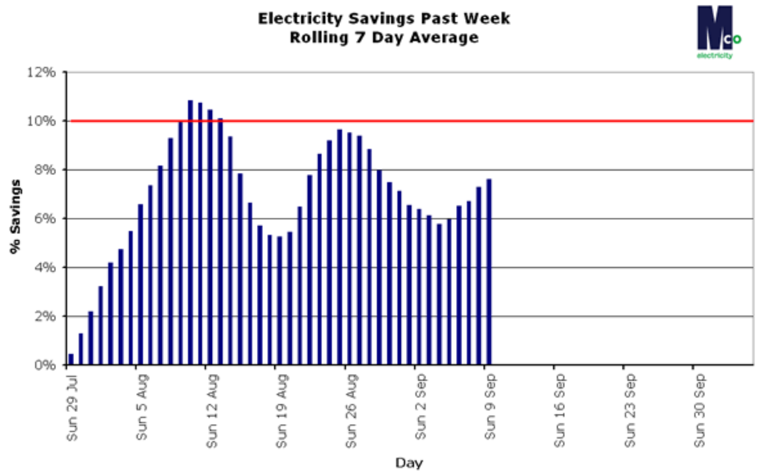
(14-day rolling average of final price and off take)




Source: EC (2007)

As described before, most of the commercial and residential sectors are not exposed to wholesale prices and are therefore not price responsive. However, response to public savings campaigns can be substantial. Total savings (industrial as well as residential/commercial) over the ca. 6 weeks of the ‘crisis’/campaign from July to September 2001 were claimed to be 450 GWh (@ ca. 5,000 GWh expected demand for that period, indicates ca 9% total demand reduction). Figure 6 below indicates 6-8% average savings over the period.

Figure 6




Source: NZEM (2001), EECA (2001)

The 2008 hydro crisis

2008 started with a very dry summer and low lake levels (54% of average) going into winter. The problems were aggravated by the shutting down (since the end of 2007) of half of the interisland HVDC-line[148], restricting the power transfer from the North Island (with all the major thermal generation) to the South Island and subsequent increased draining of the Southern hydro lakes. Also the old New Plymouth power station (420 MW, gas/oil-fired, 1976) had been shut down due to asbestos-problems. Other, shorter aggravating events were the temporarily taking out of service of TCC power station (370 MW, gas-fired, 1998 – several weeks), and Tongariro Hydro station (360 MW) due to unexpected maintenance.

By the end of April (Week 18) the Electricity Commission announced that the lake levels and expected inflows had dropped below the 'Minzone', a model used by the Commission to determine the hydro lake situation. At the start of May 2006 (week 19), when weekly average prices started to exceed NZ$ 200 /MWh (2008-dollars), large users like Tiwai Point Aluminium Smelter announced that cut back of its demand by 30MW (ca. 5%) later to be increased to 66 MW (ca. 12%) and timber, pulp&paper processors started responding similarly.[149] The Electricity Commission-

[148] Half of 'pole 1' was recommissioned in early 2008 to help meet winter peak demand. Limitations were among others:1) only run in a northwards direction; 2) be permitted at times of critical system need (expected to occur between 15–20 days a year); 3) limited to 20 starts per year. This does not assist the low lake levels in the South Island, however. (Source: TPNZ Electricity Industry Newsletter – March 2008)

[149] Comalco (owner of Tiwai Point) indicates in its submission that they are generally ca. 90% hedged and 10% spot exposed. PanPac (a pulp&Paper mill) indicates that they are normally 50-60% hedged. Other large industrials vary in between.

controlled Whirinaki diesel-powered backup plant (150 MW) started, initially bidding in at NZ$ 200 / MWh, but as diesel fuel bought at historical prices was being replaced with newly bought diesel, Whirinaki's Reserve Energy Trigger Price gradually rose to NZ$389/MWh. On 30 May (Wk 27) the Electricity Commission decided, however, to cap the price at NZ$289/MWh.

At the start of June 2008 average weekly wholesale power prices were exceeding NZ$ 350/MWh and preparations were made for a national power savings campaign, led by Transpower and coordinated among the power industry. First the power industry launched and advertised a new website: www.winterpowerwatch.co.nz to provide more, highly visible information on hydro storage levels, winter power demand and residential power saving tips.

Other 'emergency' measures on the supply side included:

Contact recommissioned one 100 MW generator unit at its mothballed New Plymouth power station.

Mighty River Power announced its new geothermal plant at Kawerau was expected to come on-line ahead of time and begin output in mid July instead of October

Half June the electricity industry expanded its public information campaign to conserve power.

By the middle of July above average inflows were observed, lake levels started to recuperate above Minzone levels. By 27 July the public savings campaign was ceased. Wholesale prices dropped below NZ$ 100 /MWh and the public savings campaign was eased.

Indications of Demand Side Response

A Winter Review was announced. In expectation of the review report (due in December 2008, but delayed) not all data has been publicly released yet. The first estimated demand reductions have been released, however, and are cited below in table 4.

Table 4

| Estimated Demand Reduction | | |
|---|---|---|
| Wk | Ex-large industrials | Incl large industrials |
| 27 | 3.1 % | 5 % |
| 28 | 3.2 % | |
| 29 | 4.6 % | |
| 30 | 4.9% | 6.8 % |
| 31 | 4.6% | |

Source: Transpower (2008)

Preliminary conclusions Demand-side management in hydro crises

Both hydro crisis in New Zealand in 2001 and 2008 are ranked as serious, led to similar price rises and induced a range of demand-side and emergency measures and public savings campaigns, but stopped short of involuntary rationing.

Estimations indicate that demand side response to spot prices in the industrial sector was significant, depending on hedge contracts, and in the order of 5-6% overall of industrial sector demand, potentially peaking at 10% in the weeks of highest spot prices. Residential (and small-commercial) demand side response to increased wholesale prices was very limited in both crises because the majority of such end-users are not exposed to such price variations. However, a well-targeted public savings campaign seems to be capable of inducing in the order of 3 to 5% demand reduction. [150]

Comparison with the Norwegian hydro crisis in 2002/2003 (Von der Fehr (2005)) shows that residential consumers exposed to variable or spot price contracts led to a demand reduction of 7%. This residential demand side response in Norway was reached while the vast majority of these users were still provided traditional, simple meters, indicating that metering infrastructure is not a pre-requisite of residential demand side response, but rather contract structures offered by retailers. However, as indications are that New Zealand's hydro shortages are more frequent and faster to develop due to the limited hydro storage capacity, the advent of smart meters that are presently being rolled out in New Zealand, could give more flexibility in retail price adjustment (weekly instead of monthly timeframe). Several retailers have indicated interest in developing such more variable price plans, but none have been introduced as yet. Contributions of residential smart metering to hydro shortage management could include: offering of spot-related/variable price contracts that could induce medium-term price demand response; improved feedback to consumers that reinforces energy efficiency (information & attention effect); improved residential peak demand management (lowering T&D losses and releaving transmission constraints that induce hydro stations to run harder).

The Norwegian industrial demand response seems more limited than in New Zealand (less than 5%, Von der Fehr (2005)). Norway also has a very flexible dual-fuel boiler market that can respond 100% to electricity price. New Zealand does not have this flexibility.

Additional demand response measures identified in New Zealand are (source: EC, 2008):

Involuntary, emergency measures to reduce demand by another 3% to 6% once the emergency zone is breached, including; and extended use of ripple control[151] at a cost of $1,000 to $5,000/MWh

---

[150] This fits well with Electricity Commissions estimates of 4 -6 % demand side response before involuntary measures (EC, 2007)

[151] Extended use of hot water ripple control (12-16 hrs p day) is estimated to save maximum 2% of national energy demand (EC (2005)) if applied for short periods

Rolling outages as a last resort at an estimated cost of between $5,000 and 20,000/MWh.

References

EC (2005). “Mandatory Use of Extended Water Heating Cuts as an Emergency Measure” *Electricity Commission, Wellington, New Zealand,* October 2005

EC (2007). “Issues Paper – Survey of Market Performance - Market Design Review” *Electricity Commission, Wellington, New Zealand,* 2007

EC (2008). “Hydro Risk Curves and Reserve Energy Dispatch Guidelines” *Electricity Commission, Wellington, New Zealand,* November 2008

EC-CDS (2008). “Centralised dataset” *Electricity Commission, Wellington, New Zealand*, October 2008

EECA (2001). “Submissions to the Post Winter Electricity Review” *Energy Efficiency and Conservation Authority, Wellington, New Zealand*, October 2001

EnergyLink (2008). “Weekly Market Review” *EnergyLink, Wellington, New Zealand*, April-November 2008

Evans, L.T., R.B. Meade (2005). “Alternating Currents or Counter-Revolution – Contemporary Electricity Reform in New Zealand” *Victoria University Press, Wellington, New Zealand*, December 2005

M-Co (2008). “New Zealand Weekly Hydro Inflows & Storage 1979-2007” *The Marketplace Company, Wellington, New Zealand,* January 2008

MED (2008). “Energy Data Files- June 2008’ Ministry of Economic Development, Wellington, New Zealand, June 2008

Nair, N.K., Rehan Nayagam, Roman Francis (2008). “New Zealand Utility Experience with Demand Side Management” *IEEE,* 2008

NZEM (2001). “Submission to the Electricity Post-Winter Review” *New Zealand Electricity Market, Wellington, New Zealand*, October 2001

SKM (2005). “Auckland’s Electricity Demand Characteristics and Applicability of Demand Management” *Sinclair Knight Mertz, Auckland, New Zealand,* 2005

Von Der Fehr, N.H.M., E.S. Amundsen, L. Bergman (2005). “The Nordic Market: Signs of Stress? In: *Electricity Market Reform by* Sioshansi, F.P , 2005

# 37. Changing the Paradigm of Electric distribution Quality Regulation

**Rodrigo López G.**

Laboratory of economic analysis of energy networks and systems,

Bâtiment C, 27 av. Lombart, 92260 Fontenay aux Roses, France.

Phone : +33 (0)1 40 91 69 74, Fax : +33(0)1 40 91 64 27.

Email: rlopezg@ieee.org

Keywords - Electricity, distribution, incentive, regulation, quality.

Abstract: It is now well know that economic regulation models (traditional, incentive or by competition) of the electricity distribution sector do not consider, at least not correctly, the quality of electricity. The incentive and competition schemes provide strong incentives for efficiency, unlike the traditional regulation. However, the quality of the offered services is at risk because these systems mostly focus on costs reduction. To ensure that cost cuts are not introduced by distributors at the expense of quality setting in place incentives for high quality is essential. Quality is a complex issue as it is composed to several parameters, each of them with its own characteristics. Consequently, 1) the difficulties to reveal the information of how constructing the so-called “cost function of quality”; as well as 2) the conviction, by different actors, that to invest in quality of service do not generate benefits; seems to be the today accepted paradigm of the distribution sector. This is justified mainly by monopolistic character of the distribution activity (essentially: captive clients, concession zones, and investments return). Literature shows us that regulators are motivated by political as well as economic factors, and that companies may not respond primarily to the regulator’s financial rewards or penalties for their quality targets. Against this background, it became necessary to rebuild the regulation of the electricity distribution sector by holding quality in the heart of the regulation and how to finance it. It will be necessary to develop new

analysis tools that take account the new “information” and the new institutional situation. These regulatory instruments must be fair and simple to be applied. Clear regulations play a fundamental role in data measurements and recollection

In this paper we analyze and compare regulatory approaches and policies regarding quality of service in electricity distribution; we discuss the old paradigm of electricity distribution quality; then we highlight difficulties to establish the “benefice function of quality” (cost function of quality); furthermore we show up that quality of service generate benefits for both society and investors. Finally, we explore an incentive regulation of service quality for electricity distribution activity which answers the following objectives: an adequate return for distributors according to the level of quality offered; incentives for distributors to invest in order to reach the optimal level of quality from the social point of view; to guarantee an effective level of quality to all the customers; and a redistribution of the benefit of the overall costs reduction associated with quality of service between distributors and customers.

# 38. Creation of Cooperative of Clean Energy Generating Companies As a Model for Rural Development

**Jaime de Pablo Valenciano- Juan Uribe Toril - Ramón A Ramos Arriagada- Cristina Castillo Gatica - Luis Poblete Davanzo- Arturo M. Kunstmann F.**

Jaime de Pablo Valenciano.

Universidad de Almería

Juan Uribe Toril

Universidad de Almería

Ramón A Ramos Arriagada

Universidad de Santiago de Chile

Cristina Castillo Gatica.

Universidad de Santiago de Chile

Luis Poblete Davanzo

Universidad de Magallanes

Arturo M. Kunstmann F.

Centro de Estudio de los Recursos Energéticos

Universidad de Magallanes

Universidad de Almería. Facultad de Ciencias Económicas. Despacho 0.10. juribe@ual.es

## 1.- CONSIDERACIONES INICIALES

En esta comunicación se pretende poner de manifiesto la íntima relación que existe entre el desarrollo rural y las energías alternativas necesarias para poder atender las necesidades del entorno, además de conjugar la relación de este desarrollo con el medio ambiente. Para llevar a cabo este estudio se procedido a estructurarlo de la siguiente forma: En primer lugar se analizan las sinergias entre economía social y desarrollo rural. En segundo lugar se plantea la influencia que tiene la energía eléctrica convencional y las posibles alternativas existentes para su utilización. En tercer lugar se explican las distintas políticas energéticas seguidas por las diferentes instituciones en España y se estudian diversos casos a nivel de Comunidades Autónomas (Navarra y Andalucía). En cuarto lugar se realiza un planteamiento de un estudio que se va a realizar en la Tierra del Fuego (Chile) que está siendo financiado por la Agencia Española de Cooperación Internacional para el Desarrollo (AECID). Por ultimo se realizan una serie de conclusiones que servirán como reflexiones que se plantean ante las sinergias que se pueden producir de la aplicación de la creación de cooperativas de generación de energía limpia en el desarrollo rural.

## 2.- SINERGIAS ENTRE DESARROLLO RURAL Y ECONOMÍA SOCIAL

La Economía Social en el mundo rural, especialmente en España ha venido desarrollando un papel muy importante en zonas tradicionalmente deprimidas, que venían dedicándose casi en exclusiva a la agricultura, donde las rentas per capita siguen siendo inferiores a la media de otros sectores económicos.

Se está intentando potenciar las iniciativas que no se limitan a las producciones tradicionales, y conseguir la diversificación económica de esas zonas, como la agricultura ecológica, agroturismo, turismo local, energía alternativas, actividades de conservación y mejora del medio ambiente, del patrimonio, etc.

Como consecuencia de ello se está generando, en los últimos años, un mayor dinamismo que repercute en la generación de nuevos proyectos de PYMES y por cierto, de experiencias de Economía Social, lo cual está haciendo posible que se estén reflotando sectores económicos españoles que hasta ahora permanecían sumergidos, con los perjuicios sociales y económicos que ello conllevaba.

Pero además, la Economía Social se erige como una auténtica alternativa al desempleo juvenil y de la mujer, que en el entorno rural es especialmente problemático.

Podemos afirmar, por tanto, que ello está contribuyendo a la radicación de la población en sus lugares de origen y a evitar así, al menos en parte, que los jóvenes y las mujeres rurales se vean obligados a migrar como única salida posible para tener acceso al mercado de trabajo.

La Economía Social y el desarrollo rural persiguen objetivos paralelos, llegando incluso a complementarse. Así, pues, podemos determinar algunas similitudes o sinergias entre desarrollo rural y economía social:

a) Ambos conceptos contribuyen al proceso reactivador de la economía y a la dinamización de la región en donde se desarrollen.

b) Ambos tratan de aprovechar eficientemente los recursos endógenos existentes en una determinada zona.

Las entidades inscritas en el ámbito de la Economía Social están especialmente ligadas al entorno en el que se desarrollan, ya que al no ser empresas intensivas en capital, deben suplir la escasez de medios financieros con un mejor aprovechamiento de los demás recursos a su alcance, ya sean recursos naturales, humanos, infraestructuras y servicios locales, etc.

En el ámbito rural se está llevando a cabo una especial función de revalorizar los recursos endógenos, conservando el medio natural, y tratando de sacar el máximo partido a éste. Ejemplos de esta tendencia son las diversas iniciativas de desarrollo de energías alternativas que están proliferando.

c) Ambos son capaces de estimular el crecimiento económico, crear empleo y mejorar la calidad de vida de la comunidad.

d) Ambos tienen un enfoque a largo plazo.

De un lado, con el desarrollo rural se pretende crear las condiciones que permitan un desarrollo sostenido de la zona, y esto sólo es posible con la fijación de una estrategia a largo plazo. De otro lado, la actuación de las entidades de economía social, más orientadas hacia los beneficios sociales de empleo y bienestar social, provoca que no se orienten a la creación de beneficios a corto plazo, objetivo siempre peligroso para la subsistencia de toda unidad económica y social.

e) Ambos desarrollan industrias alternativas y nuevos yacimientos de empleo.

El desarrollo rural trata de promover los nuevos sectores emergentes en cada zona y consigue hacer converger la diversificación de las economías locales hacia actividades con proyección de futuro. Estos nichos de mercado, por sus características, constituyen una buena guía para la Economía Social, ya que son actividades nuevas por lo que la competencia no es muy fuerte, y pueden ser cubiertos en una dimensión local.

Cuadro 1.- Nuevos Yacimientos de Empleo (NYE)

| CLASIFICACIÓN DE LOS NYE SEGÚN 4 ÁREAS GENERALES | |
|---|---|
| A) Los servicios de la vida diaria | C) Los servicios culturales y de ocio recreativo |
| 1. Servicios a domicilio<br>2. Cuidado de los niños<br>3. Nuevas tecnologías de la información y de la comunicación<br>4. Ayuda a los jóvenes en dificultad y la inserción | 10. Turismo<br>11. Sector audiovisual<br>12. Valorización del patrimonio cultural<br>13. Desarrollo cultural local |
| B) Los servicios de mejora del marco de vida | D) Los servicios de medio ambiente |
| 5. Mejora de la vivienda<br>6. Seguridad<br>7. Transportes colectivos locales<br>8. Revalorización de los espacios públicos urbanos<br>9. Comercios de proximidad | 14. Gestión agua y residuos<br>15. Gestión del agua<br>16. Protección y mantenimiento de las zonas naturales<br>17. Normativa, control de la contaminación e instalaciones correspondientes |

f) Ambos prestan especial atención a la formación y mejora de la capacitación de la mano de obra.

Todos estos factores de convergencia entre ambas realidades hacen que merezca la pena contar, de manera destacada, con la Economía Social dentro del marco del desarrollo rural, dada su repercusión en la sociedad en que se originan.

El desarrollo rural es un modelo de estrategia integral del territorio, por lo que para su diseño se deben tener en cuenta todos los elementos que lo componen, el nivel económico, social, cultural, medioambiental, institucional, etc.

Para conseguir esto será necesario un esfuerzo de todos los agentes económicos y sociales, de forma que ello permita llegar a una detección realista de las necesidades y potencialidades del medio. Pero la cooperación no puede limitarse a la fase de diagnóstico, sino que debe ir más allá, ya que deberá fomentarse una dinámica de participación para que las políticas de desarrollo sean asumidas por todos, y, de esta forma, adquieran una mayor legitimidad.

La Economía Social, como parte importante del sector empresarial, pero también por la concordancia de objetivos con el desarrollo local, no debe quedarse al margen como simple espectadora de este motor de cambio, sino que debe participar en todo el proceso involucrándose, a fin de avanzar todos en un mismo sentido.

## 3) LA IMPORTANCIA DE LAS ENERGÍAS ALTERNATIVAS EN LAS ZONAS RURALES.

El consumo de electricidad es uno de los indicadores económicos utilizados con más asiduidad al momento de cuantificar grados de avance social y económico. La electricidad es necesaria para el desarrollo y el aumento del bienestar, y una buena manera de medir éstos es analizar la evolución de aquella. El medio rural no es —lógicamente— ajeno a esta relación, por lo que su desarrollo está íntimamente ligado a su electrificación.

A veces, que el desarrollo llegue a un país o a una comarca con cierto retraso tiene sus ventajas, pues puede beneficiarse de las últimas tecnologías y lograr prácticamente los mismos niveles de servicios que los países o zonas más desarrollados, con un menor impacto medioambiental e, incluso, con un menor coste. Un ejemplo lo tenemos en la telefonía móvil en los países en desarrollo: comunicación sencilla sin necesidad de fuertes inversiones en infraestructura (torres y tendido de líneas).

Gracias a los planes de electrificación rural llevados a cabo en las últimas décadas, la mayor parte del territorio español cuenta ya con este servicio, pero esto no quiere decir —ni mucho menos— que sea un asunto resuelto sobre el que ya no sea necesario insistir.

Por un lado, porque de todos es sabida la altísima dependencia energética de España, como la mayoría de los países del mundo; dependencia, sobre todo, del exterior, por las importaciones de petróleo y gas natural que se deben hacer, en muchos casos, con una excesiva concentración en países que no se caracterizan precisamente por su estabilidad política (en 2007, por ejemplo, alrededor del 65% de las importaciones de gas natural de España procedía de Argelia). Dependencia, también, del régimen de lluvias, que aumenta o disminuye, en función de los fenómenos climáticos.

Por otro, por los altos costes, tanto de la energía primaria no renovable importada, como del carbón nacional.

Y, por último, por el fuerte impacto medioambiental que esas energías provocan. Impacto que unas veces —la mayoría— es objetivo, pero otras, aunque no lo sea tanto, así lo piensa

—o se lo hacen pensar— buena parte de la población; podríamos hablar, en este caso, de fuerte impacto medioambiental subjetivo, pero generalmente aceptado.

El desarrollo y la paulatina utilización de energías renovables (solar, eólica, hidroeléctrica, biomasa…) ayudará a solucionar bastantes de los anteriores problemas, ajustándose —por sus peculiaridades— especialmente bien a las necesidades del mundo rural.

Aunque siempre es peligroso generalizar pues —lógicamente— podemos encontrar casos que se separan del modelo propuesto, vamos a admitir que algunas de las características comunes a buena parte del medio rural son las siguientes:

- Núcleos urbanos de reducido tamaño.
- Deficiencia en las infraestructuras.
- Abundancia de viviendas unifamiliares.
- Cierta dispersión de las viviendas.
- Pérdida de población en las últimas décadas. Sobre todo de población joven, que emigra a las ciudades en busca de trabajo y de un mayor bienestar.
- Estrecho contacto con el medio ambiente.

Algunas de las ventajas de las energías renovables para la electrificación y el desarrollo del medio rural son las siguientes:

- Aprovechamiento de las potencialidades medioambientales de la zona: sol, viento, saltos de agua, biomasa... Algunas de ellas pueden pasar de ser una carga (el sol y el viento excesivos son frecuentes causas de despoblamiento de ciertas zonas geográficas) a ser un factor de riqueza para el lugar.
- Alto grado de disponibilidad en comparación con los recursos no renovables: petróleo y carbón no hay en todos los sitios, sol y viento (—en mayor o menor medida— sí).
- Bajo grado de impacto medioambiental.
- Creación de puestos de trabajo directo, favoreciendo la permanencia de la población.
- Creación de puestos de trabajo indirectos (por ejemplo, en actividades ligadas a la atracción de visitantes que pudiera generar la existencia de este tipo de instalaciones: parque eólico, pequeño pantano…), con el mismo efecto del punto anterior.
- Cuando se hace referencia a las economías de escala para justificar la construcción de grandes centrales eléctricas alimentadas con energías no renovables, con frecuencia se olvidan los impactos medioambientales que generan y los costes asociados a su anulación o minimización. Las economías de escala, en el caso de instalaciones que se sirven de energías renovables, se alcanzan para plantas relativamente pequeñas, pero de tamaño suficiente como para atender un núcleo urbano rural, ocupando a gente del lugar y con unos costes medioambientales mínimos.
- Favorece el proceso de descentralización y, por tanto, de disminución de la dependencia eléctrica de una comarca o un núcleo urbano rural.

Lógicamente, también existen inconvenientes:

- Aunque sea bajo, sobre todo si lo comparamos con otras fuentes energéticas, también las renovables generan un impacto ambiental. Los aerogeneradores, por ejemplo, producen un impacto visual y acústico, pudiendo afectar, este último, a las especies del lugar.

- Para poder utilizar energías renovables se deben dar unas condiciones mínimas (de sol, viento, corrientes de agua…), que aseguren la rentabilidad de las instalaciones.

- En el caso de los parques eólicos es necesario encontrar el emplazamiento adecuado: superficies despejadas, accesibles, con regímenes de viento regulares y de velocidades medias elevadas (5-6 metros por segundo) y sin un valor medioambiental especial.

- Con la excepción del agua, que se puede acumular en lagunas o depósitos similares para después aprovecharla hidroeléctricamente, y la biomasa, otras energías renovables no son susceptibles de acumulación para su posterior utilización (viento y sol), lo que genera cierto grado de incertidumbre sobre su disponibilidad en un momento determinado futuro. Esta desventaja no la tienen los recursos no renovables (petróleo, carbón, energía nuclear, gas natural); de hecho, los países conservan stocks estratégicos de estos recursos.

- El motivo anterior obliga a que cada pequeño núcleo de población rural, aunque cuente con energías renovables en su entorno para abastecerse de electricidad, esté conectado a alguna red para asegurar el suministro. Así, en función de la disponibilidad de estas energías se cubrirán las necesidades locales en parte, acudiendo a la red para cubrir el resto, o se alimentará a la red en los casos excedentarios.

De todas maneras, conviene tener presente, a la hora de evaluar las inversiones destinadas a obtener energía eléctrica por medio de recursos renovables, no sólo la rentabilidad económica sino también la rentabilidad social, que incluye —entre otros aspectos— la preservación del capital natural (que con frecuencia es difícilmente amortizable en su totalidad). Por lo que, junto a los costes de oportunidad que pudieran existir, consecuencia del posible ahorro en inversiones para tener acceso al servicio eléctrico a través de las fuentes energéticas no renovables (tendidos de red, transformadores, centros de distribución…), también hay que tener en cuenta los costes de limpieza medioambiental que éstas energías generan —costes que, en buena parte, las energías renovables ahorran— y los costes, la mayor parte de las veces vía subvenciones, que lleva consigo mantener en el medio rural a un mínimo de sus habitantes, algunos de los cuales, en el caso de apostar por las energías renovables, trabajarían en ellas.

## 4) POLÍTICAS DE ELECTRIFICACIÓN EN ZONAS RURALES DE ESPAÑA

La iniciativa privada es insuficiente para atender las necesidades que, en materia de electrificación, son imprescindibles para facilitar el desarrollo de las zonas rurales, en una doble vertiente:

1) Evitar la despoblación.

2) Tecnificar el campo.

En el primer caso es evidente que hay que recurrir a soluciones energéticas que cumplan con proporcionar un mínimo vital energético, donde los costes de instalación sean los más bajos posibles y, por otro lado, la dispersión de la población hace necesario buscar soluciones casi unipersonales, ya que la red de distribución es extensa, lo que la encarece de forma muy notable. Estas son razones de tanto peso que hacen necesario acudir a este tipo de soluciones sobre la base de energías alternativas, distintas de la solución convencional.

Energías alternativas, como la solar, eólica, minihidráulica y biomasa, hacen muchas veces que sean soluciones recurrentes dado su bajo coste de inversión en comparación con el sistema tradicional del suministro eléctrico. En este sentido las instituciones en el ámbito nacional español (Ministerio de Industria y Energía), regional (comunidades autónomas), provincial (diputaciones y ayuntamientos), incentivan y promueven proyectos que solo se justifican dentro de un concepto de economía social.

La Unión Europea, a través del Fondo Europeo de Desarrollo Regional (FEDER), en ayuda a las regiones más desfavorecidas, facilita fondos destinados a financiar proyectos orientados a la mejora de la calidad de vida de los núcleos rurales. Impulsa estas iniciativas con importantes aportaciones económicas, independientemente de las entregadas por las propias compañías eléctricas. Como alternativa a los sistemas de apoyo público convencional, tal como las subvenciones o líneas de crédito preferente, para proyectos de energías alternativas, el Instituto para la Diversificación y Ahorro de la Energía (IDAE) desarrolla otros instrumentos técnico-financieros mediante los cuales proporciona la solución técnica más idónea, así como los recursos económicos para facilitar la realización de proyectos energéticos.

Definidos los aspectos generales de la electrificación en el medio rural, pasamos a analizar una serie de casos particulares en el uso de energías renovables en España:

En el caso de la Comunidad Autónoma de Navarra, si se cumple el plan previsto, el 100% de la energía eléctrica que se consuma en el año 2010 estará producida por fuentes renovables: el 45% por energía eólica, el 38% por minicentrales hidroeléctricas, el 16% por biomasa (quema de residuos forestales, madereros o herbáceos) y el 1% restante, por el aprovechamiento energético de los gases de una planta de residuos. Esto tendrá como consecuencia la producción de 1.400 millones de kilowatios/hora, que, de generarse en centrales térmicas, emitirían a la atmósfera casi un millón y medio de toneladas de CO2. Además de los beneficios medioambientales, la puesta en funcionamiento y el mantenimiento de todas estas instalaciones ha generado un número importante de puestos de trabajo directos y otros tantos indirectos, en un sector de indudable proyección.

En 1989 se constituyó la empresa semipública Energía Hidroeléctrica de Navarra (EHN) con el propósito de promover e impulsar la utilización de energías renovables. Inicialmente centró su actividad en el aprovechamiento hidráulico. En 1997 la energía hidroeléctrica representaba cerca del 30% de la producción total de Navarra, con 96 centrales en servicio (entre ellas 19 minicentrales automatizadas), una potencia instalada de 42.000 KW y una producción anual de 150 millones de kilowatios/hora.

Una de las características de la Comunidad Autónoma Andaluza es la diversificación de energías renovables. Entre ellas cabe destacar la solar, eólica, residuos sólidos urbanos, biomasa agrícola y forestal, hidráulica y geotérmica.

El Centro de Investigación solar de Tabernas (Almería), destaca en el estudio y desarrollo en este campo. Resalta la electrificación de cinco mil viviendas por medio de la electrificación solar fotovoltaica de viviendas rurales aisladas de uso permanente. La energía eólica se sitúa en el litoral andaluz del Estrecho (Tarifa); la biomasa agrícola y forestal utiliza residuos del algodón, girasol y cereales y es importante, también, la utilización de los residuos procedentes del olivo (alpechín). Los residuos sólidos urbanos se centran en las áreas metropolitanas de Sevilla, la Bahía de Cádiz y la Costa del Sol. En cuanto a los recursos hidráulicos, si bien ya no existen recursos importantes susceptibles de ser explotados en centrales de cierta envergadura, en Andalucía hay, en cambio, un potencial relativamente interesante representado por la instalación o rehabilitación de minicentrales. También podemos hablar de energías geotérmicas, aunque son muy limitadas, las cuales se sitúan en la zona oriental de la cordillera Bética (Granada).

En cuanto a costes de la energía eólica, podemos, por ejemplo, tomar como referencia el coste kilowatio generado por el parque eólico de Tarifa, el cual se recoge en el siguiente cuadro:

Cuadro 2.- Aplicación del modelo eólico al término municipal de Tarifa.

| ZONA | VELOCIDAD MEDIA | POTENCIA INSTALABLE | GENERACION ANUAL | COSTE kwh GENERADO |
|---|---|---|---|---|
| A | 9,0 m/s | 24 MW | 89 GWh | 7,70 Pta |
| B | 7,5 m/s | 83 MW | 245 GWh | 9,50 Pta |
| C | 6,5 m/s | 59 MW | 136 GWh | 11,50 Pta |
| D | 6,0 m/s | 66 MW | 127 GWh | 13,90 Pta |
| TOTALES | | 232 MW | 597 GWh | 10,62 Pta* |

* Coste medio ponderado

Fuente: Gracia Navarro, S; Hormigo León, A (1993)

## 5) MODELO DE DESARROLLO ENERGÉTICO EN TIERRA DEL FUEGO (CHILE)

La Región de Magallanes se caracteriza por corresponder a la zona austral extrema de la República de Chile. Con una extensión total de 132.000 $km^2$, cuenta con una población total de 150.000 habitantes, lo cual implica apenas el 1% del total de Chile y una densidad de solo 1,15 habitantes por $km^2$. Frente a la ciudad capital de la Región, Punta Arenas, y separada de ella por el Estrecho de Magallanes, se encuentra Tierra del Fuego, isla en la cual ejercen soberanía Chile y Argentina, ubicada a cerca de 3.000 kilómetros de distancia de la capital nacional, Santiago de Chile.

En el sector chileno de Tierra del Fuego, con una extensión total 60.800 $km^2$, vive solamente un total de 7.000 habitantes y se ha presentado una disminución promedio anual del orden del 3% en los últimos 10 años. La actividad económica se realiza básicamente en dos grandes sectores productivos: la ganadería extensiva ovina y la extracción petrolífera. Esta última se encuentra en franco proceso de disminución por agotamiento de los pozos productores, pero se ha iniciado este año un amplio proceso de exploración, con participación de empresas especialistas extranjeras.

Lo señalado en el párrafo anterior implica que la densidad poblacional de la Tierra del Fuego chilena es sumamente baja: apenas de 0,11 hab/km$^2$. Por lo tanto, el abastecimiento de energía eléctrica generada por plantas termoeléctricas resulta bastante oneroso por las distancias existentes entre estas plantas y los escasos puntos y centros poblados que consumen dicha energía. Agréguese a lo anterior el hecho de que estas fuentes productoras son de naturaleza contaminante, ya que operan sobre la base de gas lo que, por otra parte, implica también que se está utilizando un insumo no renovable, de costo creciente y de provisión dudosa en el futuro.

Otra de las características de este territorio es la persistencia de fuertes vientos a lo largo de todo el año, con valores medios sobre los 9 metros por segundo, medidos a 40 metros sobre el suelo. La pureza de los cielos magallánicos es también excepcional, lo que implica tanto una riqueza especial desde el punto de vista ambiental y turístico, como desde el punto económico.

De acuerdo con lo dicho, se está ante dos valores: el patrimonio ambiental que se quiere mantener y mejorar, y otro, potencial, que se desea poner al servicio de las personas que viven en una región de rasgos inhóspitos durante una parte substancial de cada año.

Las especiales características reseñadas y la necesidad de dotar de energía a los dispersos centros poblados en Tierra del Fuego se han compatibilizado en el proyecto que está financiando la Agencia Española de Cooperación Internacional para el Desarrollo (AECID) y cuyos objetivos generales son:

- Promocionar las Empresas de Base Ecológica generadoras de energías renovables.

- Fortalecer la vinculación entre las Universidades de Chile y España, fomentando la creación de conocimiento sobre el papel de las empresas como interfase entre los sectores científico-tecnológico.

- Propiciar la creación, desarrollo y consolidación de un tejido empresarial innovador.

- Contribuir a difundir la cultura de la innovación y el emprendimiento en la población, en general, en el sector universitario y en el científico-tecnológico, en particular.

- Producir, difundir e intercambiar información, conocimientos y experiencias sobre creación de empresas cooperativas, estableciendo un nexo de comunicación fluida y permanente.

- Dar a conocer y difundir entre los diversos agentes sociales la función de la asistencia técnica dirigida a la creación de empresas cuya característica más sobresaliente sea que oficien de instrumentos para la creatividad e innovación sobre base tecnológica.

- Promover la capacitación de recursos humanos especializados.

- Celebrar jornadas y reuniones de trabajo con los responsables expertos en la materia para intercambiar información y experiencias.

- Comprobar el grado de implantación y su repercusión en el impulso, desarrollo y supervivencia de empresas creadas.

- Obtener resultados globales concretados en el surgimiento y consolidación de iniciativas empresariales.

Este los objetivos específicos están los de beneficiar a un conjunto de, aproximadamente, 100 grupos familiares, cuya actividad está asociada a la propiedad y manejo de las estancias, establecimientos de crianza ovejera, y a los 1.400 habitantes del centro poblado de Cerro Sombrero, capital de la Comuna de Primavera. En concreto:

- Substituir fuentes de energía contaminantes, de costos actuales altos y en proceso de crecimiento constante, no renovables, riesgosas y no almacenables, por otras de autoabastecimiento, amigo-ambientales, renovables, de bajos costos actuales y que pueden descender en el futuro, de bajo riesgo y que no hacen necesario un hipotético almacenamiento.

- Mejorar las condiciones de vida de un conjunto de 1.600 habitantes y de quienes pueden incrementarla en el futuro, abriendo acceso a la Informática y a las herramientas de educación digital vía Internet.

- Detener el proceso de migración desde el medio rural al urbano, asegurando la continuidad de labores en el medio rural, por medio de proveer la creación de empresas y la extensión del suministro de energía eléctrica.

- Crear una fuente de ingresos adicionales para quienes emprendan la generación de energía amigo-ambiental, mediante la venta de energía eléctrica a terceros interesados, posibilitando el progreso y apertura de la zona hacia la comunidad nacional e internacional.

- Promover la asociatividad de los pobladores rurales de Tierra del Fuego y ayudarles a organizarse para generar nuevas iniciativas que contribuyan al desarrollo social de la zona.

## 6.- CONSIDERACIONES FINALES

La economía social en su conjunto ha encontrado en el desarrollo rural y en sus iniciativas una demanda de actividad y nuevas ocupaciones.

A lo largo de esta presentación hemos podido apreciar la complementariedad existente entre la Economía Social y el desarrollo rural.

La Economía Social es importante en su aportación al bienestar social, como instrumento valioso en las políticas de empleo y formación, y por su cualidad de pasar a formar parte del engranaje que pone en marcha el desarrollo rural.

Con carácter general los programas de Desarrollo Rural deben dar respuestas a las nuevas demandas que la sociedad requiere del medio rural y agrario, conservación del medio natural y ecológico, espacio para el descanso y esparcimiento, así como diversificación económica, generación de empleo y mantenimiento de la población en el medio rural.

Los nuevos modelos de desarrollo han de ser integrados y sostenibles, basados en una planificación de abajo a arriba y en la participación de los agentes socioeconómicos.

La economía social desempeña un papel importante en favor del empleo y la integración locales. Muchos estudios y evaluaciones recientes muestran que tiene un potencial significativo en la generación de empleo. En gran medida, esto se debe a sus características: la economía social persigue objetivos económicos, sociales y de interés general, establece límites sobre los niveles de beneficios privados e individuales, trabaja con particulares o grupos de personas locales con intereses comunes, y adopta un mecanismo de autogestión en el que participan sus empleados, los trabajadores voluntarios y los usuarios.

Estas características permiten que la economía social aporte algo realmente nuevo en dos aspectos: por un lado, atiende las necesidades locales que aún no han sido satisfechas por el mercado o por el Estado. Por otro lado, muchas organizaciones de la economía social ofrecen formas de trabajo nuevas o alternativas.

Un proyecto de Economía Social es ante todo un proyecto empresarial. Es, por tanto, necesario garantizar la eficacia del mismo para que pueda asegurarse también la consecución de otros objetivos sociales y ello solo es posible a partir de la necesaria profesionalización de la gestión.

La función de la economía social en las áreas rurales se traduce no sólo en una función económica a través de generación de riqueza y de los empleos creados, sino también en el mantenimiento y promoción de modos de vida y culturas locales.

En este sentido, la implementación de empresas de economía social en el área de las energías renovables es una posibilidad real. En España hay Comunidades Autónomas muy avanzadas en el aspecto de las energías renovables como es el caso de Navarra, cuya experiencia es susceptible de transferir a Chile y, en particular, a Tierra de Fuego, región que cuenta con recursos endógenos que representan ventajosas potencialidades en el sector de las energías renovables.

Debemos de diferenciar dos aspectos importantes cuando hablamos de la electrificación en las zonas rurales:

Tipo técnico.-

1.- Está íntimamente unida al desarrollo rural.

2.- Las necesidades energéticas de las zonas rurales favorecen el desarrollo de otras clases de energías.

3.- Las energías renovables son un buen aliado de la conservación del entorno y del medio ambiente.

4.- Facilitan, de manera notable, el desarrollo tecnológico del campo.

Tipo social.-

1.- Es un elemento disuasorio y básico para evitar las migraciones.

2.- Ayuda a la generación de empleos directos e inducidos.

3.- Acorta las diferencias entre las rentas generadas en las zonas urbanas y rurales.

4.- Mejora la calidad de vida de los habitantes del medio rural.

En conclusión, se espera poder aprovechar las sinergias de las empresas de economía social en el desarrollo de la diversificación de las zonas rurales de la Isla de Tierra del Fuego, Magallanes, Chile, apoyadas en el relevante rol de sustentabilidad que juegan en el presente y en el futuro las energías renovables.

## BIBLIOGRAFÍA

Documental.


ALVAREZ MÉNDEZ- BENEGASSI, M.L (1996).- *La Economía Social en Andalucía 1996.* CEPES.

ATIENZA L (1992). "Del proteccionismo agrario a las nuevas tendencias del Desarrollo Rural". *Revista Estudios Agro-Sociales* N° 161, MAPA, 1992.

BAREA TEJEIRO, J. y LUIS MONZÓN, J.L. (1990). *Libro blanco de la Economía Social en España.* Ministerio de Trabajo y Seguridad Social.

BAREA TEJEIRO, J. Y LUIS MONZÓN, J.L. (1996). *Informe sobre la situación de las Cooperativas y Sociedades Laborales en España.* CIRIEC España.

BEL DURÁN, P, CABALEIRO CASAL, M.J.(2002).- "La sociedad cooperativa: fórmula empresarial idónea para el desarrollo rural endógeno y sostenible". *Revista de Estudios Agrosociales y Pesqueros*, n 194.

CEÑA *F* (1992). *Transformaciones del mundo rural y políticas agrarias,* Revista Estudios Agro-Sociales n' 162, MAPA.

CHAVES AVILA, M.(1996).*La Cooperación empresarial en la Economía Social.* CIRIEC España.

COMISIÓN DE LA CE (1988).- *El futuro del mundo rural.,* Comunicación de la Comisión transmitida al Consejo y al Parlamento Europeo el 29 de julio de 1988, (COM(88) 501 final).

DE PABLO VALENCIANO, ET ALL (2007).- *El desarrollo en el ámbito rural de Almería*. Universidad de Almería.

GARCÍA SANZ B.(1996). *La sociedad rural ante el siglo* XXI, Colección Estudios, MAPA.

IDAE (1998).- Las energías renovables en España. Ministerio de Industria y Energía.

García Muñoz, J.M. (1993).- "Actuación de UNELCO en el sector eólico en las Islas Canarias". Jornadas de Energía Eólica en el Sur de Europa. Cádiz, 11-12-13.

Gracia Navarro, S., Hormigo León A.L. (1993).- Integración de la Energía eólica en Sevillana de Electricidad. Jornadas de Energía Eólica en el Sur de Europa. Cádiz, 11-12-13.

PÉREZ B. Y CARRILLO E.(2000). *Desarrollo local: Manual de uso*, Federación andaluza de municipios y provincias, ESIC.

RAMOS E. Y CRUZ J. (1995).- *Hacia un nuevo sistema rural, Colección Estudios, MAPA.*

Internet

- RED IBEROAMERICANA DE ELECTRIFICACION RURAL CON ENERGIAS RENOVABLES. http://axp16.iie.org.mx/FnoC/RIER/Welcome.html .

- FAO. PLAN DE ACCIÓN LATINOAMERICANO Y DEL CARIBE SOBRE ENERGIZACIÓN PARA UN DESARROLLO SOSTENIBLE. http://www.fao.org/waicent/faoinfo/sustdev/Egdirect/Egre0006.htm

# 39. Energy Efficiency in the Power Distribution Industry

**Enzo E. Sauma**

Industrial and Systems Engineering Department, Pontificia Universidad Católica de Chile, Santiago, Chile

(Phone: 56-2-354-4272; fax: 56-2-552-1608; e-mail: esauma@ing.puc.cl).

Keywords: energy efficiency, decoupling mechanism, performance-based incentive mechanisms, tradable certificates, legal imposition of energy efficiency levels.

EXTENDED ABSTRACT:

In the power industry, it is a well-known fact that, under traditional regulatory schemes, such as rate-of-return regulation, power distribution companies (DISCOs) have disincentives to provide energy efficiency (EE) programs because this rate design ties utilities' revenue directly to the volume of commodity sales. Consequently, the debate about EE in power distribution has focused on the design of regulatory mechanisms to mitigate disincentives and/or to incentivize DISCOs to implement EE programs. This paper studies the most recent trends in EE policies aimed to mitigate disincentives and/or to incentivize DISCOs to implement EE programs. Basically, we analyze four types of mechanisms to promote energy efficiency of the DISCOs: (i) mechanisms that decouple the income and the sales volume of DISCOs through periodic rate adjustments; (ii) performance-based incentive mechanisms aimed to reach certain goals of EE programs; (iii) tradable certificates (permits) of EE programs; and (iv) legal imposition to reach certain goal levels of EE.

Decoupling mechanisms

Roughly, “decoupling” refer to a tariff-tuning mechanism that decouples the DISCOs’ ability to recover their costs (and earn profits) from the realized sales volume, guaranteeing a fixed revenue level to DISCOs during a specific period. There are several ways to perform the tuning of tariffs: adjusting only by energy consumption (either symmetrically or asymmetrically with respect to over- and under-estimation of sales), adjusting by number of customers, or normalizing according to weather (as it is used in the Oregon state in USA). However, the basic principle is always the same: once sales are realized, tariffs are adjusted to guarantee a fixed revenue level to DISCOs during a determined period.

The main advantage of this mechanisms is that they effectively disincentive DISCOs to encourage increases in the energy consumption. Another advantage of this mechanism is that the initial estimation of energy sales is not critical since it is only relevant in setting the tariffs for the first trimester (and any forecast error can be adjusted in the following trimesters).

Performance-based incentive mechanisms

Performance-Based Ratemaking (PBR) is a form of utility regulation that strengthens the financial incentives to lower rates, lower costs, or improve non-price performance relative to traditional regulation, which we call rate-of-return regulation. Although the electric utility industry has considerable experience with incentive mechanisms that target specific areas of performance, implementation of mechanisms that cover a comprehensive set of utility costs or services is relatively rare. In recent years, interest in PBR has increased as a result of growing dissatisfaction with rate-of-return regulation and as a result of economic and technological trends that are leading to more competition in certain segments of the electricity industry. In addition, incentive regulation has been used with some success in other public utility industries, most notably telecommunications in the U.S. and telecommunications, energy, and water in the United Kingdom.

There are many specific approaches that can be used to provide financial incentives that reward DISCOs for successfully reaching or exceeding program goals. These include: allowing DISCOs to earn a rate of return on EE investments equal to supply-side and other capital investments, providing DISCOs an increased rate of return either on the EE investment specifically or overall DISCO investments, providing DISCOs with a specific financial reward for meeting certain targets, and providing DISCOs with an incentive equal to some proportion of the overall net benefits the programs produce (i.e., “shared savings”).

Mechanisms of tradable EE certificates

An EE certificate represents a certain amount of energy saving that is to be realized during a pre-specified time span as result of an energy saving investment, which has been typically undertaken in the framework of the EE certificate regulatory system. The owner or operator of the location where the saving is realized can either receive investment support from a so-called obliged party in exchange for delivery of the agreed amount of EE certificates or, in case of 100% self-finance (and provided some conditions are fulfilled), sell the EE certificates to any interested party (i.e., the EE certificate is tradable).

Legal imposition mechanisms

Under this mechanism, a regulatory authority fixes a minimum investment level in EE programs. Basically, the government (or the corresponding authority) imposes a requirement to DISCOs of spending at least x% of their revenues in EE programs.

One of the main problems of legal imposition mechanisms is the lack of economic incentives given to DISCOs to both have a high performance in the implemented EE programs and invest in the most cost-effective EE programs. On the contrary, DISCOs may have incentives to invest in the most capital-intensive (and, probably, least cost-effective) EE programs in order to easily fulfill the legal obligation.

# 40. Feasibility Study of a Solar Generation Plant in Northern Chile

**Rodrigo Moya L., Carlos Silva M., Ph.D.**

Center for the Innovation in Energy

Universidad Adolfo Ibáñez

Avenida Diagonal Las Torres 2640, Peñalolén, Santiago, Chile

(56-2) 331 1456, c.silva@uai.cl

Keywords: Renewable Energy, Solar Energy, Solar Thermal.

Abstract: Chile and most other countries have an energy matrix highly dependent on fossil fuels. This exposes the energy sector not only to high and volatile prices, but also makes the sector one of leading polluters of the economy, with very high levels of $CO_2$ emissions. It is imperative then to investigate new energy sources and to diversify the energy matrix, reducing the fossil fuels dependency and providing stability to the system. Solar energy fits perfectly this need, especially in regions with significant solar resources, such as northern Chile.

The main objective of this study is to assess the economic and technical feasibility of one of most advanced solar energy technologies: the application of cylinder-parabolic-trough-concentrator mirrors on a utility scale, feeding its power to the Chilean Northern Interconnected System.

This research collects all relevant information about the technology, evaluating it feasibility in both the technical and economical realms. The research includes investment costs considering local labor and material prices on three alternative plant sizes: 20, 50 and 100 MW. Revenues are calculated using payments from energy, power and from the trading of credits from Certified Emission Reductions (CERs) for equivalent carbon dioxide ($CO_2$) reductions. The analysis also includes different options for the plant cooling system, and the potential hybridization with natural gas.

The economic feasibility calculation corresponds to the assessment of a private investment project, including the calculation of the Net Present Value (NPV) and the Internal Rate of Return (IRR) indicators for multiple plant configurations.

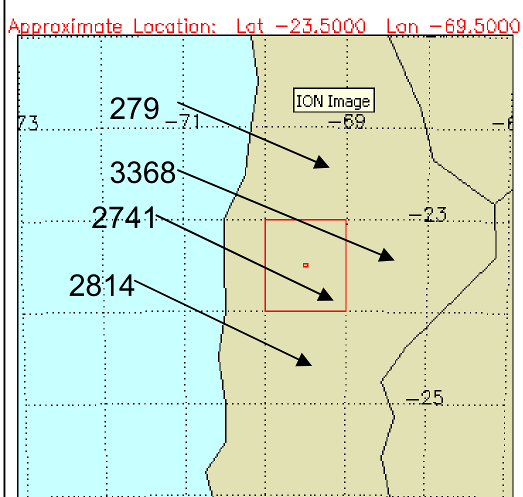
The results from the analysis show that the technology does not reach the level of return required by the energy sector in Chile, with an IRR of 8.45% for a 50 MW plant. However, the analysis also shows that the return improves significantly through the inclusion of a fossil backup system, increasing the income from energy and power to an IRR of 10.34% for the same plant size, making it viable project for a wide range of investors.

Solar resource in Chile

There are several criteria to assess the feasibility of the exploitation of solar energy on a specific area. Perhaps one of the most used is the one given by the World Bank [1], which classifies zones into three groups: unusable, less than 1700 [kWh/m2/year]; usable, with radiation from 1700 [kWh/m2/year] to 2700 [kWh/m2/year]; and finally optimal places, with irradiation over 2700 [kWh/m2/year].

Figure 1 shows the levels of radiation in northern Chile, where the lowest radiation level is around 2741 [kWh/m2/year]. For the region defined between parallel 23° and 25° latitude south, all locations meet the optimal radiation level requirement.

Figure 1 Radiation in Northern Chile




Source:

## Solar Technology

At present, Cylindrical-Parabolic-Trough-Concentrator (CPTC) technology appears as the most completive in its class, with many plants in service, and others soon to be commissioned, with a installed capacity of around 100 MW per plant, while its closest competitor, the power tower (solar plant based on a central receiver), has only 10 MW.

CPTC is also the only solar technology that is in a commercial stage, with almost no technology risks on its implementation, and with the lowest, and continuously declining, investment costs.

Also, operation costs for the CPTC technology are among the lowest for any thermal solar technology.

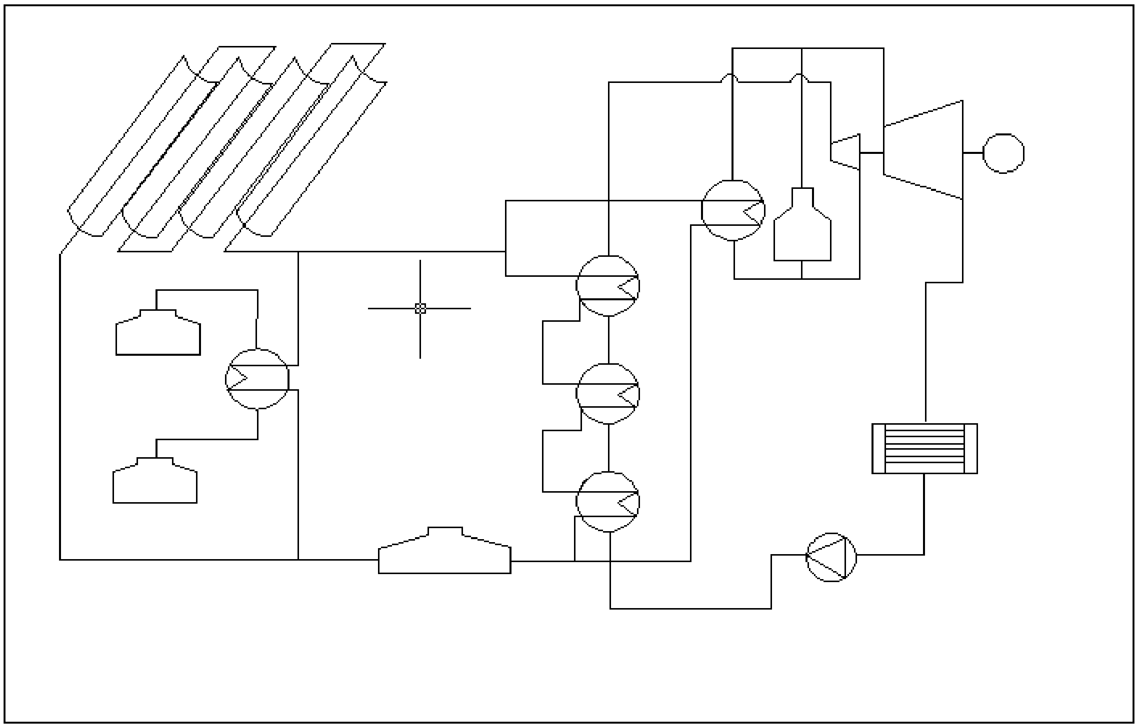
## CPTC Generation Plant

A CPTC solar plant can be divided into three functional blocks: the solar field, the heat exchanger and the thermal cycle.

The role of the solar field is to transform solar energy into thermal energy. This transformation is implemented by concentrating solar energy using parabolic mirrors and transferring this energy into the circulating thermal fluid.

The heat exchanger permits the transfer of the thermal energy from the fluid to the Rankine cycle fluid (i.e., water).

Finally, the energy in the Rankine cycle is transformed into kinetic energy through a turbine connected to a generator that converts rotation motion into electrical energy (see Figure 2).



Solar Field

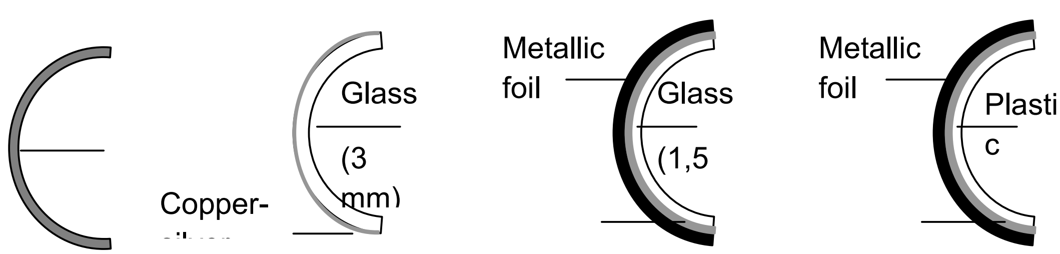
The main component of the solar field is the array of cylinder-parabolic mirrors, with absorber tubes in their focus line. A thermal fluid is circulated through these absorber tubes, gathering the thermal energy from the solar field. Additional components of the solar field include a support system, trackers and a piping system.

Cylinder-parabolic mirrors

The mirrors are parabolic in shape and reflect and concentrate the direct radiation from the Sun onto the absorber tube. The material from the mirrors should have high reflectivity and it must be moldable and rigid to take and keep the parabolic shape.

The leading manufacturer of mirrors is the German company *Flabeg*. Their mirrors are installed in all the plants operating commercially at this time [2].

Figure 3 Cylinder-parabolic mirrors



Aluminium foil

Copper-
silver film

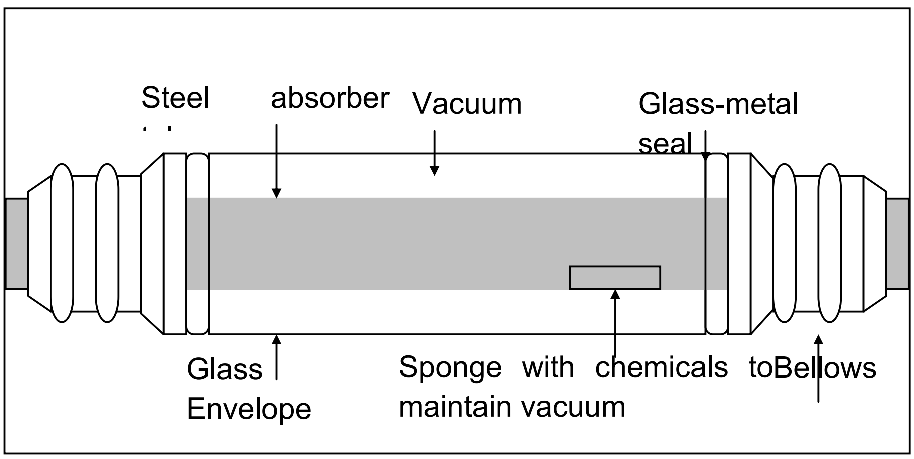
Copper-
silver film

Absorber tube

The thermal energy is concentrated by the mirror into the absorber tube. The design of the tube minimizes the thermal losses to improve the overall efficiency of

Figure 4 Absorber tube

the system. Figure 4 presents a basic outline of the absorbent tube.




The absorber tube is formed by two tubes: an outer tube made of glass and inner one made of metal. The glass tube has an anti-reflective coating to maximize the penetration of solar radiation; this tube minimizes the heat losses by convection and protects the inner tube from weather conditions. The space between the two tubes is filled with a sponge with chemical substances.

The inner tube contains the circulating thermal fluid. This tube has a low emissivity for infrared radiation to reduce thermal losses.

The assembly of the tubes includes junctures to ensure that the different coefficients of expansions of the metal and the glass are compensated and that the tubes are kept properly sealed.

Thermal fluid

The thermal fluid is typically synthetic oil. This oil has the property of staying fully liquid during the range of working temperatures (from 200 ºC to 400 ºC) and pressures (from 10 to 15 bars).

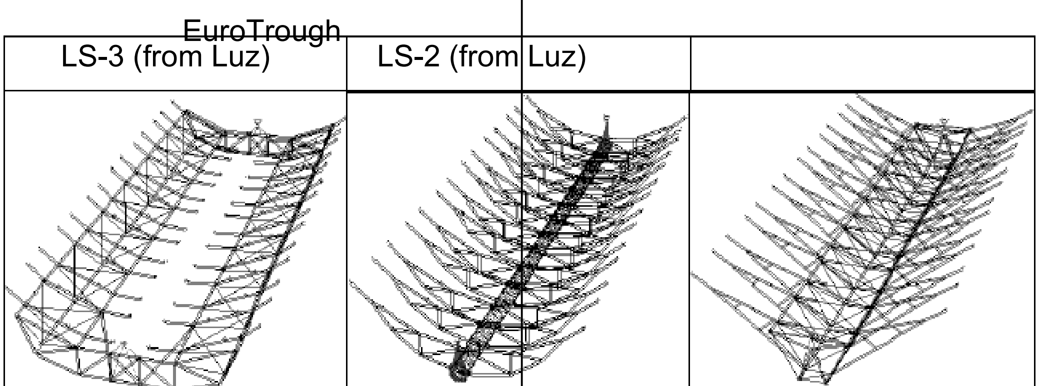
Phase I of the Solar Energy Generating Stations plants (SEGS) in the Mohave Desert, uses Santotherm 55 as thermal fluid, operating at temperatures up to 300ºC, all the remaining phases of SEGS use oil Therminol VP1 that operates up to 400ºC. This oil is manufactured by Monsanto [3].

Collector and support structure

Current implementations of CPTC use one of three types of solar collectors, depending on its manufacturer: Luz, Solargenix and EuroTrough.

Luz and Solargenix are from the United States and EuroTrough is an initiative of a European consortium formed by Flabeg, Solel, CIEMAT and others.

Figure 5 Collector structure




Source: German Aerospace Center (DLR).

Condenser and cooling systems

The Rankine cycle requires the use of a cooling system and a condenser. Most of the existing CPTC plants use cooling systems based on cooling water flowing through the condenser to remove the heat from the cycle water. Once the cooling water exits the condenser, after absorbing all the required heat, it is cooled down using a cooling tower, where a significant portion of the cooling water evaporates. The remaining water, now at a lower temperature, is reused in the condenser.

SEGS plants use systems based on cooling water. The water consumption is around 3-4 liters per each kWh generated.

Many of the existing solar plants are located in or near desert areas, where significant amounts of water are not available. If water is extremely scarce, the plant can use a cooling system based on circulating air, however, in these systems efficiency decreases in around 3 to 4% [4].

Additional Subsystems

The design of a solar power plant also involves two optional features: a thermal storage unit and a backup subsystem for generation using fossil fuels. These two subsystems are explained below:

Thermal Storage Unit

The thermal storage unit stores the energy that is captured by the solar field, but not sent to the Rankine cycle. This energy is then used to produce electricity when no solar radiation is available (for example, after sunset), or to supplement the radiation in the presence of clouds. The storage is implemented by using salts (from potassium and nitrates) and large containers to store the hot and cold salts.

Fossil backup subsystem

Solar plants are unable to produce power at all times because of the variability of solar radiation levels, both during the day and during the year. A fossil backup subsystem provides an alternative to complement the solar energy partially or totally, by operating when radiation is low or not present, and the thermal storage unit has no energy left.

The most common implementation of a fossil backup system adds a boiler to the steam cycle to reheat the water from the Rankine cycle before entering the turbine.

This subsystem increases the plant’s firm power, driving up its plant factor.

Finally, it is important to note that fossil fuel subsystems for solar plants are less efficient than those for conventional thermal plants.

Design and operation

The most important design variables for a CPTC plant are: the size of the solar field, the capacity of the storage system and the size of the thermal cycle.

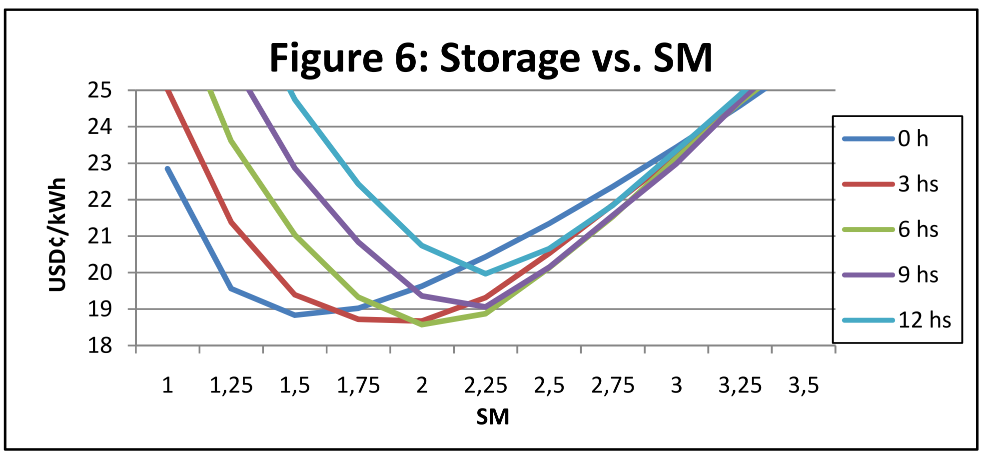
A widely used design variable is the Solar Multiple, SM, which defines the ratio between the installed power of the solar field and the thermal cycle. In a solar plant with an SM of one, the solar field is dimensioned so turbine will generate at full load only at noon during the summer season (maximum radiation point).

As the value of SM increases, the size of the solar field increases, allowing for more energy to be converted into electricity. This drives the plant factor higher because the solar field can produce the necessary energy to keep the thermal cycle at full capacity, even when the radiation is not at its maximum.

When a storage system is added to the configuration, all the energy in excess of the thermal cycle capacity is stored to be delivered to the Rankine cycle at a later moment, when radiation levels are lower.

The optimal SM for a particular project is chosen by simulating all conditions using an optimization model. This model assists the designer in obtaining the SM that provides the most energy for the lowest investment. Software such as the NREL´s SAM package, properly configured with climate data (including hourly radiations levels), allows the designer to choose an optimal SM and storage capacity. These simulation packages typically provide important information such as: energy production, plant factor, investment requirements and energy cost. Figure 6 shows energy costs for various SM configurations and storage system dimensioning.

Figure 6 Energy cost for various storage capacities and SM values



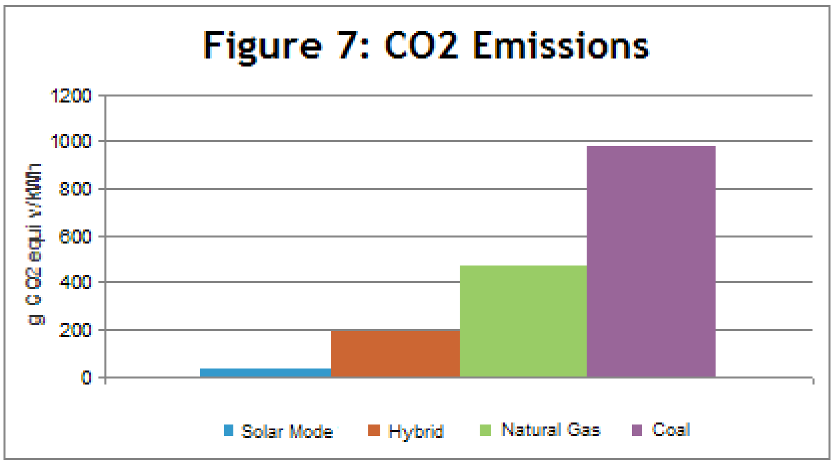

Environmental impact

Solar technology is one of the cleanest mechanisms available to generate electricity. Solar radiation is considered renewable and its application in technologies such as CPTC allows for significant reductions of greenhouse gases, compared with technologies based on fossil fuels.

If the plant operates only with solar energy (without the use of fossil fuel), the emission levels are very low in its life cycle. Particularly, in its operation phase, emissions are very close to zero.

Figure 7 shows a comparison of CO2 equivalent emissions in the complete life cycle of a solar plant compare with fossil fuel plants. The figure includes solar plant configurations in pure solar mode and hybrid solar/fossil fuel. The hybrid plant considers a scenario where its natural gas backup contributes with 15% of annual production. The figure shows that emissions from natural-gas plants exceed twice the amount of a hybrid plant and five times the emissions from a coal-firing plant.

Figure 7 CO2 Emissions




Loosely based on Lechón et al, 2006. & Meier, P., 2002.

Location: How to choose?

This section reviews the key elements that make a location suitable for the installation of a CPTC solar plant.

Climate

Cloudiness and temperature are the key climate parameters to monitor when assessing the technical feasibility of the development of solar energy based on CPTC.

The coastal area of the north of Chile is subject to a strong influence from the Pacific Ocean within the first 20 to 40 kilometers from the ocean, and below 1,000 meters of altitude. The weather from this zone is characterized by abundant clouds, especially during the winter season, and by high humidity. These conditions make the zone unusable for the purposes of solar generation.

Temperature is the other key variable when selecting a location. The temperature requirements are given by the chemical characteristics of the thermal fluid, which crystallizes at around 12ºC. If a location has significant periods of temperatures under 12ºC, the plant would have to use energy to keep the thermal fluid warm and prevent crystallization, decreasing the overall efficiency.

Grounds

CPTC plants need between 2-4 hectares per MW installed. In this area, the inclination of the terrain should not exceed 2%, to permit the flow of the thermal fluid as designed.

The composition of the soil is also important; the dust from the soil should not be overly sticky, to allow the mirrors from the solar field to be cleaned only by the action of pressurized de-mineralized water.

Connection to the grid

Due to the high cost of the CPTC technology, it is important for the connection to the grid to be as close as possible to the plant site, avoiding the high cost of long transmission lines.

Availability of water

CPTC plants need an important amount of water: a 50 MW plant requires about 700,000 [m3/year] using a water-based cooling system and 35,000 [m3/year] using a dry cooling system.

Proximity to cities & towns

The construction of any power plant, including a CPTC, requires a significant amount of labor, so the proximity to a city or town would be advantageous. However, it is not recommended to locate plant within or close to city limits to minimize the impact of the plant on the population. The mirrors from the solar field are delicate, so it is important to consider the effect of potential vandalism.

Measurements

The site selection for the CPTC plant should include a monitoring period for all climate variables, including the amount and characteristics of the dirt, of at least six months. Previous data from weather stations and other monitoring equipment from locations near the site should be used to obtain a more accurate profile of the site conditions.

Economic evaluation

Investment

In 2005, Nexant, Inc. prepared a detailed report on the cost of a 250-MW- CPTC plant with 3 hours of storage for the NREL [5]. The authors took this report and updated the information to fit the Chilean labor market and local cost of land and materials. Table 1 shows a summary of costs obtained in this process.

| Table 1 Investment | | |
|---|---|---|
| Item | Cost | |
| Land | 0.5% | Total |
| Structures and Improvements | 5,157 | USD$/ha |
| Collector System | 258 | USD$/m$^2$ |
| Storage System | 44 | USD$/kWh$_t$ |
| Thermal Cycle | 195 | USD$/kW |
| Power Generation System | 343 | USD$/kW |
| Dry Cooling system | 200 | USD$/kW |
| Gas Backup (optional) | 1% | Total |
| Master Control System | 2,148,000 | USD |
| Connection to the Grid | 200,000 | USD$/km |
| Clean Development Mechanism (CDM) | 130,000 | USD |

Revenues

Chilean electricity market provides revenues to power plants based on energy and power (or capacity). Renewable energy plants may also receive payments for reduction of carbon emissions.

The Chilean market also establishes a fine to companies that use less than a quota (progressive from 5% to 10%) of renewable energy (from the law known as "Ley Corta III"). The effect of this fine in the energy price should go from zero to the full amount of the fine, depending on the renewable energy available to the market. Due to the limited supply of renewable energy in Chile in the short to mid terms, this research assumed that the fine will boost the price in a significant percentage of the penalty (i.e., 75% of the fine).

Energy: The economic analysis considered an energy price of 0,101 [USD$/kWh], corresponding to the averaged price between October 2011 and March 2012, published by the Chilean National Energy Commission, CNE [6]. In addition to this, the analysis considered a component of 75% of the fine establish in "Ley Corta III". This amounts to 0.021 [USD$/kWh], totaling a final price for energy of 0.122 [USD$/kWh].

Power: The analysis considered an averaged price for power (or capacity) of 8.4306 [USD$/kW/month], based on the prices set by CNE [6].

Clean Development Mechanism: The analysis considered a certification based on an initial term of seven years, extendable to two more consecutive terms. The selling price of the equivalent ton of CO2 was considered to be 18.2 [USD$/tCO2] for the first seven years, and 22.1 [USD$/tCO2] for the next two terms [7].

Costs

The operation and maintenance costs were divided into various components, as shown in Table 2.

Table 2 Annual cost of operation and maintenance

| O&M Cost | Cost [USD$/year] |
| --- | --- |
| Staff | 444,371 |
| Parts & Material Replacement | 412,759 |
| Specialized Equipment | 89,703 |
| Water | 1,442,574 |
| Others (10%) | 238,940 |
| Total | 2,628,350 |

Evaluation parameters

Table 3 shows the parameters used in the economic evaluation.

Table 3 Evaluation parameters

| Variable | Value |
| --- | --- |
| Horizon | 30 years |
| Discount Rate (WACC[152]) | 10% |

[152] Weighted Average Cost of Capital

| | |
|---|---|
| Enterprise Tax | 17% |

Standard Configuration - Results

Table 4 shows the results for three plant sizes with cooling systems based on water re-circulation (i.e., wet cooling).

| | | Table 4 Results | | |
|---|---|---|---|---|
| | | Power [MW] | | |
| | | 20 | 50 | 100 |
| Solar Field | $M^2$ | 175,200 | 438,000 | 876,000 |
| Storage | MWht | 353 | 882 | 1,764 |
| Radiation | kWh/m²/year | 7.51 | 7.51 | 7.51 |
| Generated energy | MWh | 72,224 | 184,002 | 370,187 |
| Investment | USD$/MW | 5,696,743 | 5,260,187 | 5,009,836 |
| Fixed Cost | USD$/Month | 50,962 | 98,815 | 184,806 |
| Variable cost | USD$/MWh | 7.84 | 7.84 | 7.84 |
| LCOE[153] | USD$/MWh | 183,649 | 165,912 | 157,391 |
| NVP[154] | USD$ | -24,230,988 | -32,430,377 | -37,352,853 |
| IRR[155] | % | 7.29% | 8.45% | 9.07% |

The rates of return of these plant configurations are low, decreasing as the plant sizes go down, due to the economies of scale. The investment cost is over 5 [MUSD$/MW] for all sizes.

---

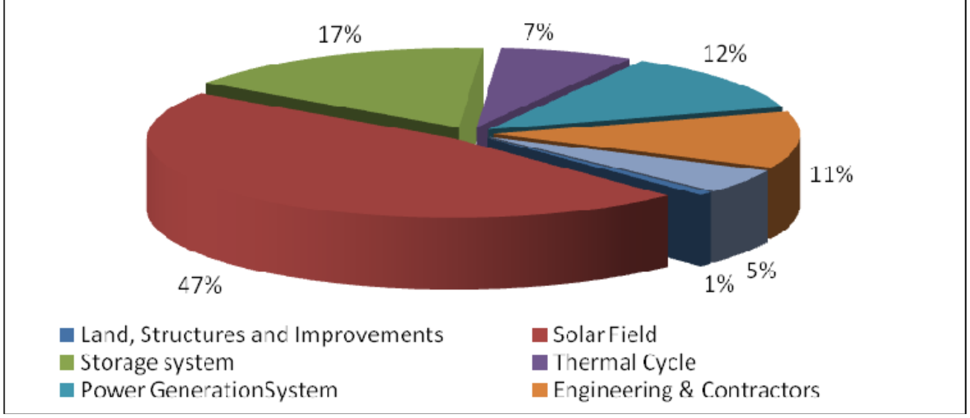
153 Levelized Cost of Energy

154 Net Present Value

155 Internal Rate of Return

Figure 8 shows a break down of investment on a by component basis. In this figure about half the cost corresponds to the solar field, followed by the storage system (17%) and the power generation unit (12%).

Figure 8 Investment composition




One of the main operating costs is the cost of water, especially in plants cooled by wet systems. Figure 9 shows the change in generation costs by switching the cooling system of the plant. The cost difference accounts to around 4 [USD$/MWh] for any plant size.

Figure 9 Wet cooling vs. dry cooling

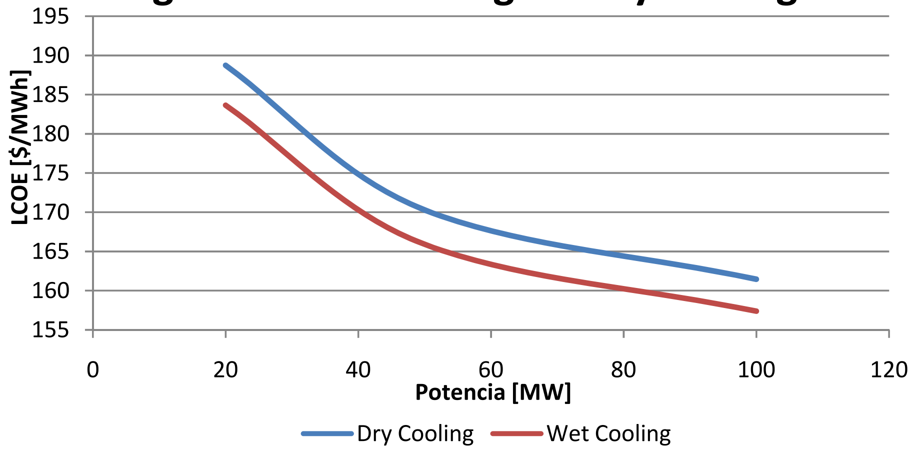


Figure 9: Wet cooling vs. Dry cooling

### Fossil backup - Results

If natural gas is available for a fossil-fuel backup (i.e., hybrid system), the CPTC can operate with a much higher plant factor.

Table 5 presents the results for the same plant sizes from the previous section, but incorporating a 25% of total production based on fossil-fuel backup. This evaluation assumes that firm power revenues correspond to the installed capacity of each plant.

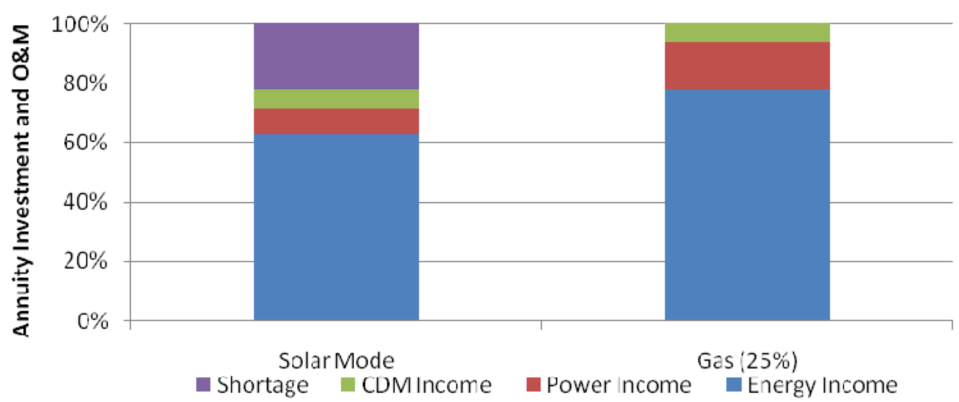
Table 5: Results gas hybridization

| | | Power [MW] | | |
|---|---|---|---|---|
| | | 20 | 50 | 100 |
| Solar Field | $m^2$ | 175,200 | 438,000 | 876,000 |
| Storage | MWht | 353 | 882 | 1,764 |
| Radiation | kWh/$m^2$/year | 7.51 | 7.51 | 7.51 |
| Generated energy | MWh | 90,280 | 230,002 | 462,733 |
| Investment | USD$/MW | 5,724,314 | 5,285,857 | 5,034,383 |
| Fixed Cost | USD$/Month | 50,962 | 98,815 | 184,806 |

| | | | | |
|---|---|---|---|---|
| Variable cost | USD$/MWh | 17.95 | 17.95 | 17.95 |
| LCOE | USD$/MWh | 147,567 | 133,322 | 126,475 |
| NVP | USD$ | -8,668,265 | 7,382,746 | 43,672,446 |
| IRR | % | 9.06% | 10.34% | 11.06% |

These results show a significant increase in NVP and IRR for all plant sizes, reaching profitability for the 50 and 100-MW plants. This is due to the increment in income from energy and power revenues. A hybrid operation also brings an increase in variable costs due to use of gas. Figure 10 compares the cost of energy with the income structure in a 50-MW plant. It is quite apparent the increase in revenue for both energy and power through the use of gas, this is turn, makes possible the profitability of the project.

Figure 10 LCOE vs. Income



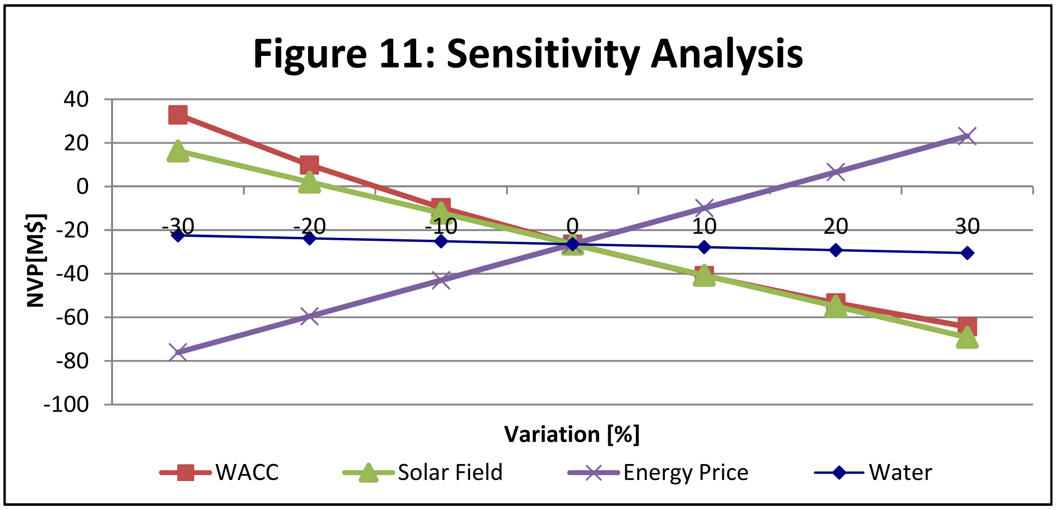

Sensitivity Analysis

As part of the economic analysis, the researchers also performed some sensitivity analysis to evaluate the robustness of the results. The base case was set to a 50-MW plant with storage system.

Energy & water prices and solar field size

Figure 11 shows the sensitivity on the NVP of the base case with respect to changes in the discount rate (WACC, Weighted Average Cost of Capital), size of the solar field, on the price of energy and on the price of water (all in percentages).

Figure 11 Sensitivity Analysis




Sensitivity with respect to the discount rate (WACC): the project is profitable for discount rates of 8.48% and lower. This is a low rate of return, making it unlikely for energy investors to pick CPTC technologies as part of their investment portfolio.

Solar field: the cost of the solar field (including the collectors, mirrors, tubes and structures) is quite significant in the overall investment of a CPTC power plant. A 19% decrease in the solar field price tag can make the project profitable (positive NVP). A price drop of this magnitude is anticipated to occur as the solar industry builds some economies of scale in the medium to long term.

Energy price: an increment in energy prices by 15% can make the project profitable (positive NVP). This corresponds to an energy price of 0.137 [USD$/kWh], including 75% of the “Ley Corta III” fine. This may seem a high price, but the spot price in the SING has exceeded this value in multiple occasions for peak hours in the last few years.

Price of water: the sensitivity with respect to variations in the cost of water shows little influence in the NVP of the project. The key problem with water is not so much its price, but rather its availability in the required amounts.

Discount rate and efficiency

Figure 12 shows the sensitivity of the project with respect to the discount rates and the efficiency of the technology.

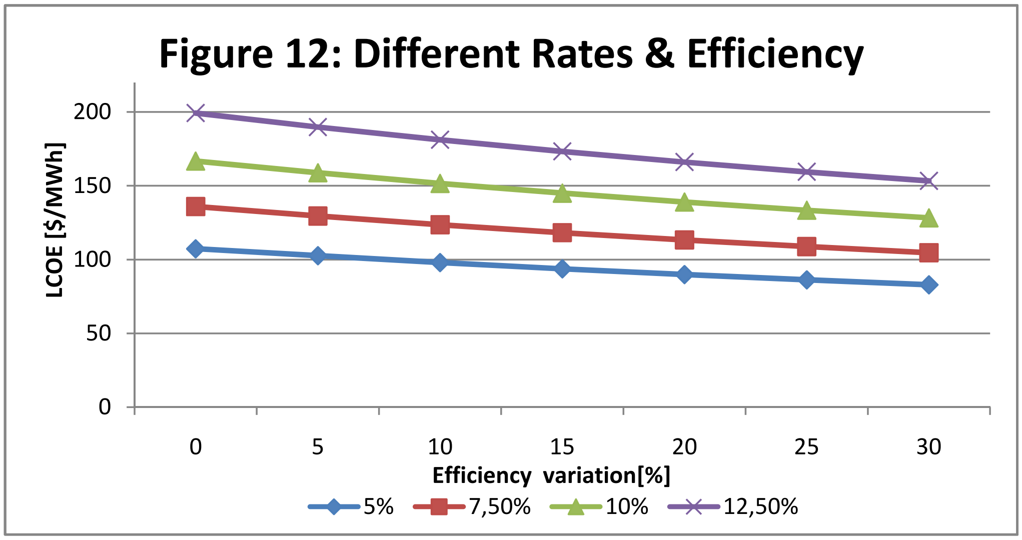


Figure 12: Different Rates & Efficiency

This figure shows that increments in efficiency, as expected for the coming years for this technology, will steadily force down the price of the energy produced by the CPTC plant.

Conclusions

The current research includes the evaluation of the application of the CPTC technology in three different plant sizes: 20, 50 and 100 MW. The evaluation of these sizes of plant demonstrates the existence of economies of scale for manpower, equipment and assets, which is demonstrated by the direct relation between installed power and the IRR of the plant. The 20-MW plant was not profitable in any of the configurations considered, and larger plants were only profitable using hybrid configurations.

For instance, a small plant of 50 MW with storage system has an IRR of 8.45%. This rate of return increases to 10.34% with the addition of a fossil fuel backup. It is important to note that the sensitivity analysis shows that the technology could reach profitability, even without a fossil fuel backup, if the cost of the solar field is reduced by 19%, or if the selling price of energy increases by 15%.

An important limitation to current of CPTC is that the solar fields are only manufactured by a limited number of companies in Europe and the United States. This tend to keep prices high, limiting further expansions of the technology to wider range of countries, including Chile.

Another factor to consider is potential increases in the efficiency of the CPTC plants. Solar energy is an endless source of energy, but it has a significant limitation in terms of its transformation to electricity. CPTC plants have very high losses in the solar field and they use low thermal fluid temperatures, keeping the efficiency of the overall system just above 10%.

On the other hand, most governments have been slow in promoting solar technologies, maintaining regulatory frameworks with little or no incentives that would permit solar technologies archive higher productions levels, allowing for competition and economies of scale to drive down prices.

References


[1] Enermodal engineering limited. 1999. C*ost reduction study for solar thermal power plants*, prepared for The World Bank, Washington D.C., USA.

[2] http://www.renewables-made-in-germany.com/es/centrales-termicas-solares/stp/company/1858/ (June 2008).

[3] Romero M., 2000. *Energía solar termoeléctrica*, CIEMAT, Spain.

[4] Kelly B. 2006. “Task 2- Comparison of Wet and Dry Rankine Cycle Heat Rejection”, *Nexant Parabolic Trough Solar Power Plant Systems Analysis*, NREL, NREL/SR-550-40163, California, USA.

[5] Kelly B. 2005. “Task 1 - Preferred Plant Size”, Nexant Parabolic Trough Solar Power Plant Systems Analysis, NREL, NREL/SR-550-40162, California.

[6] Informe Preliminar de Precio Nudo, April 2008, http://www.cne.cl.

[7] Carbon 2008 report, http://www.pointcarbon.com.

# 41. Renewable Electricity Bill: The Mexican Case

**Belizza Janet Ruiz Mendoza, Claudia Sheinbaum Pardo**

Institute of Engineering of the National Autonomous University of Mexico

Instituto de Ingeniería, circuito escolar, edificio 12, Ciudad Universitaria,

CP 04510, México D.F., Apartado Postal 70-472, Delegación Coyoacán,

+ (52) (55) 56233600 ext. 8866,

bjrmco@gmail.com

Key words: Renewable energy sources, Mexican renewable electricity bill, and Renewable energy policy

Abstract: Two renewable electricity bills have been proposed in Congress since 2005 in Mexico. The first one was rejected by the Senate and the second one was approved by both the House of Representatives and the Senate in October 2008. Our objective is to explain the nature of both bills and to analyze each of them bearing in mind the Mexican electricity sector management scheme. In the Mexican single-buyer electricity scheme, the state-owned companies (*Comisión Federal de Electricidad* and *Luz y Fuerza del Centro*) are responsible of the public services and the private sector generates electricity under six modalities: self-supply, cogeneration, independent production, small production, export, and import, which are not considered a public service. This scheme has caused controversies related to the constitutionality of the 1992 Power Public Services Law that allowed this scheme to be implemented. Both bills, the rejected one and the approved one, were formulated and based on that controversial law and their objectives are linked precisely more to the controversial issues than to the promotion of renewable electricity technologies; therefore, the current Mexican

renewable electricity law widens the gap among environmental, political and social issues.

## 1. Introduction

The promotion of renewable energy sources has become an important piece in the cluster of solutions proposed in order to face the climate change. Developed countries through their national and international institutions apply two approaches to deal with environmental problems. The first one seeks domestic solutions; a good example of this approach is found in the European Union. There, since 1996 with the Green Paper "Energy for the future: Renewable sources of energy"[156] the discussions related to objectives, programs, financial supports, among other issues were analyzed widely. Since then, numerous legislative initiatives were passed until a regional commitment in 2001 was reached under "Directive 2001/77/EC on the Promotion of Electricity Produced from Renewable Energy Sources in the Internal Electricity Market"[157]. The second approach seeks solutions of international scope. These solutions are thought in developed countries to be taken to developing countries by means of cooperation programs, mechanisms, and international agreements.

This second approach is the starting point for our analysis because the two measures to promote renewable energy sources in Mexico echoed recipes made by international institutions such as the World Bank and the Global Environment Fund. These encourage guidelines or policies which favor foreign interests mainly. During the formulating process of both Mexican bills, there were not consultations with the interested and affected actors. What has been happing since then? On one hand, the affected rural communities have rejected renewable energy projects; and on the other hand the current renewable policies reveal evident problems because of their unconstitutionality.

To analyze this subject, this article develops three aspects. In the first part the Mexican electricity sector is shown mainly with regards the regulatory elements. The second and third parts present the positive and negative sides of the bill (2005) and the law (2008) respectively. The document ends with conclusions

---

[156] European Communities (1996). Communication from the commission – Energy for the Future: Renewable Energy Sources – Green Paper for a Community Strategy, COM (96) 576, Belgium (Brussels).

[157] Directiva 2001/77/CE del Parlamento Europeo y del Consejo de 27 de septiembre de 2001 relativa a la promoción de la electricidad generada a partir de fuentes de energía renovables en el mercado interior de la electricidad, en el *Diario Oficial de las Comunidades Europeas*, Nº L 283, 27.10.2002, pp. 33-40.

stating the importance of involving communities in democratic processes tending to public awareness on the positive aspects of the current 2008 Law in order to make a more sustainable use of renewable energy sources.

## 2. Mexican Electricity Sector

The regulatory framework, institutions, and the management model define the coordination scheme of the Mexican electricity sector. A description of this will be done from a perspective of the renewable energy sources.

### 2.1. Regulatory framework

The Mexican electricity sector is controlled under three different instances: the Ministry of Energy (*Secretaría de Energía* - SENER), the Energy Regulatory Commission, and the provisions of Articles 27 and 28 of the Mexican Political Constitution, and more recently, by the Power Public Services Law[158] that was reformed in 1992 in order to allow the private sector to generate electricity under six modalities[159].

Article 27 establishes that the Mexican Nation will develop exclusively activities related to the power public services. This article also provides that concessions will not be awarded to the private sector. Article 28 states that electricity is a strategic resource and the activities performed by the Mexican State on the electricity sector will not be considered a monopoly.[160]

The 1992 reform of the Power Public Services Law carried out a partial liberalization of the Mexican electricity sector; it modified the regulatory framework in order to favor new investors. The reform included six new modalities granting permission for the private sector to generate electricity and provided that electricity generated under these six modalities would not be considered as a public service avoiding thus a contradiction with Constitutional Article 27, which concedes the Mexican Nation exclusive title to generate electricity. The modalities defined by the

[158] Secretaría de Energía, Minas e Industria Paraestatal (1993a). *Ley de Servicios Públicos de Energía Eléctrica*, México.
[159] Reforma a la Ley del Servicio Público de Energía Eléctrica, *Diario Oficial de la Federación*, México, 1993.
[160] Constitución Política de los Estados Unidos Mexicanos de 1917, México, 2005.

Power Public Services Law are: self-supply[161], cogeneration[162], small production[163], independent production[164], export[165], and import.[166]

In 2006 the private sector participation was increased from 30.4% to 35%. The increments for each modality were: independent production 22.8%; self supply 6%; cogeneration 3%; and export 2.7%.

Control over activities of transmission, transformation and distribution of electricity were kept by the Federal Electricity Commission (*Comisión Federal de Electricidad)* and Central Light and Power (*Luz y Fuerza del Centro)* that are state-owned companies.

## 2.2. Coordination and management scheme of the Mexican electricity sector

The reform of the Power Public Services Law transformed the coordinating scheme of the Mexican electrical sector from a centralized control to a single-buyer model.[167] The single-buyer scheme has three main components: 1. Opening of the electricity market. 2. The state-owned company becomes a single buyer; namely, it buys the whole electricity generated by the private sector. 3. Creation of a competitive market by means of a public bidding system.

Currently, these three aspects can be distinguished easily. 1. Private participation was inserted under the six modalities to generate electricity. 2. The Federal

[161] The beneficiaries must be owners of the electricity generation plants. These cannot purchase electricity from another electricity plant owned by any private company. Secretaría de Energía, Minas e Industria Paraestatal (1993b). *Reglamento de la Ley de Servicios Públicos de Energía Eléctrica*, México.

[162] Cogeneration consists of producing electricity from steam or some kind of secondary thermal energy or both; direct or indirect production of electricity coming from remaining of thermal energy not used in any process; or direct or indirect production of electricity using remains of fuels produced in respective processes. Ibid.

[163] A small production is considered: 1.Electricity coming from smaller plants of less than 30 MW. This electricity must be sold to the Federal Electricity Commission; 2. Self-supply of electricity coming from smaller plants have less than 1 MW. Small rural communities without electricity must own these power plants. 3. And, electricity for export generated in stations of up to 30 MW. Ibid.

[164] The independent production modality refers to electricity coming from plants with higher electrical capacity than 30MW and delivered the Federal Electricity Commission or for export. Ibid.

[165] Electricity for export must be generated through the following modalities: cogeneration, independent generation and small generation. Ibid.

[166] Ibid.

[167]. Pistonesi H, Rodríguez V, Chávez C., analyze the different coordination schemes in Latin America in: *Energía y desarrollo sustentable en América Latina y el Caribe: guía para la formulación de políticas energéticas*, OLADE, CEPAL y GTZ, Ecuador, 2000.

Electricity Commission' status of single-buyer is based on the fact that independent production modality exists. Article 108 of the guidelines of the Power Public Services Law defines this modality[168]. 3. The public bidding system is defined in Articles 124 to 134 of the guidelines of the Power Public Services Law. The Mexican Ministry of Energy indicates how much additional annual electrical capacity should be built. Consequently, Mexican authorities call the private sector in order to achieve the expected goals.

## 3. Mexican Renewable Energy Sources Bill (2005)[169]

In this section, the positive and negative aspects of the Mexican Renewable Energy Sources Bill are analyzed. The bill was discussed and approved by the House of Representatives and rejected by the Commission on Energy and Legislative Studies of the Mexican Congress. Its argument was focused on juridical inconsistencies found in the bill.

Although the bill has a short-term objective as its only aspect to highlight, it has inconsistencies too in the incentive mechanisms proposed as means to achieve this same objective, as it will be explained later. Formulating the bill again would eliminate this legal problem; however, it is not the most important issue. A renewable energy law should be based on a correct sustainable platform; namely a law built over a multifactor concept.

To describe the bill, we split it into four categories: The first one contains the criteria to implement it; the second one proposes operational elements of this draft; the third one shows the aspects of national industrial work required to implement it, and the fourth tries to incorporate a social corporate responsibility approach.

### 3.1. Implementation Criteria

*Short-term objective:* The bill proposes to generate electricity from renewable energy sources up to 8% of the gross electricity generation. Hydroelectricity plants smaller than 30 MW would be included to achieve that objective.

---

[168] Sener 1993b, op. cit.

[169] Proyecto de dictamen de las comisiones de energía y estudios legislativos a las iniciativas del partido verde ecologista de México y del partido revolucionario institucional en materia de aprovechamiento de las energías renovables y para el financiamiento de la transición energética, Senado de la República LX legislatura, México, 2008.

*Renewable energy program:* To be developed by the Ministry of Energy. At the moment in which the bill was submitted to Congress there was not such a program supporting it.

*Incentive mechanisms or instruments:* The draft document suggests two instruments to promote the renewable energy sources. One would be a tradable renewable energy certificates system and the other one would consist of a trust with six funds, which are:

A green fund for mature technologies interconnected with electrical networks.

Fund for costly developing technologies that could be interconnected with electrical networks.

Fund for rural electrification if it is developed under self-supply and small production modalities.

Fund for biofuels.

General fund for renewable technologies to be used in projects different from electricity ones.

Fund for technological research and development in order to encourage national industry and assess potential renewable energy sources.

3.2. Operational Issues

*Methodology:* The Ministry of Energy would develop a methodology in order to evaluate economic advantages that would result from long-term stable prices by using renewable energy sources.

*Regulation:* The Energy Regulatory Commission would be in charge of formulating rules, guidelines, directives, methodologies and contract models and managing the administrative and juridical matters.

*Access:* The bill suggests that whenever renewable electricity is generated, it should be connected to the national electrical network. The two state-owned companies (*Comisión Federal de Electricidad* and *Luz y Fuerza del Centro)* would perform the technical, administrative and methodological requirements.

*Involved Actors:* Financial incentives would be given to the private sector under the small production, self-supply and cogeneration modalities; the state-owned company (*Comisión Federal de Electricidad*) would keep its role as single-buyer; and Mexican institutions would regulate the system.

3.3. National Industry Issues

The production of Mexican components related to renewable energy technologies would be promoted by the Ministry of Energy and Economy. The bill also proposes to define a technological integration share for each technology.

3.4. Social Issues

There are two proposals: the first one, states that the investors should give 2% of the financial incentives coming from the trust to the communities where the projects would be implemented. The second one consists of creating a committee that would evaluate the impacts of hydroelectric projects larger than 30 MW.

3.5. Comments on the bill

A short-term objective and a program are important elements of the bill because these determine a goal and lead specific actions in order to achieve a policy. The short-term objective is indispensable because it outlines a horizon over which the policy is developed and makes further evaluation easier. However, each technology should have its own specific objectives, and the program should be a previous step before formulating the renewable energy policy. This would help defining a quantitative value for the short-term objective and identifying any troubles among the involved actors. In other words, the program is a means to achieve the policy.

Incentive mechanisms implement the policy. These are not the policy itself, but are central to it. The bill has some problems with the instruments suggested. For instance, tradable renewable energy certificates system is a market instrument that seeks to broaden private participation whereas coordination system of the Mexican electricity sector constrains such participation. In other words, the legal support of the Mexican electricity sector would be undermined. A tradable renewable energy certificates system could be regulated by the State, so it would avoid some incompatibilities between both systems. Nevertheless, the tradable system tries to maximize private profits. Its idea is inconsistent with the coordinating system seeking to maximize social benefit as one of the objectives of the Mexican electricity policy. The last argument does not include an evident contradiction between the notion of a strong, true sustainability and the increasing commercialization of environment.

A financial mechanism is proposed in the bill as a second instrument to install renewable energy technologies by the private sector that would receive public funds to develop such activity. But at the same time, the *Comisión Federal de Electricidad* and *Luz y Fuerza del Centro* would be limited to build those kinds of projects. So the first state-owned company would continue being a single-buyer and its electricity capacity would decrease while the private electricity capacity would increase. This is a liberalization process using public money.

By means of both mechanisms (financial and tradable certificates), the state-owned companies role is minimized. These would portray a functional role if that bill had been approved.

Strengthening the national industry and creating a technological research and development fund for renewable energies are adequate decisions that would positively affect the employment and small industry fields.

The bill should have been framed inside the Mexican regulation to force the private sector to operate under legal terms and not to reframe a new law to favor it.

4. Law For Using Renewable Energy Sources and Financing Energy Transition (2008)[170]

In October 2008, a new bill for using renewable energy sources and financing the energy transition in Mexico was discussed in the Mexican Congress. Although this bill was different from the one presented in 2005, both contained a same controversial issue grounded on the private participation. In November 2008, after discussions and, some changes the bill was finally approved by the Mexican Congress.

This Law is clearer and shorter than previous initiatives and has been structured in four chapters. The five most important aspects of it are:

4.1. The Program

The core of the Law is the program. This will be led by the Ministry of Energy and consists of objectives, goals for each technology, plans of electrical infrastructure construction, goals to increase the renewable energy diversity, mechanisms and definition of the Mexican institutions' functions related to the energy sector.

4.2. Transparency

The first article of the Law states clearly that its objective is to regulate the usage of renewable energy sources to generate electricity with different purposes different from a public service. This is to say, the Law's objective is clear: to regulate the private sector.

There are two questions to highlight: One, related to the two draft documents mentioned above and the other, addressing the relevance of the Law itself. The two previous legislative draft documents hid the main objective of governmental initiatives that consisted of promoting private involvement in electricity generation. On the contrary, This Law is transparent in this point; it does not hide its objective,

---

[170] Decreto por el que se expide la Ley para el Aprovechamiento de Energías Renovables y el Financiamiento de la Transición Energética, DOF: 28/11/2008, México.

so the question on relevance is easier to explain. This second issue deals with the pertinence of the Law. The Power Public Services Law that was amended in 1992 regulates the Mexican electricity sector. That reform allowed the private sector to start its activities in the electricity generation segment under six modalities. Since then, the private sector is free to generate electricity with whatever technology -conventional and no conventional- (it could use renewable energy technologies). A reform of the Power Public Services Law had been sufficient to encourage the private sector; therefore, a question emerges: Why was that law formulated?

### 4.3. Mechanisms

The main mechanisms used internationally to promote renewable energy technologies are grouped into four categories: subsidy, regulated subsidy (feed-in tariff and tradable renewable energy certificates), taxes decrease, and market (tradable renewable energy certificates system and tradable emission certificates system). There are other mechanisms to promote those technologies; these are the mechanisms from the Kyoto Protocol (Joint Implementation, Clean Development Mechanism, and Emissions Trading). In the Law we analyze there is not an explicit statement about incentive mechanisms to promote renewable energy sources while there is a commitment to use the mechanisms for reducing greenhouse gases emissions. Namely, the renewable energy projects would be promoted by emissions trading, joint implementation and clean development mechanism systems.

### 4.4. Disconnected zones from the electrical networks

The Law states: “To define strategies to promote projects using renewable energy sources to supply electricity aimed at rural communities which do not have power public services. Those communities could be isolated or not from the electrical networks”[171]. A controversial matter is identified here between social interests and for profit expectations. The international experience has proven that many renewable energy projects in the countryside are not lasting; perhaps these were technically successful but not as a long-term policy. Concretely, rural zones do not constitute a for profit expectation for the private sector; therefore, the State should

---

[171] Capítulo III. De la planeación y la regulación, Articulo 11, Fracción VII., Decreto por el que se expide la Ley para el Aprovechamiento de Energías Renovables y el Financiamiento de la Transición Energética, DOF: 28/11/2008, México.

provide electricity public services, in this case through the Comisión Federal de Electricidad. If the purpose of the Law is to promote investments in disconnected zones by the private sector we can question if it is the State that should grant any financial support for it.

### 4.5. Social issues

The Law includes some social corporate responsibility considerations such as the participation in consultation processes of the concerned communities, payment of rent for the lands occupied by these electricity schemes, and the promotion of social development. However these issues are defined only according to the extent of the electrical capacity of the plant installed. That is to say that the communities are taken into account in social corporate responsibility processes only if the projects are smaller than 2,5MW.

## 5. Conclusions

The 2005 Mexican renewable energy sources bill contained some important elements such as a short-term objective and a proposal to formulate a program. However, these issues were not supported by the mechanisms proposed in it since an inconsistency emerged between the coordinating scheme of the Mexican electricity sector and those instruments. A single-buyer scheme involves a stricter regulation for the private sector and an open market system seeks minimal rules. Although this bill was rejected, it constitutes the starting point for legislative initiatives that followed it on renewable energy sources in Mexico.

The 2008 Law for using renewable energy sources and financing energy transition comes from a discontinued process that started in 2005. In the period 2005 - 2008 there is an incipient discussion of the renewable energy sources issues in Mexican educational institutions, like universities and research centers. But in 2008 the oil reform captured the public’s attention and the new bill was vaguely discussed. Nevertheless, the first proposal did not pass and was modified until the current Law document was finally approved.

The main objective of the Law is to implement a program. Even though the program should be the first step to achieve a renewable energy policy, it was not necessary to pass a Law because we think that a strong, consistent program may give results that help to think how the law should be. The current legislation regulates and allows devising initiatives that include projects, plans, and programs, but it may also force to do something which is not so clear yet in the current Law for using renewable energy sources and financing energy transition.

What to do? Since silent liberalization of the electricity sector is something that may have negative impacts in Mexican rural communities in isolated areas, community leaders representing different sectors of the concerned groups have to bring pressure the Mexican government to design a program that includes concrete sustainable goals where expectation for profit is not the main criteria, but meeting the real needs of improving electricity public services according to social and environmental sustainable criteria.

## 6. References

Constitución Política de los Estados Unidos Mexicanos de 1917, México.

Decreto por el que se expide la Ley para el Aprovechamiento de Energías Renovables y el Financiamiento de la Transición Energética, DOF: 28/11/2008, México.

Directiva 2001/77/CE del Parlamento Europeo y del Consejo de 27 de septiembre de 2001 relativa a la promoción de la electricidad generada a partir de fuentes de energía renovables en el mercado interior de la electricidad, en el *Diario Oficial de las Comunidades Europeas*, Nº L 283, 27.10.2002, pp. 33-40.

European Communities (1996). Communication from the commission – Energy for the Future: Renewable Energy Sources – Green Paper for a Community Strategy, COM (96) 576, Belgium (Brussels).

INEGI (2002). Estadísticas del medio ambiente del Distrito Federal y Zona Metropolitana 2002 – Archivo 1, México.

“Ley de la Comisión Reguladora de Energía”, *Diario Oficial de la Federación*, México, 1995.

Pistonesi H, Rodríguez V, Chávez C. (2000). Energía y desarrollo sustentable en América Latina y el Caribe: guía para la formulación de políticas energéticas, OLADE, CEPAL y GTZ, Ecuador.

Proyecto de dictamen de las comisiones de energía y estudios legislativos a las iniciativas del partido verde ecologista de México y del partido revolucionario institucional en materia de aprovechamiento de las energías renovables y para el financiamiento de la transición energética, Senado de la República LX legislatura, México, 2008.

“Reforma a la Ley del Servicio Público de Energía Eléctrica”, *Diario Oficial de la Federación*, México, 1993.

Secretaría de Energía (2005), Prospectiva del sector eléctrico 2006-2015, México.

Secretaría de Energía, Minas e Industria Paraestatal (1993a). *Ley de Servicios Públicos de Energía Eléctrica*, México.

Secretaría de Energía, Minas e Industria Paraestatal (1993b). *Reglamento de la Ley de Servicios Públicos de Energía Eléctrica*, México.

# 42. La energía solar y el desarrollo económico en América

**Dra. Lioudmila Oleinikova, Dr. José Antonio Gómez Reyna, Dr. Boris Voronin, Mtro. Juan José Cárdenas Grajeda**

Cuerpo Académico de Energías Renovables

División de Ingenierías

Centro Universitario de Ciencias Exactas e Ingenierías

Universidad de Guadalajara, México.

Av. Revolución 1500 Guadalajara, Jalisco, México

<loleinik_l@bk.ru>,gomezrey@yahoo.com, boris.voronine@cucei.udg.mx, cardenasgrajeda@yahoo.com.mx

ABSTRACT

La energía producida por las radiaciones de nuestro sol, han acompañado a la creación de nuestro planeta y según cálculos se estima que tendremos radiaciones energéticas por más de seis mil millones de años más. Esta energía producida por las reacciones del componente principal de nuestro sol el hidrogeno, produce explosiones que generan una gran radiación de fotones fuertes que viajan por el espacio y al llegar a nuestra atmósfera se transforman en fotones débiles y que algunos niveles de energía los podemos ver a simple vista como luz, otros son niveles de; infrarrojos, ultravioletas, ondas de radio, entre otros. Este gran flujo de energía dio origen a la vida. Gran parte de esta energía se ha almacenado en lo que conocemos como combustibles fósiles que hemos utilizado en los últimos cien años, los cuales están a punto de colapsar junto con la tecnología de la quema de estos.

Los retos de la energía solar se han iniciado con diferentes tecnologías para poder sustituir parte de la energía fósil. Los procesos de dinámica del sol y sus efectos en nuestro planeta.

En la conferencia “La energía solar y el desarrollo económico en América” se presentarán los desarrollos y políticas de los sistemas fotovoltaicos, la energía térmica-solar, así como su impacto en las economías de los diferentes países.

De igual forma se proponen sistemas simples para fabricar concentradores solares de baja temperatura para uso domestico y se presentan los desarrollos macros de alta tecnología para grandes industrias o gobiernos.

Las alternativas al usar la energía solar evitan que se siga usando energías fósiles como el petróleo, carbón y gas; que son las responsables de los gases de efecto invernadero y que al quedar atrapados en la atmósfera han incremento del calentamiento global.

## Introducción

La energía que produce nuestro Sol ha sido la base del desarrollo de los seres vivos en nuestro planeta, con una edad de 4,600 años, esta pequeña estrella que se clasifica en la astronomía como una tipo espectral G 2, tiene un rádio de 696,000 km, con una masa de 1.99 x $10^{30}$ kg., emite una energía de 3.83 x $10^{26}$ J/s, esta energía esta generada por su composición química, principalmente de hidrógeno y helio, aunque tiene trazas de más de 70 elementos más pesados, este reactor natural tiene unas temperaturas aproximadas en el centro de 16`000,000 $^{0}$K, en la superficie de 5,000$^{0}$K, en la corona de 1`000,000$^{0}$K y en mancha solar de 4,500$^{0}$K, estas manchas pueden ser de un tamaño de 8,000 km. El Sol genera grandes explosiones en donde emite radiaciones de fotones fuertes sobre el espacio, radiando en forma importante a los planetas y mientras más próximos será mayor la radiación, Mercurio es el más cercano, lo sigue Venus y acontinuación se encuentra sitiada la orbita terrestre. La distancia del Sol a la tierra no es constante por la orbita eliptica en su traslación, se sabe que la distancia mínima es de 147`100,000 km. la máxima 152`100,000 km. y la media 150`000,000 km.. Estas características señaladas nos determinan la energía solar que recibe la Tierra asegurada por los próximos 6,000 años..

La energía solar se obtiene directamente del Sol, la incidencia de dicha radiación sobre la Tierra puede aprovecharse, por la capacidad térmica que representa, o ser capturada por dispositivos ópticos e inclusive se puede aprovechar como sistemas de generación fotovoltaica.

Su aprovechamiento por la naturaleza es inmenso, desde los sistema de biomasa a través de la fotosintesis, el aprovechamiento solar de la fauna, e inclusive la dinámica de la atmósfera, el ciclo del agua y una infinidad de fenómenos naturales producidos por la radiación solar.

Este tipo de energía solar se considera energía límplia y renovable, también se le conoce como energía verde.

La potencia de la radiación varía según el momento del día, las condiciones atmosféricas que la amortiguan y la latitud. Se puede asumir que en buenas condiciones de irradiación el valor es de aproximadamente 1000 $W/m^2$ en la superficie terrestre. A esta potencia se la conoce como irradiancia.

Los mapas solares son de suma importancia para poder determinar el potencial de irradiancia, la latitud tanto Norte como Boreal definen cual es al ángulo de incidencia de radiación del Sol sobre la superficie de la Tierra, la orografía es otra de las variables que pueden generar la eficiencia para los equipos para capturar dicha energía.

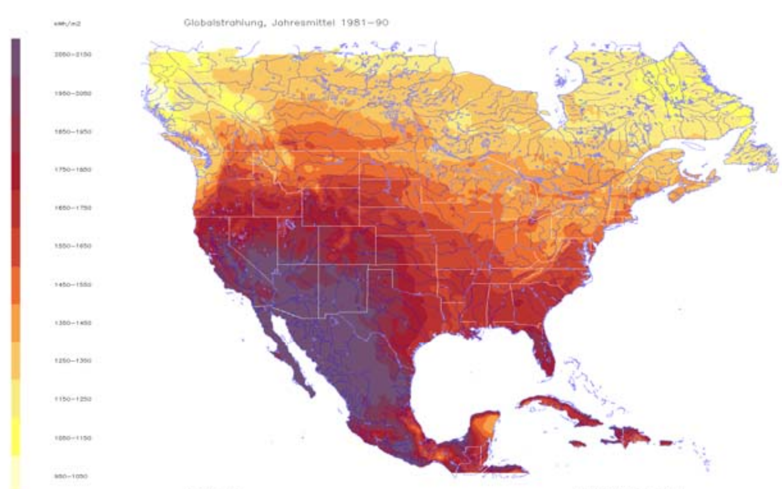



Fig. 1 Mapa de radiación solar de América del Norte

La radiación es aprovechable en sus componentes directa y difusa, o en la suma de ambas. La radiación directa es la que llega directamente del foco solar, sin reflexiones o refracciones intermedias. La difusa es la emitida por la bóveda celeste diurna gracias a los múltiples fenómenos de reflexión y refracción solar en la atmósfera, en las nubes y el resto de elementos atmosféricos y terrestres. La radiación directa puede reflejarse y concentrarse para su utilización, mientras que en la actualidad la tecnología disponible no es posible concentrar la luz difusa que proviene de todas las direcciones.

La irradiancia directa normal (o perpendicular a los rayos solares) fuera de la atmósfera, o sea la constante solar tiene un valor medio de 1354 $W/m^2$ (que corresponde a un valor máximo en el perihelio de 1395 $W/m^2$ y un valor mínimo en el afelio de 1308 $W/m^2$.). La variación de la radiación es de forma periódica dependiendo de los días del año por su trayectoria sobre su traslación.

Fig. 2 Radiación en América del Centro y Sur.

La formula de la variación periódica de la radiación:

$\delta = 23.45 \text{ sen } (360 \text{ x } 284 + n)/ 365$

En donde n representa los días transcurridos del año

Desarrollo de Tecnologías

A través del tiempo se han desarrollado diferentes tipos de investigaciones generando una serie de tecnologías; los sistemas fotovoltaicos se desarrollan por células de cristales de silicio policristalino o monocristalino, tienen un bajo rendimiento desde un 10 a un 15%. En los sistemas térmicos, existen colectores de baja temperatura, mediana o alta temperatura. Las eficiencias varían dependiendo de la tecnología, materiales utilizados, operación de los mismos y zonas en donde se instalan.

Los paneles solares fotovoltaicos pueden ser diseñados en forma específica y existen líneas de investigación sobre diferentes materiales, como los polímeros que se están empleando para la construcción de paneles híbridos que permiten generar energía eléctrica y térmica simultáneamente.

Los seis lugares en donde existe una mayor insolación en el mundo están distribuidos en Australia, Asia, Medio Oriente, Norte de África, Norte América y América del Sur, estos sitios fueron monitoreados entre 1991 y 1993 y se maneja la hipótesis de que podría proveer la energía para todo el mundo.

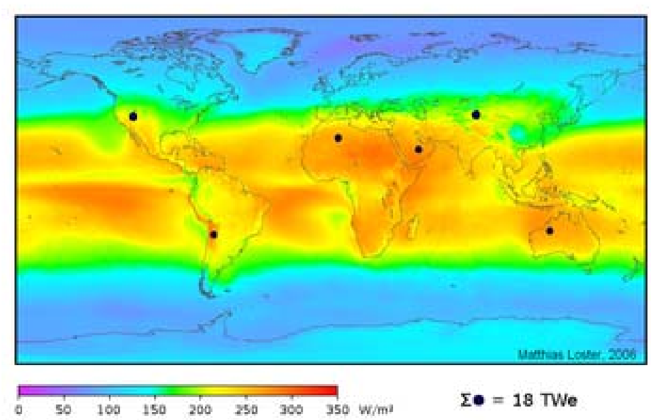



Fig. 3 Mapa que indica los seis puntos de mayor insolación mundial

La construcción de pequeños prototipos para las zonas rurales que se encuentran deprimidas económicamente. Así como de grandes proyectos solares podrán se soluciones en diferentes países y regiones. La construcción de huertas solares o centrales térmicas solares de gran capacidad ya se construyen en el mundo con diferentes capacidades, de 24 GWh al año como las de Sevilla España o las de Calahorra, cerca de Guadix con una capacidad de 50 MWh de potencia.

Los sistemas solares son tan amplios que pueden ser utilizados para potabilización de agua, como cocinas solares; para destilación, evaporación, fotosíntesis y secado. Otras importantes aplicaciones son para la calefacción doméstica, aire acondicionado, calentamiento de agua, refrigeración, energía para aparatos electrodomésticos, entre otras aplicaciones.

## 43. Rural and Urban Solar Stove both of Solar Concentration, Distributed, clean and viable energy alternatives.

**José Antonio Urbano Castelán, José Antonio Moreno Cadenas,**

**Yasuhiro Matsumoto Kuwavara, Rene Asomoza Palacios**

**J. A. Arturo Tapia Dávila, Oscar Iván Gómez Ramírez, Andrei Franco Rentería**

Centro de Investigación y de Estudios Avanzados del Inst.Pol. Nal.

Av. IPN # 2508 Col San Pedro Zacatenco CP- 07360 México DF

Tel. (55) 5747-3778, Fax. 5447-3800 Ext. 6266

e-mail jurbano@cinvestav.mx

ESIME-IPN Departamento De Ingeniería en Comunicaciones y Electrónica

Unidad Profesional ALM- Lindavista México DF. CP

Summary

This paper presents two technological developments as follows: the first is directed to non electrified rural regions, to provide communities with energy sources, allowing in consequence, the economic and social improvement, keeping the environment as the emission of CO2 to atmosphere is eliminated and helping to reverting climatic changes. The second development is directed to urban areas as an energy source for residential sets and commerce and industrial installations, as well. With this development, no gas is fired avoiding again CO2 emission, and decreases the conventional electricity consumption to 15 % only. This strongly

helps to family economy, industry competitiveness and services quality. Both prototypes are operating as distributed generators of energy.

The Rural Solar Concentration Stove was designed as an option for food baking, having excellent possibilities for cooking of corn wafer (tortilla), beans, bread and meat. This is achieved with the help of 360 flat mirrors, whose function is to concentrate the energy from the sun light on a container filled with recycled engine oil, heating it up to 250 °C. Inside this container, an 8 liters commercial pressure pot is placed, where food is cooked. Additional benefits as sterilization of medical instruments and elimination of bacteria from water can be reached with this stove. The calculated price of a stove designed for the use of 8-10 people, is as low as USD $0.33 per day, USD $0.036 KW/day and USD $1.3 the W-peak, within an average operating time of 5.2 peak hours of direct solar radiation through 300 days per year, and a 30 years lifetime. In conclusion, it can be seen that the developments are ideal for communities without electricity, having many sunny days, then preserving the environment and avoiding polluting power plants that use firewood and gas.

The Urban Solar Concentration Stove was designed as a convenient solution in big metropolis for food cooking. This can be achieved using 610 flat mirrors that concentrate sun light energy upon a copper coil, heating recycled oil up to 400 °C, stored in a thermally isolated reservoir with a capacity of 500 to 1000 liters. It can be autonomous as long as 5-7 days, without sun illumination. The heat stored in the thermal reservoir is re-circulated through four coil heaters used then for cooking. This principle can be used also in commerce and industry. For this design, the costs are as follows: $0.68 pesos per KW-hr with a lifetime of 30 years and decreasing the conventional electricity use down to 15 %, applied in the operation of the oil pump that is used for re-circulating the fluid through the copper coil and the heaters. The investment done in this design is recovered in 3-5 years in a 365 days use scheme, if compared with electricity costs.

# 44. Indicadores de Seguridad Energética: Aplicación al

**H. Rudnick, J. Molina, V. Martínez**

# Sector Energético de Chile

Pontificia Universidad Católica de Chile.

Departamento de Ingeniería Eléctrica, fono 56-2-3547566, hrudnick@ing.puc.cl

**Keywords:** Energy Security, Energy diversity, Energy matrix.

**Abstract:** Securing energy supplies is a complex subject broad wide political, economic and environmental variables. The purposes of the methodologies that seek to evaluate the security of energy supply are focused on the analysis of trends on the demand and supply of energy, either globally or in the electric power sector. In this paper we analyze indicators for energy security and global energy system to be implemented in Chile. The literature describes various indicators, which generally have two options. The one option is deliver qualitative assessments, where the main idea is the weighting or use of checklists to allow a relationship between supply and demand. And the second one show indicators with quantitative information that allow to gauge the changes or the evolution of the energy system key variables, such as energy diversity, strength, energy firm, power and economic aspects. Consistent with the indicators described above the indicators were implemented for the diversity over-installation and robustness, with data from public use of the CNE of the Chilean energy sector to determine their evolution to 2007. In turn, according to energy policies and discussions inside the country, discussed scenarios for the evolution of the energy matrix to 2020 considering the expansion of the system, renewable energy, nuclear and gas natural liquefied, in order to determine the behavior of the indicators mentioned. The indicators allow an evaluation of the various strategies for expansion of the energy matrix of a country considering a variety of aspects that influence the development of a strategy secure and robust diversification, implying that its components and expansion decisions are of increasing degree of adaptability to possible changes in the environment. Establishing the importance of evaluating the energy security not only in the aspect of the installation of power generation capacity, but also the diversity of energy sources and their dependence on resources from other regions.

**Resumen:** Garantizar el abastecimiento de energía es una materia compleja con una gran diversidad de variables de carácter político, económico y ambiental. El propósito de las metodologías que buscan evaluar la seguridad del suministro energético se centran en el análisis de la evolución de la demanda y suministro de la energía, ya sea a nivel global o en el sector de la energía eléctrica. En este trabajo se dan a conocer indicadores de seguridad energética utilizados a nivel mundial y su implementación al sistema energético de Chile. En la literatura se describen diversos indicadores, los cuales en general presentan dos

alternativas. La primera, entregar evaluaciones cualitativas, en donde el eje central es la ponderación o utilización de listas de chequeo que permiten establecer una relación entre el suministro y la demanda y la segunda, entregar indicadores con información cuantitativa que permiten establecer el grado ó evolución del sistema energético en variables principales, tales como diversidad de energía, robustez, energía firme, potencia y aspectos económicos. De acuerdo a los indicadores descritos se implementaron los de diversidad, robustez y sobre instalación, con datos de uso público de la CNE del sector energético Chileno para determinar su evolución a 2007. A su vez, de acuerdo con las políticas energéticas y los debates al interior del país, se analizaron escenarios de evolución de la matriz energética al 2020 considerando la expansión del sistema, energías renovables, nuclear y gas natural licuado, con el fin de determinar el comportamiento de los indicadores mencionados. Los indicadores permiten realizar una evaluación de las diversas estrategias de expansión de la matriz energética de un país considerando una multiplicidad de aspectos que condicionan el desarrollo de una estrategia de diversificación segura y robusta, que implica que sus componentes y decisiones de expansión presenten un creciente grado de adaptabilidad ante posibles variaciones del entorno. Se establece la importancia de evaluar la seguridad energética, no sólo en el aspecto de sobre instalación de la capacidad de generación de energía, sino también en la

diversidad de las fuentes energéticas y su dependencia con los recursos de otras regiones.

## 45. Brazil's Energy Portfolio and the Value of Diversification

**Carlos Bastian-Pinto, Luiz Brandão and Marta Dalbem**

Pontifícia Universidade Católica, Rua Marques de São Vicente, 225 – Gávea, Rio de Janeiro, Brazil

Warren J. Hahn

Pepperdine University, 24217 Baxter Drive, Malibu, California 90265, USA

With the recent increases in the level and volatility of energy commodity prices, ever more challenging oil producing environment and projected increasing demand for energy in the coming years, the different governmental policy approaches for ensuring a sustainable energy supply have come under increasing scrutiny. Brazil's energy supply is somewhat unique in the world in that it includes both significant resources of traditional fossil fuels, largely through the exploration of offshore leasehold positions, as well as one of the world's largest alternative fuel industries, sugarcane-based ethanol. In this paper, we analyze the role of Brazil's energy policy in promoting these two energy supply sources, paying particular attention to the initiatives that led to the parallel development of the supply- and demand-sides of the ethanol market. We also take a look forward at the potential value that can be derived from Brazil's flexible energy portfolio. Specifically, we consider the case of an option to switch inputs on a per unit basis, given recent and projected information on energy commodity price volatility, and extend this to the projected consumption level for the country. With this value defined, we conclude with a cost-benefit analysis of Brazil's energy policy approach and discuss the implications.

## Introduction

The recent volatility in energy markets raises many questions about the optimal balance between investment in oil and fossil fuel production and the development of alternative renewable sources of energy such as biofuels, wind, hydro and solar power. Advocates of fossil fuel production claim that the current production and consumption technologies for alternative sources of energy inhibit their capability for significantly reducing dependence on fossil fuels. On the other hand, critics argue that fossil fuels are destroying the environment and contributing to global warming by increasing the amount of carbon in the atmosphere. Both of these claims are reasonable, leaving energy policymakers with the challenge of developing a transitional energy policy that optimally balances the costs and benefits fossil fuel production against renewable alternative energy sources. Clearly we are at the beginning of this process, as renewable energy sources account for about approximately one percent of energy consumption in the G7 economies.

Fortunately, Brazil provides a useful case study of the design, implementation and issues with an integrated energy policy. Through its energy policies over the past 30 years, Brazil has essentially become energy self-sufficient by increasing its domestic oil production while also developing the world's largest clean renewable alternative energy source for automotive fuel, sugarcane ethanol. In this paper, we first analyze the role of Brazil's energy policy in promoting these two energy supply sources. We begin the analysis with a brief history of the development of Brazil's oil and sugarcane ethanol industries. This is followed by an empirical analysis of a data set of recent oil and ethanol prices in Brazil. We then use the resulting price models to quantitatively estimate the value that can be derived from Brazil's flexible energy portfolio as regards automotive fuel consumption. We conclude with discussion of the implication of our findings and areas for further research.

## Brazil's Oil Industry

Prior to the formation of the state-owned Petrobras in 1953 and the institution of pro-development policies, Brazil had for decades been almost entirely dependent on foreign oil. In that year, Brazil produced only 2,700 barrels of oil a day and consumed 137,000 barrels a day. In 1968, the company began searching offshore in the Campos Basin near Macae, 180 kilometres (110 miles) east of Rio de Janeiro. The first major discovery, the Garoupa field, occurred six years later. Other new discoveries followed and the Campos Basin grew to become Brazil's top oil producing area. Nonetheless, Brazil was still importing 85 per cent of the oil it consumed in the 1970's and the country was plunged into debt when oil prices soared during that decade, raising inflation to quadruple digits and pushing the country to the brink of bankruptcy.

Petrobras continued its ambitious exploration and development plans, and in the process became a world leader in deep-water drilling, developing state-of-the-art equipment and setting world records for deep-water drilling. Even after the government terminated the company's oil monopoly in 1995, Petrobras remained in control of the market, acquiring most exploration zones that Brazil put up for auction to international bidders. Today, Brazil has become a net exporter of oil, with more than 80 per cent of its production from offshore fields. In December 2008, an average of 620,000 barrels of crude per day was produced, an increase of approximately 5% from the previous year, and a new record. More importantly, the exports are a boon to Brazil's economy. December's oil exports contributed US$ 574 million to Brazil's trade balance. The main destination of Brazil's exports is the United States, with 63% of the total, followed by Europe with 21.4%. The bulk of Petrobras' production, however, is used in Brazil. The country currently has a population of 186 million inhabitants and an emerging economy, which make it the world's 10th biggest consumer of energy.

Looking forward, Petrobras will likely need to continue to raise oil output to keep pace with demand, which is growing even with the contributions from the expanding ethanol industry and the rising sales of flex-fuel cars that run on both gasoline and ethanol. The increases in production are expected to come from new offshore projects, with would result in production exceeding demand by nearly 300,000 barrels a day in 2010, if current Petrobras projections are accurate. Brazil has also had several recent offshore discoveries of oil and gas along its southern coast in water depths of over 5,000 meters, but the required technology to develop these reserves is currently is prohibitively expensive. If development becomes feasible in the future, these discoveries have the potential to turn the country into one of the world's leading oil producers and exporters. In any case, extending the net-exporter status by any margin will boost Brazil's trade surplus and have the desirable effect of protecting the country's economy from oil-price shocks seen in the past.

Brazil still imports light crude oil, since the country primarily produces heavy crude oil, which must be mixed with the light oil in the refining process. For its overall energy needs, Brazil also still depends on natural gas imported from Bolivia, on its own nuclear power and on hydroelectric dams to produce electricity, and on ethanol made from Brazilian sugar cane. Nonetheless, the country is in the enviable position of having the flexibility to produce locally or buy abroad, whichever is cheaper.

## Brazil's Ethanol Industry

Ethanol has a 30-plus year history as an alternative fuel in Brazil and is a likely candidate as a replacement for fossil fuels, although so far it has only displaced approximately 2% gasoline consumption worldwide. Discussion and analysis of the current and potential future economic and environmental impacts of ethanol has often been focused on corn-based ethanol, due in part to its predominance in U.S. ethanol production and its role in the U.S. fuels market, by far the world's largest (Farrell, 2006). In Brazil, however, ethanol is almost entirely from sugarcane, and the country provides an interesting case study the development of both the supply and demand sides of Brazil's ethanol market. As part of this case study, we characterize the capacity and prospects for sugarcane ethanol production growth, compare the unit production costs for sugarcane ethanol to other sources, including the natural advantages embedded in a flexible sugarcane-to-ethanol/sugar production process, and discuss what can be learned from the Brazilian experience to address issues limiting future development.

## Sugarcane-Based Ethanol Production in Brazil

Currently, about 5.8 million hectares (ha)[172] of agricultural land in Brazil are utilized for growing sugarcane, and that area is roughly evenly split between production for ethanol and sugar. This split is somewhat variable, due to switching between production outputs based on the respective commodity prices. Currently, the ethanol yield is approximately 6,800 liters[173] per each ha planted with sugarcane. By comparison, in the United States where ethanol is mostly derived from corn, the yield is 3,200 liters of ethanol per each ha. Brazil's ethanol production industry therefore benefits from a significant cost advantage relative to corn based ethanol, which is heavily dependent on government subsidies as a result.

Brazil's sugarcane growers benefit from a near-perfect combination of climate, territorial extension and water reserves. As a renewable crop, sugarcane provides two annual harvests on average, in some instances up to five annual harvests, and is mostly grown in the Southeast Region, which contains approximately 3 million ha. The State of São Paulo accounts for 2.6 million ha, with an average productivity of 79 tons/ha[174], while the Northeast region, with a little more than 1 million ha, has an average productivity of 56 t/ha. On average, approximately 150,000 ha of sugarcane planted area are necessary for every billion liters of ethanol produced. With production of 5,019 million gallons in 2007, Brazil currently ranks second among the world's largest ethanol producers, just behind the United

[172] 1 hectare = 2.45 acres
[173] 1 liter = 0.264 gallons
[174] 1 ton = 907.18 kg

States production of 6,499 million gallons, and ahead of China's production of 1,004 million gallons, and India's production of 449 million gallons (RFA, 2007).

As shown in Figure 1, Brazil also has the resources to significantly expand its current production base, as it possesses the largest inventory of unused agricultural land in the world, even after allowing for area set aside for national parks and ecosystem preservation such as the rain forest and the Pantanal region. Of this inventory, about 90 million ha are available for immediate use for agriculture expansion, while the rest would require additional infrastructure investments. If even 10% of the available area were directed for sugarcane based ethanol, the corresponding production would be equivalent to more than the 2005 world output of 12.15 billion gallons.

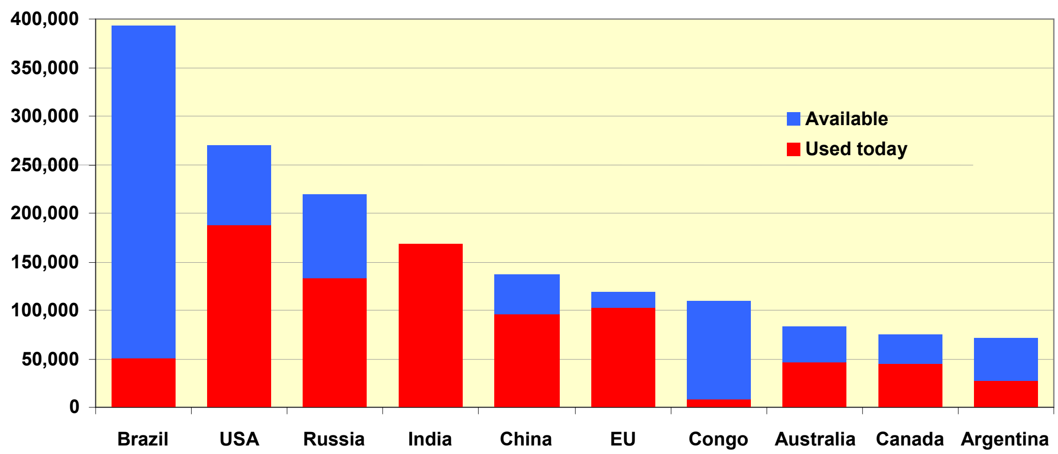



Figure 1: Available Agricultural Land by Country[175]

A Natural Hedge: Brazilian Sugar Production

Brazil is the also world's largest producer and exporter of sugar, and has been so since the end of the colonial era during the sixteenth century. Sugar from Brazil remained the main cash crop for Portugal until its independence and was the main reason for the Dutch invasions and occupation of the Northeast of the country in the seventeenth century. Even after the decline of the demand in the eighteenth

---

[175] Source: Valor Econômica, April 20, 2007. "With Available Land, Brazil is Center for Food and Bioenergy." Pensa/USP e FAO.

century, it remained as an important part of Brazil's export agenda. The world sugar market today is a mature one, with vegetative increase and a small degree of overproduction. It is also a highly protected market in the northern hemisphere (US and Europe), with heavy subsidies to production as well as large entry barriers, although these are being increasingly challenged in international forums. Due to local natural conditions, Brazil has the lowest sugar production cost in the world, approximately 34% of that of the European Union production, which is mostly concentrated in France (UNICA, 2008). The Brazilian sugar market serves a valuable function for sugarcane processors, providing a natural hedge against fluctuations in ethanol price and providing a stable business environment.

## The Consumption Side: Brazilian Ethanol Market

It is fair to say that, at least initially, the Brazilian ethanol market did not evolve from free market competition. Sugarcane ethanol was first promoted as an alternative automotive fuel in Brazil during the 1970's oil crisis when the country was highly dependent on oil imports and had a large deficit in its foreign trade balance. Recognizing that sugarcane is a renewable crop, and that each ton of sugarcane has the energy equivalent of 1.2 barrels of oil (Goncalves, 2006), the Brazilian government initiated a program to promote both the supply and the demand of automotive ethanol fuel. Demand was to be developed through the use of 100% hydrated ethanol fueled cars. Ethanol production was subsidized by taxes on gasoline sales, and vehicle manufacturers benefited from tax incentives for some time. The program was largely successful at first, and by 1986, the vast majority of new automobiles produced ran exclusively on ethanol.

By the end of the 1980s, however, oil and ethanol prices had dropped and sugar prices had risen, therefore processors exercised their option to switch production modes from ethanol to sugar. At the same time, short of cash, the government began to reduce its intervention in the market and its incentives for ethanol production. As it became more difficult to find ethanol at gas stations, consumer confidence in the fuel collapsed and ethanol car production fell to 13% of the total consumption, even though the ethanol shortage at fuel pumps lasted less than a year.

The turning point for the ethanol industry came in 2003, when the first flex fuel automobile was launched in the market. This vehicle was a result of the research done at Bosch of Brazil, where the technology that allowed a combustion engine to burn any mix of ethanol and gas was developed. Flex fuel auto production grew exponentially from 3.9% in 2003 to 52.7% in 2006, and it is expected to stabilize at 90% of the Brazilian automobile production per year (2007 data). As these cars became available in increasing numbers after 2003, ethanol was again competitive with gasoline and the industry regained large production scale. Today, Brazil presently ranks second in the world in terms of total use of bio-fuels, with ethanol currently accounting for just over 50% of total small vehicle fuel consumption (UNCTAD, 2006). Additionally, gasoline today contains a mixture of 20% to 25% of anhydrous ethanol, which has replaced MTBE as an anti-knocking agent due to environmental concerns. Thus, while the ethanol market in Brazil was initially supported by government policies, the eventual development of the market was driven by technological change, with some assistance from environmental regulatory requirements and market forces through increased fossil fuel commodity prices.

## Valuation of Flexible Energy Policy

To illustrate the value of a diversified energy policy and the ability to choose from different energy sources, we consider the case of fuel consumption in Brazil. We use the five-year period from July 2001 through July 2006, as this includes data that is recent enough to include the effects of Brazil's energy policy (especially on the ethanol side), yet also more stable and representative of long-run market conditions than data from the past two years.

Although ethanol typically has a lower pump price than gasoline, this difference is not always advantageous to the consumer, since ethanol has a lower volumetric energy yield (in kilometers per liter) than gasoline. As a rule of thumb, CEPEA-USO (Centre for Advanced Studies in Applied Economics) recommends drivers not to use ethanol if its price is greater than 70% of the price of gasoline. In this analysis we assume that a flex fuel car owner always makes the optimum decision of choosing the most economic fuel each time he fills up his car, considering the ethanol to gasoline yield rate. The BTU content of ethanol is usually given as 20,077 BTU/liter, but gasoline can vary substantially, from 30,379 BTU/liter to 33,022 BTU/liter. Therefore, we consider a range for this yield rate from 61% to 66%, which is based on these BTU figures.

In order to determine the value of the switch option that exists in the flex fuel car, we assume that the decision of fuel choice is made once a month over our study period of 60 months. Although there are models with larger engines, most flex fuel cars in Brazil come with smaller 1.0 liter (61 cu in) engines that offer high mileage per gallon (MPG), so we conservatively assume that monthly consumption will be 100 liters (27.8 gallons) of gasoline equivalent per month. This way, if the owner adopts only ethanol in any particular month, he will purchase a minimum of 100 liters/0.66 and a maximum of 100 liters/0.61.

The prices of ethanol and gasoline used in this analysis were taken from historical series of monthly Brazilian average retail prices from July of 2001 to October of

2006. These series are available from the Brazilian government Oil & Fuel Agency (ANP – Agência Nacional do Petróleo), and are based on national average prices collected from approximately 43,000 gas stations countrywide. Figure 2 shows the series of deflated ethanol and gasoline prices, as well as ethanol prices adjusted by its yield ratio, that is, multiplied by the reciprocal of either 61% and 66%.

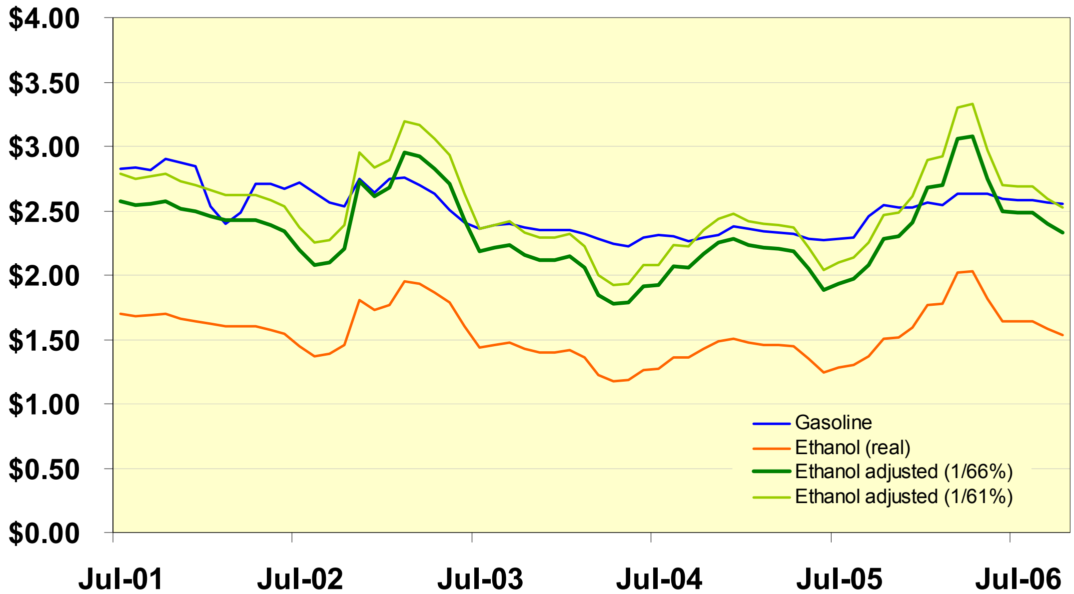



Figure 2: Deflated prices of gasoline, ethanol and ethanol adjusted

Using refinery spot prices series (also available from the same source) would yield similar parameters estimates, as both series are highly correlated (0.96 for ethanol prices and 0.91 for gas prices). The series in Figure 2 were deflated by the IGP-M price index, which is the most widely used Brazilian inflation index.

By simple observation of the price series, it is clear that there were only two short periods within this time frame where the price of gasoline was significantly more attractive than that of the adjusted ethanol, which helps explain the appeal and popularity of flex fuel cars as a lower costs alternative. But the high volatility of the later makes that the possibility of choosing the fuel relevant for a financial valuation.

In comparing the differences between gasoline only, ethanol only, and optimal (minimal price) fuel consumption, we assume that the consumption of ethanol will be follow the range of ratios discussed above, so when computing the number of fuel tanks used with ethanol, it will be multiplied by the appropriate ratio. Also, for comparison purposes, the 2008 exchange rate was R$1.70 per US$ Dollar.

The non-flexible costs for the respective fuels are:

Expenditure with gasoline per month: number of fuel tanks used per month ∗ tank capacity in liters ∗ price of gasoline in R$/liter.

Expenditure with ethanol per month: number of fuel tanks used per month ∗ tank capacity in liters ∗ price of ethanol in R$/liter / ethanol efficiency factor.

The fuelling decision in the flexible case is always a corner solution, since every time one fuel prevails economically over the other, we assume it will be optimal to fill 100% of the tank with that type of fuel. As mentioned previously, we assume that the fuel choice decision will be made once a month, and that the car owner will consume a fixed volume of 100 liters of gasoline equivalent fuel per month. This assumption is reasonable for the small engines that typically power Brazilian flex-fuel cars, and introduces fixed discrete decision points in the model. We also assume that this decision is exclusively based on the economical cost of fueling at that specific decision point, which is dependent on the relative prices of both fuels at that moment. To calculate the cost of each approach – ethanol only, gasoline only, and optimal – over the five year period we numerically integrate under a cost curve, which is simply the product of the price data shown in Figure 2 and the assumed monthly consumption rate. Although improved approximation can be achieved by reducing the time interval between each refueling, the change would not be significant for our overall findings. Therefore we initially consider a cash flow series for 60 months, assuming the fueling is done solely with gasoline, as well as a similar series assuming fueling only with ethanol. Considering $G_t$ the price of gasoline at time *t*, $E_t$ the price of ethanol at time *t*, and *t* representing the $t^{th}$ month of the projected simulation, then the cash flows series are determined as follows:

Cash flows with gasoline in *t*:

$CFG_t = G_t * 2.5 \text{ (tanks)} * 40 \text{ (liter/tank)} = G_t \times 100$

Upper and lower bounds for cash flow with ethanol in *t*:

$CFE_t = E_t * 2.5 \text{ (tanks)} / 0.61 \text{ (ethanol yield)} * 40 \text{ (liter/tank)} = E_t * 163.9$

$CFE_t = E_t * 2.5 \text{ (tanks)} / 0.66 \text{ (ethanol yield)} * 40 \text{ (liter/tank)} = E_t \times 151.5$

After determining these two series, a third series is defined by the exercising the option to choose the lowest cost alternative between the first two in each month:

$CFM_t = \text{Minimum } (CFG_t \,;\, CFE_t).$

The results of this relatively straightforward analysis, shown in Table 1, demonstrate the cost reductions in the optimized flexible case. If the ethanol yield ratio is taken to be 66%, there is a significant (almost 9%) reduction versus the gasoline-only case, since the ratio penalty to ethanol is lower, with a rather slight savings over the ethanol case. In the more conservative case, where the ethanol yield is assumed to be only 61%, there is more of a balance, with a 3-4% savings of the optimized flexible case versus either non-flexible case. On an absolute basis, having the flexibility to purchase the lower priced fuel can save Brazilians somewhere between $500 to $1200 over a five year period, depending on the ethanol ratio, relative to the case where they would have access to gasoline only. To put this in perspective, the average annual wage in Brazil during this period was $ 5,000. Although not investigated here, it is also a plausible assertion that Brazilians can expect to enjoy another benefit related to the ability to choose fuels; less volatility, and hence less uncertainty, in their fuel costs.

| | 5-year Total Cost | | |
|---|---|---|---|
| **Ethanol Yield Ratio** | **Ethanol Only** | **Gasoline Only** | **Optimized** |
| 66% | $14,965 | $16,039 | $14,752 |
| 61% | $16,192 | $16,039 | $15,551 |

| | % Cost Reduction | |
|---|---|---|
| **Ethanol Yield Ratio** | **vs. Ethanol Only** | **vs. Gasoline Only** |
| 66% | 1.4% | 8.7% |
| 61% | 4.1% | 3.1% |

Table 1: Absolute 5-year Costs and % Reductions

Conclusions

The fact that Brazilians today have the choice to choose between fuel alternatives, as well as alternatives for their other energy needs, can be directly attributed to the decision several decades ago to pursue a diversified energy policy. In most other countries, including the largest energy consuming nations of the world, consumers do not yet have such options. In spite of its relatively long history, the Brazilian fuel market remains in transition, with heightened expectations for both increased demand and supply. It is now expected that in less than five years time, ethanol should attain legitimate commodity status, with its own sustainable market. The Brazilian oil exploration and production industry also continues to evolve, with much potential for growth. Therfore, there is no expectations that the benefits of this diversified policy will disappear in the near future.

Here we have examined the effects of Brazil's energy policies as a direct outcome; specifically the value of flexibility in fuel consumption choice, and found the cost reduction to be on the order of 1.4% to nearly 9%. Existing empirical studies on the impact of Brazil's energy policy on its overall economic growth (Hamilton, 2003 and Kilian, 2008) to include a country's share of oil imports as a fraction of total oil consumption and production, but do not directly consider the value derived from flexibility. Those analyses suggest that real GDP is approximately 35 percent higher in Brazil because the country has reduced its share of imported oil by increasing domestic oil production and developing sugarcane ethanol so that rents go to domestic factors of production. They also report a reduction in business-cycle volatility in the range of 14-22 percent as a result of Brazil's energy policies, with the most significant reductions coming over the past decade. The benefits we have characterized here accrue *incremental to* these impacts.

As was seen in the development of Brazil's ethanol market, a combination of support mechanisms – government subsidy, technological development on the production and consumption sides, and supportive environmental standards – was required to fully develop an alternative fuels industry. Given this difficult process, any obstructive government regulation would likely hinder such development. Yet, when examining the current global market, there are numerous examples of trade *barriers*. Perhaps the most notable example is the cap on imported ethanol volumes and import tariff of $0.54/gal imposed by the United States government. Many question the appropriateness of such protective measures for a developing market; indeed Brazil has threatened to request that the World Trade Organization review whether the tariffs are even legal.

The efficiency advantages of sugarcane based ethanol have been well defined based on industry data in Brazil and elsewhere, and the economic case for ethanol is strengthened further by the fact that sugarcane based processors derive additional value from a flexible production process and benefit from a natural hedge in the market for sugar, which is a well established commodity (Pretyman, 2005). As a result, some studies conducted outside of Brazil have recommended that sugarcane based ethanol should be developed preferentially to corn based ethanol where both options exist (Quintero, 2007). The mode of ethanol production is an important consideration for potential investors in ethanol's still developing world market. Evidence from the Brazilian case suggests that such a developing market might be best served if the balance of trade is allowed to define both the nature and the location of ethanol production. Brazil's energy policies also suggest that, when the option is available, a country should not ignore its domestic oil production industry while it is promoting the development of alternative sources of energy.

References

Center for Advanced Studies in Applied Economics (CEPEA), 2007. Indicator of prices. http://www.cepea.esalq.usp.br/.

Farrell, E., 2006. Ethanol Can Contribute to Energy and Environmental Goals. Science 311, 506-508.

Goldemberg, J., 2007. Ethanol for a sustainable energy future. Science 315, 9.

Goncalves, D., Neto, J., Brasil, H., 2006. The option of switching an investment project into an agribusiness project. 10th International conference on real options. New York.

Hamilton, J., 2003. What is an Oil Shock? *Journal of Econometrics* 113: 363–98.

Kilian, L., 2008. A Comparison of the Effects of Exogenous Oil Supply Shocks on Output and Inflation in the G7 Countries. *Journal of the European Economic Association* 6: 78-121.

Pretyman, A., 2005. The growth in the demand of ethanol fuel and its impact on the production mix of a sugar cane mill. Undergraduate dissertation, PUC-Rio de Janeiro, Brazil.

Quintero, J., et. al. (2007). "Fuel Ethanol Production from Sugarcane and Corn: Comparative Analysis for a Colombian Case." Energy 33: 385-399.

Renewable Fuels Association (RFA), 2007. The industry – Industry statistics." http://www.ethanolrfa.org/.

Szwarc, A., 2006. Issues in large scale biofuel production. International seminar on biofuels. MME – OLADE, Brasília, Brazil.

Union of the Sugar Cane Agroindustry of São Paulo (UNICA), 2007, Portal UNICA., http://www.unica.com.br.

United Nations Conference on Trade and Development (UNCTAD). 2005. Biofuels – Advantages and Trade Barriers. www.unctad.org.

# 46. Building an International Market for Ethanol Fuel: some lessons from the Brazilian Experience

**Taynah Lopes de Souza**

DsC in Economics by the Federal University of Rio de Janeiro (UFRJ/RJ) and Technical Assistant of the National Institute of Metrology,

Standardization and Industrial Quality (Inmetro)

Av. Nossa Senhora das Graças 50, Xerém/RJ – Brazil – CEP: 25250-020

**E-mail:** tlsouza@inmetro.gov.br **or** taynah@terra.com.br

Key words: ethanol fuel, commodity, Brazilian experience.

**Abstract:** More intensively from 2006 onwards, politicians and economists have been discussing the role of ethanol fuel in the energetic matrix of all countries, in face of the increase of oil prices and of environmental concerns, posing the need of developing alternative energy sources. In this context, the Brazilian experience with ethanol fuel and the success of related activities have been calling attention all over the world. The strategy of turning the ethanol into a real international commodity, nevertheless, is surrounded by obstacles posed not only by political interests – as it is related to a very strategic activity – but by some technical problems as well. For building an international market for ethanol fuel, therefore, two important initiatives have to be envisaged. Firstly it is related to the guarantee of ethanol supply. Being Brazil the main and practically only exporter of the product, some doubts have been raised with concerns to the capacity of supplying the consumer market, as the fear remains that a new dependency could be promoted, resulting from the existence of just a few producers, who could even act similarly as OPEP's cartel. The second initiative is related to the need of having

standardized technical specifications for the product, to concede clear quality requirements and the necessary confidence to trade in a commodity market.

The aim of the present paper is then to present the Brazilian initiative in overcoming these two obstacles and its contribution to building an international market for ethanol fuel, with important implications for other developing countries. For overcoming the first obstacle, Brazil has invested on transfering technology to other developing countries interested in producing biofuels, in order to increase ethanol supply. Strategies related to the second obstacle pertain to setting specific policy for the theme, with emphasis on sound investments on R&D in the area of scientific metrology, as the basis for the standardization process of ethanol fuel.

## 1.- Introduction

Biofuels is a recent subject in the economic literature which has been raising a lot of interest due to its strategic role in the energetic sector. Since the oil crisis in the 1970s, oil production faces growing instabilities, raising concerns in importing countries like USA and Europe Union who are in a constant search for reducing their dependency on this fuel. Therefore, the scale production of biofuels has definitely entered technical and political discussions all over the world, aiming at diversifying the energy matrix of countries.

On the other hand, much criticism has been directed at this renewable source of energy, involving not only concerns about the social and environmental effects of its production but also about the competition with the food sector, since the main raw materials utilized for biofuels production can be used with this end. Nevertheless, recent studies (BNDES and CGEE, 2008) have shown that these threats can be easily faded through the technological innovations to mitigate the negative social and environmental impacts, and that, moreover, there is much land for increasing the production of raw materials for biofuels without compromising the food production[176].

One could conclude that such criticism is due to the political and strategic role of any source of energy in the international scenery. As stated by the Brazilian Ambassador Simões (2007), those countries that lead the process of energetic matrix transition usually detain a huge comparative advantage, as has already happened to England and its leading role in the coal era, and to USA in the petroleum era.

---

[176] The conclusion of the study developed by BNDES and CGEE (2008) goes in the direction of affirming that the impacts of biofuels must be differentiated according to its origin (both regional and of raw material), having the Brazilian one clear advantages over its competitors.

The leading role of Brazil in the production of biofuels – especially ethanol, since the 1970s in economy scale – in this context is fundamental to be analised, since it represents the paradigm in this field and experience that must be used and strengthened to overcome the criticism.

The country enjoyed what we consider to have been a '*window of opportunity*' (Perez and Soete, 1988) during the oil crisis in the 1970s to envisage the 'Proalcool', a program that invested significant resources for the ethanol industry. Along the last thirty years Brazilian firms, supported by the government, have been able to develop a strong competitiveness in the ethanol fuel production and when a '*new*' window of opportunity appears with the debate about environmental protection and the need for alternative sources of energy in 2000s, Brazil shows a leading role.

In the international arena, the Brazilian experience deserves attention. Given the interest in the consumption of ethanol by many countries with the aim of 'greening' their energy matrix, the issue now has moved to the forefront strategy of turning ethanol into a fully fledged world commodity. For the advance of the international market for the product, two main pre-conditions remain. Firstly there is the need of increasing the number of producers of ethanol in order to avoid undersupply crisis. The second pre-condition concerns the need of having internationally harmonized specifications for the product, through the standardization process.

The objective of the present article is then to present the Brazilian experience directed at overcoming these two obstacles. For that, the article is divided into four sections. The first one is dedicated to a brief presentation of the ethanol fuel industry in Brazil, and of the main elements of this industry in the world, emphasizing the necessary steps to turn the product into an international commodity. The second and the third sections are then dedicated to a deeper analysis of the Brazilian initiatives to advance in this process – respectively approaching the initiatives of technology transfer to help increasing the number of suppliers of ethanol fuel and of the standardization process, involving not only sound investments on research and development (R&D) in the area of scientific metrology to develop the standard (certified reference material, CRM) for the fuel but also the elaboration of documentary international standards to help overcoming technical barriers to trade.

The concluding remarks will be provided in section four, where some proposals are made to the wider biofuels sector and also to future policies formulation in developing countries.

## 2.- The Evolution of the Ethanol Fuel Industry

The production process of ethanol fuel may use as raw material the most diverse biomasses. Following Brazilian tradition, the most utilized source for this production in the world is the sugar cane, the most efficient one with regards to energetic profitability. There are two types of ethanol fuel – hydrated and anhydrous[177], being the first one more adequate to vehicles exclusively run on alcohol and the second one to be mixed to petrol gas. Brazil is the most efficient country in the production of ethanol fuel, as can be observed through Table 1.

Table 1

Anhydrous Alcohol Production Cost in selected countries

US$ /liter

| Country | Anhydrous Alcohol Production Cost | Raw material |
|---|---|---|
| Brazil | 0,20 | Sugar cane |
| USA | 0,47 | Corn |
| Europe | 0,97 | Beetroot, wheat |
| Thailand | 0,29 | Sugar cane |
| Australia | 0,32 | Sugar cane |

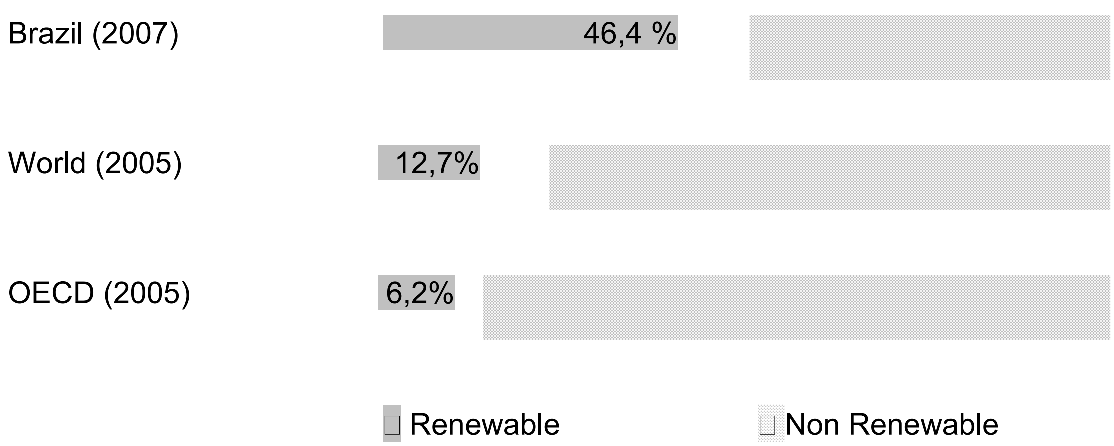
Based on Unicamp (2005, p. 142).

The evolution of the sector in Brazil allowed the country to reach an outstanding position with regards to its energy matrix, when compared to other countries in the world. According to preliminary results of the 2008 National Energy Balance (BEN, in Portuguese) (EPE, 2008), products derived from sugar cane reached the second position in the Brazilian energy matrix in 2007. With this, Brazil increased the participation of renewable sources in its energy matrix, which is now composed of 46,4% of renewable sources, significantly ahead from the rest of the world (Graphic 1).

[177] The first one is not yet very used in foreign markets.

Graphic 1:

Domestic Energy Supply: Brazil, World and OECD




Adapted from EPE (2008).

Although the first steps for the ethanol fuel sector in Brazil were taken in the beginning of the twentieth century, the setting-up of policies more specific to the sector started in the 1970s. Initially, the production of ethanol as a fuel was attached to conjunctural matters, as instabilities in the international market for sugar and restrictions in the import capacity. In the 1970s, two successive oil shocks – in 1973 and in 1979 –, caused an expressive increase in the barrel price, as determined by OPEP, passing from US$ 2,59 to US$ 30,00 during the first half of 1980s (Paixão, 1996).

It is at this moment of paradigmatic change that the Brazilian energy model enters into a reformulation process, searching for the reduction of its dependency on oil and derived products. The role of the State in this process has been fundamental, initiating a whole series of policies aiming at overcoming the 'energy crisis', placing great emphasis on the development of a new energy matrix of alternative and renewable character, culminating in the establishment of the National Alcohol Program (PNA), or 'Proalcool'.

The evolution of production and usage of alcohol as fuel in large scale in Brazil can be understood through the establishment of four phases (Simões, 2007). The first one is related to the start-up of Proalcool, initiating from 1975 to 1979, with the promotion of the addition of anhydrous alcohol to petrol gas, not contemplating significant technological changes in the productive process itself, but demanding an effort for the adaptation of national cars' engines, through some pioneering R&D investments in the country and abroad.

The second phase of Proalcool was launched in 1979, reflecting the peak of the Program, with the adoption of ethanol as sole fuel for vehicles – the hydrated alcohol. An important impetus came from the automotive industry, which launched in the end of 1970s, the car entirely run by alcohol.

Proalcool's third phase is extended from 1987 to 1995 and was initiated in the middle of an era of uncertainties for continuing the Program, deflagrated by the rough reduction of public resources, among other factors. From then on, elimination of governmental control and planning mechanisms for production was gradual, helping to the incitement of the crisis in the ethanol fuel industry, traditionally accustomed to State protection.

The fourth phase initiated in 2000s with the deregulation process[178]. Even if introduced in a slow and troubled manner, according to Fairbanks (2006), this liberalization process forced producers to move from a convenient situation in which they were used to production quotas, established prices, subsidies and monopoly for exporting sugar to a new situation of free market. Having been inadequately conducted, this liberalization process led to a new crisis in the sector in 1999/2000.

The sector moved to the adoption of new strategies in this new context, involving the creation of commercialization centers, the acceleration of the concentration process, product differentiation, productive diversification, outsourcing and mechanization in agriculture (Vian, 2003). Cooperative initiatives have also been intensified, leading to the creation in 2006 of the Local Productive Arrangement of Alcohol (APLA, in Portuguese) in Piracicaba, congregating distilleries, industries, R&D institutes and so forth.

In 2003, new impetus appeared for the sector – coming one more time from the automotive sector – when after almost ten years of technological development for bifuels automotive engines ('flex-fuel'), this important innovation was introduced in the market. With this launching, developed by the firms Magneti Marelli and Bosch

---

[178] In August 1997, Law 9.478 opened the oil and natural gas market in Brazil, aiming at promoting more competition in these sectors. At the same time, two institutions were established: the National Council of Energy Policy (CNPE, in Portuguese), and the National Agency for Oil (now called National Agency for Oil, Natural Gas and Biofuels, ANP ), with effects over the competitiveness of the ethanol fuel sector.

(that act in the segment of automotive technology), consumers can now choose either for gasoline or ethanol with no additional costs, and their decision depends uniquely on the price relation between both fuels[179].

Making an overall balance of this period, according to data made available at Procana (2004), one can observe that the total investment of US$ 11,7 billion, since its creation, allowed the country to save around US$ 38 billion until the end of the 1990s, through importing substitution. Macedo (2005) also defends that the substitution of petrol for alcohol, between 1976 and 2004, was responsible for an economy of up to US$ 121,3 billion. Considering the execution of a sound evaluation about the whole period Waack and Neves (1998, p. 10) affirm that such task is a difficult and challenging one.

The high investment in R&D is one of the preponderant factors for the success and growth of the sector. Martines-Filho *et al*. (2006) show that the productivity of sugar cane and of the industrial activity in this sector have grown, respectively, at a rate of 2,3% and 1,17% per year between 1975 and 2004. Explanation for such growth rates lays on aspects such as the development of new varieties, the introduction of biological control of species, management improvements and soil selection.

The main feature of this present phase is the strategy of internationalization of the product and the interest of turning ethanol fuel into an international *commodity*, ambitioned by its producers in the search for more competitiveness.

The first initiatives that allow the formation of an international market for ethanol fuel were given in May 2004, when future contracts for the product started being negotiated at the New York Board of Trade (Nybot), specific market for negotiating commodities, in which quotations and specifications for the traded products are defined.

For the consolidation of this international market, nevertheless, many challenges must be overcome. First of all, there are still trade barriers imposed by the main world importing markets. The USA imposes a tariff of US$ 0,54/gallon of ethanol fuel (1 gallon ≈ 3,78 liters), plus 2,5% *ad valorem*. In Europe, the tariff is of €0,102/liter for denatured alcohol and €0,192/liter for non-denatured alcohol. The tariff for entering the Japanese market is of 27,2% *ad valorem* (Goldemberg, *et al.*, 2008). The elimination or reduction of these trade barriers is under discussion at the political arena, especially under the rules of the World Trade Organization (WTO). The Brazilian government has been acting intensively, trying to promote the liberalization of the trade in the sector, ambitioned by the exporters of ethanol fuel.

---

179 Nowadays, around 70% of the annual production of cars in Brazil belong to this category (ANFAVEA, 2008).

Other two challenges for the consolidation of the international market for ethanol fuel lay on the core of the present discussion: the need of creating a significant number of producers to avoid undersupply crisis, as well as the establishment of technical standards for the product, so it can be traded in accordance to clear quality criteria.

In this pursuit, political efforts were reinforced by the two world leading producers of the fuel, expressed through the signature, in March 2007, of the 'Memorandum of Understanding between the United States and Brazil to Advance Cooperation on Biofuels'[180]. Even though the tariffs reduction was not an issue included in this initiative, the document establishes a strategy based on three levels, reflecting the intention of advancing in the cooperation for the development and diffusion of biofuels as a whole – bilateral level, of third countries and global.

At the bilateral level there have been included actions that refer to advances in R&D for the second generation biofuels. With regards to the level directed at third countries, the Memorandum establishes activities dedicated to the transfer of technologies for the production of biofuels to selected countries, clearly trying to widen the number of suppliers in the international arena. Finally, the third level – the global one – encompasses the cooperation for the establishment of uniform international standards for the product (BRASIL and EUA, 2007, p. 2).

The next two sections, respectively, are addressed to discuss the two last levels of such strategy – the one related to third countries and the global one, emphasizing the Brazilian experience in this pursuit.

## 3.- Technology Transfer and Technical Cooperation

As stated by Freeman and Soete (1997), the mechanisms for international transfer of technology are strategic to policy-makers in developing countries. Nevertheless it is important to single out that the technology transfer exerts even more positive effects when the receiving country is capable of efficiently assimilating and operating the technology under question, adapting it to its particularities when necessary. For that it is a pre-condition some investment on R&D, even if in its less sophisticated level.

In the energy sector the risk is the lock-in effect since the technology for producing more traditional types of energy (as for instance petroleum and coal), are already consolidated, presenting some sunk costs that hamper the change to alternative

[180] Available at: <http://www.defesanet.com.br/y/br_usa_biofuel.pdf>, access on 25/10/2007.

sources of energy, as the biofuels. In this context it is extremely important to be aware of the need of promoting the adequacy of the new technology to the particular characteristics of less developed countries and to develop mechanisms to help in this transition.

The Brazilian strategy is then to help LDC in this transition, with the interest of strengthening the market of ethanol fuel, through increasing the number of suppliers in order to meet the demand for the product, expected to reach in 2015 around 162 billion liters (BNDES and CGEE, 2008). The Brazilian government has engaged to the promotion of exports and investments. Some agreements in the sector of ethanol fuel have been signed, as the one with Indonesia, Gana, Senegal, Benin, South África, Honduras, Haiti, El Salvador, Mexico, Ecuador, Paraguay, Uruguay, Chile, Colombia, Nicaragua, Panama and Jamaica[181].

Most agreements involve technical cooperation not only to sell machines, equipment and turn key mills, but also for transferring technology of production to these countries. The targeting countries of the Brazilian technical cooperation activities have also been considered as those with greater potential for producing biofuels without compromising food production, represented in a recent study by the regions of SubSaharian Africa, Latin America and the Caribbean. For that, the Brazilian cooperation has been considered strategic to these countries, not only in what regards the production technology for ethanol fuel but also for its co-products (BNDES and CGEE, 2008).

Private producers have also engaged into this strategy. Three firms in Brazil are capable of selling ready turn key mills: Dedini, Sermatec and JW. They offer all necessary equipment to the establishment of mills and distilleries, including peripheric items and process technology. Besides, there has been created a consortium of 10/15 firms that produce turn key mills under request.These are outstanding features, since: “the capacity of introducing commercially well-succeeded capital goods is conceived as one of many possible indicators of ‘strength’ in a given innovation system” (Dalum, 1992).

These producers supply plants in accordance to specifications established at ANP Resolution 36/2005, facilitating the diffusion of the Brazilian technology of process, recognized by the World Bank as the most efficient and productive one, who also affirms that the technology transfer from Brazil can consolidate ethanol as a renewable source of energy [182].

---

[181] Available at <http://74.125.45.132/search?q=cache:Zb_Ba9bhEsoJ:www.intelog.net/newsletter/go.asp%3Fcod%3D142430+etanol+transferencia+tecnologia&hl=pt-BR&ct=clnk&cd=34>, access on 01/05/2009.

[182] Available at: <http://www1.folha.uol.com.br/folha/dinheiro/ult91u465394.shtml>, access on 01/05/2009.

Both the diffusion and the transfer of technology find support on another fundamental process for the commoditization of ethanol fuel: the construction of an international standard for the product, what we shall now discuss.

4.- Building an international standard for Ethanol Fuel

Technical standards that specify the requirements with which products must comply are necessary to allow the commercialization among anonymous economic agents, as the parties involved in the transaction need to be sure of the nature and quality of tradable goods (WTO, 2005). The following proposition by Swann (1999, p. 14) clarifies this matter:

“Minimum quality or quality discrimination standards can - more generally – reduce what economists call transaction costs. If the standard defines the product in a way that reduces buyer uncertainty, then first the risk to the buyer is reduced, and second there is less need for the buyer to spend time and money evaluating the product before purchase. Consider a commodity market, for example: how could it exist in the absence of standards? Traders must be able to buy and sell large volumes without even viewing their trades. This is only possible if there is complete confidence about what it is that is being traded. That presumes a clearly defined standard grade, and certification that all produce traded meets that grade”.

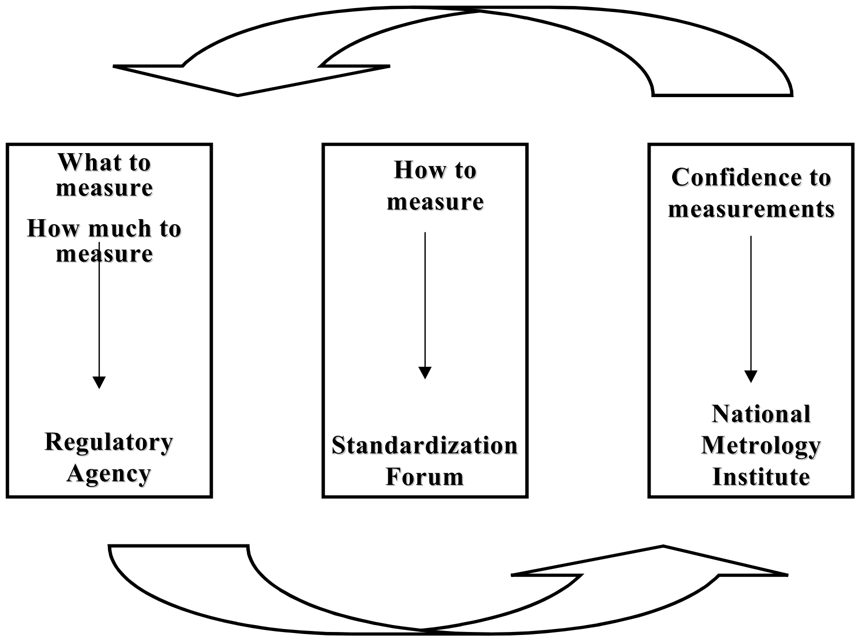
From the statement above becomes clearer the importance of the existence of standards that promote the necessary confidence to transactions that occur in a commodity market. It is then, in face of the strategy of raising ethanol fuel to an international commodity status that the relevance of well-defined standards is even more prominent.

The mechanism of the standardization process as a whole can be understood by Figure 1. Technical parameters to be monitored for the analysis of product quality (what to measure), as well as the limits they must present (how much to measure), are established by regulatory agencies on a mandatory basis. Analytical methods to conduct these measurements are developed in the scope of the standardization forum, a voluntary activity. Finally the guarantee of this whole process – its traceability[183] – and associated confidence are conceived by a robust metrology basis, supplied by a national metrology institute (NMI), usually a public entity.

[183] According to the International Vocabulary of Metrology metrological traceability is defined as "property of a measurement result whereby the result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty" (JCGM, 2008, p. 29).

Figure 1

Technical Standardization Process:




Synergy between Metrology, Standardization and Regulation

Adapted from Daroda (2008)

More recently it is being emphasized the need that this whole framework acts strategically over the competitiveness of industry. The fundamental role of metrology and of technical standardization became more evident when we started debating the initiative of transforming ethanol fuel into international commodity, aspired by its producers, in the search of greater competitiveness.

We now live in a world where divergent specifications to ethanol fuel exist in the market, in a context in which there is no common standard for the product worldwide. Divergences regard not only the usage of different measurement units, but also the establishment of different characteristics in each specification as well as the stipulation of different limits of content. An astonishing lack of information can be observed and many times more rigorous specifications – as those that springs from regulations formulated to alcohol for human consumption – are also demanded by importers of ethanol for fuel. Another problem must be emphasized, concerning the lack of confidence in the analysis that are conducted by the laboratories involved in this task.

As presented in Figure 1, the success of the standardization process as a whole lays on the complementarity of the three spheres that compose it – the regulatory agency (defining parameters and their limits), technical standardization forum (establishing the analytical methods) and the national institute of metrology (offering guarantee and confidence to the whole process). In the specific case of the Brazilian ethanol fuel sector, the three actors that act in such spheres constitute, respectively, ANP, ABNT e Inmetro. The evolution of this theme in the country allows the conclusion that if the first sphere evolved in a regular manner, the second one evolved not so regularly and the last one practically had not been initiated until recently[184].

Without this solid metrological basis, the very analysis concerning the compliance to the requirements established by ANP is impaired due to the nonexistence of a reference standard that serves as a comparison basis to effectively evaluate whether the result obtained in the analysis is compatible to the desired level, given by the associate certified reference material (CRM), in this case.

Such obstacles, though, have only become more prominent with the increasing participation of Brazilian producers in the international market, when they face more strict requirements concerning the quality of tradable goods. Importing markets need the assurance that their specifications are being considered, especially when they are related to a commodity, according to what is defended by Swann (1999). In this context, the credibility of the NMI is a fundamental condition for well-succeeded transactions in the international arena, under the threat that firms be subject to repeated analysis – increasing costs – what can only be made by those with greater bargain power and credibility.

Investments in R&D, necessary for the development of the first CRM for ethanol fuel lay on the basis of its standardization process, an imperative to its 'commoditization' in the international market and, moreover to help diffusing the technological aspects of its production.

Until the beginning of the present century Inmetro, the Brazilian NMI, did not possess – in the contrary to what already had been happening to developed countries – a strong strategy for more advanced fields of metrology, such as Chemical Metrology, either to conduct R&D, this last one a pivotal condition for advances in the metrological area.

The activities held at the Brazilian NMI have always been more associated to legal metrology, with a mainly surveillance character. Nevertheless, a blank remains latent – the development of reference standards in areas of national interest. This situation started to change from the twenty-first century upwards, with the definition

[184] More details on this process can be obtained at Souza (2008).

of new policies for the area, sustaining that the Brazilian NMI should pursue a wider strategy and not be just a mere deposit of 'national standards'[185].

Activities involved in the elaboration of the ethanol fuel CRM are consonant with these new policies and for those actions inserted in the field of scientific and industrial metrology, with emphasis on the field of chemistry, had to be undertaken. Such strategies could only become concrete in face of the initiatives that had been taken at an effort of creating the Chemical Metrology Division of Inmetro (Dquim), in 2001[186].

To capture the extent to which sound investments were made necessary, the development of a CRM for ethanol fuel must be understood as a complex process, as occurs to any chemical composition. In the last 5 years, the structuring of Dquim and the activities involved, either directly or indirectly, in the development of the CRM for ethanol fuel – mainly R&D resources – amount to about US$ 6.5 million (counting on the investments predicted to be made in 2009).

Such investments correspond to researches specifically developed for the creation of new methodologies to provide the analysis of the parameters as determined on the ANP Regulation for the fuel. The Institute managed to introduce methodologies nonexistent until then, having been well-succeeded in the development of the CRM for anhydrous and hydrated alcohol, made available to industry in the beginning of 2008[187].

The activities conducted by the Brazilian government in the process of standardization of biofuels are in consonance with those discussed under the scope of the International Biofuels Forum (IBF), created in March 2007. Initially it was envisaged as a joint project of Brazil, USA and European Union, but later on China, India and South Africa were included in the initiative, representing the main producers and consumers of biofuels. Representatives of these countries agreed to discuss, in the scope of the Forum, strategies directed at the sustainable production and consumption of biofuels. In this context, the Forum was set with the specific aim of promoting a greater coordination among its partners, viewing the establishment of common standards and the '*commoditization*' of biofuels[188].

---

185 See Inmetro and CBM (2003).

186 With regards to this specific matter, we reckon the Brazilian technological delay, of approximately 100 years when compared to USA, for example, whose production of reference materials by its NMI – NIST, at that time denominated 'National Bureau of Standards' – had been initiated still in the beginning of the twentieth century (Alves and Moraes, s/d, p. 5).

187 It is worth to emphasize that the commercialization of each CRM produced comprises a high technological content and also presents the possibility of gains obtained through the exports to other countries, as well as an economy in the purchase of CRM that would be imported in case the strategy of locally developing such artifacts had not been well-succeeded. Additional success must be singled out, with reference to the transfer of the developed technology to industry, who can from then on count on a product with high technological content, being able to aggregate value to its productive processes, since through this development it will possess a trusty instrument to measure the fuel's quality.

188 Available at: <http://www.un.org/News/briefings/docs/2007/070302_Biofuels.doc.htm>, access on 27/10/2007.

About this specific question, the analysis falls over the publication, in December 2007, of the 'White Paper on Internationally Compatible Biofuel Standards'[189], elaborated by the IBF tripartite task-force (composed of representatives from Brazil, USA and EU). The objective of this 'White Paper' was to analyze the stage of three aspects: of technical specifications for biofuels of the three partners; of measurement units used in such specifications; of test methods used to conduct such analysis.

The document concluded that the technical specifications for ethanol fuel of the three biggest actors of the sector – Brazil, USA and EU – possess many similarities, especially because the ones of the last two countries have been elaborated with basis on the Brazilian one. The differences that persist are due to some questions related to market particularities, as climate conditions and the raw materials utilized. The harmonization of units was considered liable to understanding; nevertheless, the discussion about test methods – of more delicate tone – was left to a second phase.

Based on this document Inmetro and USA advanced in the third level of the "Memorandum of Understanding", previously mentioned, to develop the CRM for ethanol fuel, a huge step towards the standardization of the product. Their laboratorial analysis are following a steady and urgent schedule, as it stands in a prioritary position for both partners (Souza, 2008). Another crucial need for advancing in the ethanol fuel standardization process is the development of international documentary standards in the ISO'scope to harmonize the specifications for the product, an initiative that has already been started, when in December 2007 a specific subcommittee was formed to deal with this issue. A third initiative that must be emphasized is the elaboration of studies by Inmetro concerning various initiatives towards the ethanol fuel sector, such as the sustainability of the fuel's production and life cycle assessments (LCA), in order to help overcoming the critical arguments directed at this industry, what hampers its consolidation in the international scenery.

Through the building-up of these three pillars, Brazil has been contributing to the standardization process and, therefore, to the building-up of an international market for ethanol fuel.

## 5.- Concluding Remarks

As we could observe along the discussion conducted at the present paper, the analysis on the ethanol fuel industry shows an emblematic case in which Brazil,

---

[189] Available at <http://www.inmetro.gov.br/noticias/conteudo/whitepaper.pdf> Access on 02/04/2008.

even though not an advanced country, has managed to forge ahead in the investment for the transition of its energetic matrix, which now comprises much more renewable sources when compared to OECD countries. There is agreement among researchers that the petroleum era is not stable and the alternative sources of energy are necessary. Biofuels will have a prominent role in this transition, but it is also recognized that they are not capable of representing a sole source for energy.

Their strategic importance, nevertheless, cannot be denied. And the opportunity for developing countries must be emphasized. According to data made available at a study of Goldman Sachs, by the end of the First Gulf War, in 1991, among the 20 biggest firms in the energy sector, 55% were North-American and 45% were European. This situation has changed dramatically as in 2007, 35% of the 20 biggest firms are from BRIC (Brazil, Russia, China e India), around 35% are European and 30% are North-American (Simões, 2007). They also present the best conditions for developing this kind of energy, posed by climatic characteristics and land in abundance.

So that developing countries can fully enjoy this window of opportunity and become exporters of the fuel, it is necessary to overcome the obstacles imposed in importing countries, and advance for the building-up of a consolidated international market for ethanol fuel, through the commoditization process.

The Brazilian role in this process was the main objective of the present paper, through the analysis of two main initiatives: the technology transfer to other developing countries in order to increase the number of supplies, and the activities involved in the development of an international standard for the product.

It seems to us that the efforts that are being undertaken by the Brazilian government are of huge importance to the sustainability of the ethanol fuel agro-industry in the international arena. Sound financial and political investments were directed to promote cooperative actions with other developing countries and to conduct the necessary R&D to advance in the production of the CRM – the standard – for ethanol fuel. This second one possesses an even more strategic role, since we defend that in case such initiative had not been pursued, the CRM for the product would have been solely developed by the North-American NMI, NIST, and Brazil would miss the chance of advancing in this technological development.

In this manner we sustain that the elevation of the country to the leading position in international standardization activities – contrary to what had been occurring with the mere import of CRM from other countries –, exerting strong influences in activities of national interest, as is the case of the ethanol fuel industry, shows itself as an important political initiative to be conducted in other selected sectors – as biodiesel for instance – and to be followed by other developing countries, in accordance to national and societal interests.

Our findings allows us to conclude that the activities involved in the technology transfer and in the standardization process play a strategic role for the consolidation of the international market for ethanol fuel, and therefore should be included in the formulation of industrial and technological policies, especially in developing countries where the issue is still a recent one.

## 6.- References


Alves, N. P. and Moraes, D.N. (2008) “Metrologia Química e a Utilização de Materiais de Referência em Medições Químicas”. No date, 19p. Available at <http://www.quimlab.com.br/PDF-LA/Artigo%20Revista%20Anal%EDtica.pdf>, acess on 03/21/2008.

Anfavea. “Estatísticas, 2007-2008” (2008). Available at <http://www.anfavea.com.br>. Acess on 13/14/2008.

BNDES and CGEE (coord.). (2008) “Bioetanol de cana-de-açúcar: energia para o desenvolvimento sustentável”. Rio de Janeiro: BNDES, 316p.

Brasil and EUA. (2007) “Memorando de Entendimento entre o Governo da República Federativa do Brasil e o Governo dos Estados Unidos da América para Avançar a Cooperação em Biocombustíveis”. São Paulo, março de 2007, 6p. Available at: <http://www.defesanet.com.br>. Access on 10/25/2007.

Dalum, B. (1992) “Export Specialisation, Structural Competitiveness and National Systems of Innovation”, *In* Lundvall, B-Ǻ (Ed.). National Systems of Innovation: Towards a Theory of Innovation and Interactive Learning. New York and London: Pinter, p. 191-225.

Daroda, R. (2008) “Presentation” at the 2º Seminário de Laboratório – IBP. Rio de Janeiro, 29 and 30/04/2008.

EPE (2008) “Resultados Preliminares BEN 2008”. Available at: <http://www.epe.gov.br/PressReleases/20080508_1.pdf>, access on 09/05/2008.

Freeman, C. and Soete, L (1997). “The Economics of Industrial Innovation”. Cambridge, Mass.: MIT Press, 3ª ed..

Goldemberg, J., Nigro, F. E. B, Coelho, S. T. (2008) “Bioenergia no Estado de São Paulo: situação atual, perspectivas, barreiras e propostas”. São Paulo: Imprensa Oficial do Estado de São Paulo, 2008, 152p.

Inmetro and CBM (2003). “Diretrizes Estratégicas para a Metrologia Brasileira, 2003-2007”. Rio de Janeiro: 2003. Available at: <http://www.inmetro.gov.br/metcientifica/diretrizesEstrategicas_11_02_2003.pdf>. Acess on 06/07/2006.

JCGM (2008) “International Vocabulary of Metrology – basic and general concepts and associated terms”, 104p. Available at: <http://www.bipm.org/en/publications/guides/vim.html>, access on 06/27/2008.

Macedo, I. C. (2005) “A Energia da Cana-de-Açúcar – Doze estudos sobre a agroindústria da cana-de-açúcar no Brasil e a sua sustentabilidade”. São Paulo: Berlendis & Vertecchia: ÚNICA – União da Agroindústria Canavieira do Estado de São Paulo.

Martines-Filho, J., Burnquist, H. L. and Vian, C. E. F. (2006) “Bioenergy and the Rise of Sugarcane-Based Ethanol in Brazil”. Choices Magazine, 2nd Quarter 2006, 21(2). Available at: <http://www.inovacao.unicamp.br/etanol/report/inte-choices2006210.pdf>. Access on 03/05/2007.

Paixão, M. (1996) “O Proálcool Enquanto uma Política Energética Alternativa: uma Resenha Crítica”. Available at: <http://www.brasilsustentavel.org.br/textos/texto7.rtf>. Access on 05/05/2007.

Perez, C. and Soete, L. (1988). “Catching up in technology: entry barriers and windows of opportunity” in Dosi et. al (1988) Technical Change and Economic Theory. London: F. Pinter.

Procana (2004). “Ethanol Guide – Guia Internacional do Álcool”, São Paulo, 320p.”

Simões, A. J. F. (2007) “Biocombustíveis: a experiência brasileira e o desafio da consolidação do mercado internacional”. *In* Biocombustíveis no Brasil: Realidades e Perspectivas. Brasília: MRE, 205p, p. 11 a 33.

Souza, T. L. (2008). “Metrologia e Padronização Técnica como Ferramentas para a Competitividade e Inovatividade Industrial: uma Análise a partir da Indústria Brasileira de Etanol Combustível”. Tese de Doutorado IE/UFRJ, Junho/2008, 245p.

Swann, P. (1999) The Economics of Measurement. Report for NMS Review. UK. June 1999, 65p. Available at: < http://www.berr.gov.uk/files/file9676.pdf >, access on 01/21/2008.

Unicamp (2005) “Estudo sobre as possibilidades e impactos da produção de grandes quantidades de etanol visando à substituição parcial de gasolina no mundo”. Relatório Final. Dezembro de 2005. Fundação de Desenvolvimento da Unicamp, Convênio: CGEE – Centro de Gestão e Estudos Estratégicos.

Vian, C. E. F. (2003) “Agroindústria Canavieira: estratégias competitivas e modernização”. Campinas/SP: Ed. Átomo.

Waack, R. S. and Neves, M. F. (1998) “Competitividade no Agribusiness Brasileiro: Sistema Agroindustrial da Cana-de-Açúcar” (volume V). (Coord. Farina, E. M. M. Q. e Zylbersztajn, D.). São Paulo: PENSA/FIA/FEA/USP, 193p.

WTO (2005) “World Trade Report 2005 – Exploring the Links between Trade, Standards and the WTO”. Genebra: 2005. Available at: <http://www.wto.org/english/res_e/booksp_e/anrep_e/world_trade_report05_e.pdf>. Acess on 03/06/2006.

# 47. Energy Bidding in a Centralized Dispatch System under Uncertain Supply

**Eduardo Saavedra**

ILADES – Universidad Alberto Hurtado

Address: Erasmo Escala 1835, Santiago, Chile

Phone: (562)6920265

Fax: (562)6920303

E-mail: saavedra@uahurtado.cl

Keywords: Energy Bidding, Uncertainty, Shortage

Abstract: Using non-cooperative game theory, this paper asseses the resulting equilibria of an energy bidding required to provide electricity to residential customers. We assume that the interconnected system is characterized by uncertain supply, risk averse agents, centralized dispatch, and asymmetry of information among generators and the distribution company. Based upon a competitive auction designed by a benevolent regulator, both an hidroelectric and a thermal firm compete by offering a price for the energy that the winner will supply to the unique distribution company. We suppose that hidroelectricity is stochastic, in the sense that nature may choose between two states: normal and drought; in contrast, we suppose without loss of generality that thermal electricity is deterministic.

The benchmark model assumes that all relevant information to make a decision is common knowledge, then the auction is awarded to the firm that fixes the price in the spot market during drought. Thus, it is the thermal firm the one that bids the lower price when drought is moderate; but it is the hidroelectrical firm the one that gets the contract when drought is deep enough to produce an energy shortage in the system. Whatever the case, the resulting equilibria produce prices higher than the theoretical regulated price that a benevolent and neutral regulator would fix in a non-liberalized market. However, being a competitive bidding, the extra rents that the winner obtains in equilibrium are enough to compensates it for the risk that it has to cope with for providing energy to a fixed price to residential curstomers. When the hidroelectrical firm has more information that its rival regarding the state of nature, it behaves more aggresively during the bidding process, such that in some cases, that are fully characterized in the paper, the outcome of the bidding changes: not

always the firm that sets the price in the spot market during drought obtain the contract. Finally, this paper asseses alternative assumptions to verify robustness in the main results, such as whether an extreme drought is legally considered to compensate non supplied demand, the effects of a binding price of reserve in the auction, among others.

# 48. Valoración de Efectos de la Incorporación de Fuentes de Energía Renovable en la Expansión de la Capacidad de

**Julio A. Hernández Galicia – Rolando Nieva Gómez**

# Generación del Sistema Eléctrico Mexicano

*(Assessment of the Economical Impact of Renewable Energy Sources Technologies on the Mexican Power Generation System Expansion Planning)*

(hgalicia@iie.org.mx) (rnieva@iie.org.mx)

Gerencia de Análisis de Redes - Instituto de Investigaciones Electricas

Reforma 113, Cuernavaca Morelos México C. P. 62490

Tel. +52(777)3623811, Fax +52(777)3623823

*Abstract:* In this paper, renewable energy source technologies are taken into account in the expansion planning for the Mexican Power Generation System. The results estimate the impact on the investment, the operating costs and evaluate the economical risk reduction related to Fossil Fuel Price Uncertainty. The economical risk is measured as the maximum regret in the set of fossil fuel prices futures.

The first part, shows the regional potential of the diverse renewable energy sources available in the Mexican System taking into account the next technologies: Wind Power Plant, Solar Plant (photothermal and photovoltaic) and Biomass Plant (sanitary landfills, solid wasted incineration, biodigestor and wood gasification). This information is used to generate expansion plans of the Mexican power generation system. The planning horizon is 21 years and the reference year is 2007.

The planning methodology takes advantage of the inherent economical risk reduction of the renewable energy source technologies and it compares such technologies with the conventional technologies under conditions of equality [4, 5, 6, 7].

With the aim of assessing the influence of the renewable energy source technologies on the power generation system expansion planning, a Subset of Plans on the two efficient trade off frontiers in the two dimensional space, defined by *Investment Cost* vs. *Risk*, and *Total Cost* (investment & operation costs) vs. *Risk*, is used as a frame of reference. The expansion plans on the trade off frontiers are Pareto-Dominant, i.e. there is no other expansion plan (not on frontiers) strictly superior, in any *Risk*-*Cost* context simultaneously.

To know if the economic risk reduction advantages of the renewable energy source technologies can surpass its high investment costs disadvantage, this technologies are contrasted with the non-renewable source technologies. The technology mix compositions are determined in each plan over the efficient frontier. The results show the plans with a great participation of the renewable energy source technologies are located in the smaller economic risk zone.

1.- Introducción

De cara a la volatilidad de los precios de los combustibles y dada la incertidumbre sobre la evolución de éstos en el largo plazo, cobra importancia el tema de la diversidad de energéticos primarios para la generación de energía eléctrica y la incorporación de tecnologías de aprovechamiento de fuentes de energía renovable.

Estudios previos de prospectiva tecnológica [1, 2, 3] han identificado las tecnologías de aprovechamiento de fuentes de energía renovable, tanto las que han probado ya su viabilidad técnica, como las que probablemente alcanzarán su madurez técnica y comercial en los próximos años.

El presente artículo tiene como objetivo presentar los resultados de un estudio de planificación de la expansión del sistema eléctrico mexicano en el cual se evalúan los efectos económicos de la incorporación de tecnologías de generación no convencionales que aprovechan la energía de fuentes renovables, tales como fotovoltaica, eólica, biomasa y solar térmica.

Para el estudio se consideró un horizonte de planificación de 21 años. La metodología empleada se apoya en el Modelo de Planificación de los Medios de Generación y Transmisión con Criterios de Acotamiento de Riesgos PEGyT/AR [16], la cual reconoce las ventajas de reducción de riesgos de precios de combustible de las tecnologías de aprovechamiento de fuentes renovables de energía, comparadas con las tecnologías de fuentes no-renovables [4, 5, 6, 7].

Las Tecnologías de Aprovechamiento de Energía Renovables no Convencionales (TAER) consideradas para el estudio son las siguientes: centrales eólicas, centrales termosolares, centrales fotovoltaicas y centrales de biomasa (incineración de basura urbana, rellenos sanitarios, gasificación de recursos forestales y el biogás que resulta del proceso de descomposición de los residuos pecuarios).

Los datos necesarios para la definición del escenario de planificación se colectaron de documentos públicos oficiales, como son la Prospectiva del Sector Eléctrico [8], el documento de Costos y Parámetros de Referencia Para la Formulación de Proyectos de Inversión en el Sector Eléctrico (COPAR) [9] y el Programa de Obras de Infraestructura del Sector Eléctrico 2005 (POISE) [10].

El conjunto de futuros de precios de combustibles, con el que se caracteriza la incertidumbre en esta materia, se estableció a partir de los escenarios presentados en el Informe *Annual Energy Outlook 2007* [11] que publica el Departamento de Energía de los Estados Unidos.

Como parte del estudio de planificación, y con el objetivo de crear un marco de referencia para valorar los efectos de la incorporación de fuentes renovables, se determinan los planes de expansión que yacen en las fronteras eficientes de Riesgo contra Costo Total en el Futuro de Precios de Referencia, y de Riesgo contra Costo de Inversión. Los planes que yacen en dichas fronteras son dominantes en el sentido de Pareto [12], es decir, no son superados por algún otro plan de expansión en los rubros de riesgo y costo simultáneamente. Para cada uno de los planes que yacen en las fronteras eficientes se determina la composición de la mezcla de tecnologías, analizando las ventajas de las TAER en la reducción de riesgos, y en contraste, su desventaja en el aumento en costos debido a sus altos costos de inversión.

*2.- El Modelo de Planificación de la Expansión de la Generación con Criterios de Acotamiento de Riesgo, PEGyT/AR*[190].

El modelo de Planificación de la Expansión de los Medios de Generación y Transmisión PEGyT [14, 15] fue desarrollado por la Gerencia de Análisis de Redes del Instituto de Investigaciones Eléctricas en 1993, desde entonces a la fecha ha servido como una útil herramienta de apoyo para los estudios de planificación de la expansión del sistema eléctrico mexicano.

La versión moderna del modelo PEGyT incluye un módulo de *Acotamiento de Riesgo* (AR) [16, 17, 18], en el cual se trata la incertidumbre de los escenarios futuros de precios de los combustibles. Este módulo es capaz de generar un conjunto de planes de expansión, entre los cuales el planificador puede escoger el plan (o los planes) que mejor se adecue(n) a las políticas de administración de riesgo y a los recursos financieros disponibles. La plataforma tiene las siguientes opciones:

---

[190] Derechos Reservados IIE (Registro: 03-2007-070611055000-01)

a) Opción para determinar el plan que minimiza el riesgo de precios de combustibles.

b) Opción para determinar la familia de planes de expansión que se ubican en la frontera eficiente de decisiones, en el contexto de los dos criterios de interés: el riesgo derivado de la incertidumbre de los precios de combustibles, y el costo de inversión.

c) Opción para determinar la familia de planes de expansión que se ubican en la frontera eficiente de decisiones, en el contexto de los dos criterios de interés: el riesgo derivado de la incertidumbre de los precios de combustibles, y el costo total (inversión y producción) correspondiente a un escenario de referencia.

El Riesgo que caracteriza cada plan de expansión es medido en términos del máximo arrepentimiento en un conjunto de futuros de precios de combustibles. El arrepentimiento del plan respecto a un futuro específico se define como la diferencia entre el costo total del plan en valor presente (capital, más costo de producción, más costo de la energía no servida) y el costo correspondiente del plan óptimo para dicho futuro. La frontera eficiente de planes son aquellos que no son dominados en el sentido de Pareto. O sea que cualquier plan en la frontera eficiente no es superado por ningún otro en términos de los dos criterios (por ejemplo: capital y riesgo) simultáneamente.

## *3.- Características del Sistema Eléctrico de Planificación.*

### *3.1.- El Sistema Eléctrico de Planificación.*

Se utilizó una representación del Sistema Interconectado Mexicano, compuesta por 42 regiones agrupadas en 7 áreas operativas y 60 enlaces interregionales. La Tabla 2.1 muestra la clasificación de las regiones por área. La Figura 1 muestra el diagrama esquemático de la red de transmisión y la distribución geográfica de las 42 regiones del sistema eléctrico de planificación.

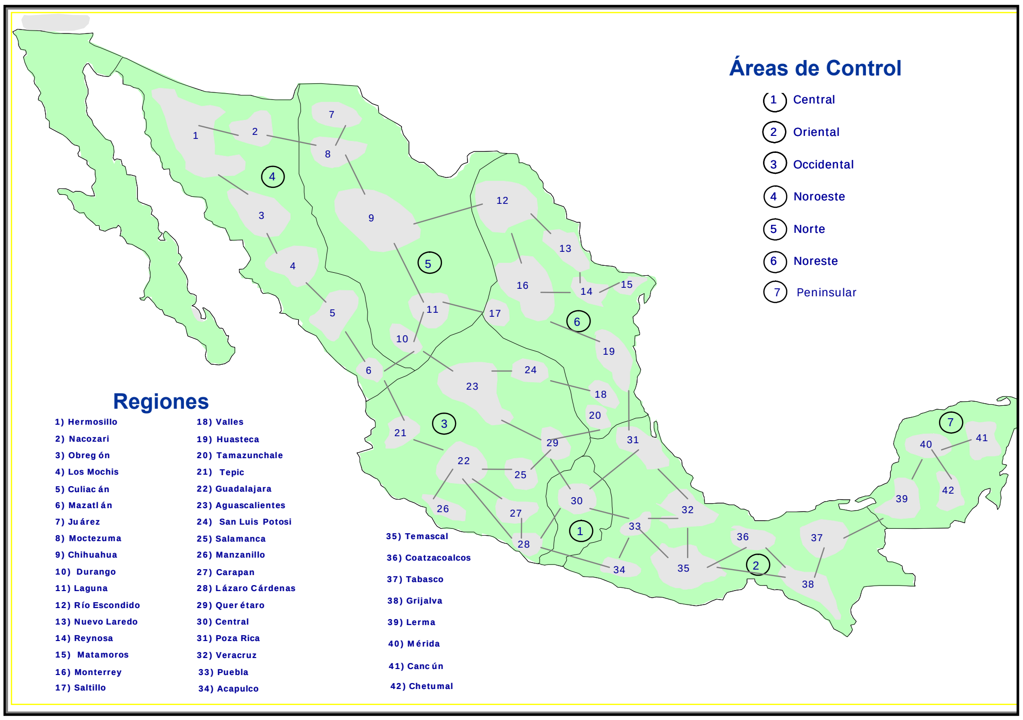
### *3.2.- Capacidad de Generación Inicial y a Evolución de las Decisiones Programadas.*

Se considera una capacidad de generación térmica instalada al inicio del periodo de planificación (año 2006) de 33,444 MW representada por 199 unidades generadoras agrupadas en 105 centrales térmicas. Con respecto a la capacidad comprometida, se consideran 9 proyectos con una capacidad total de 5,786 MW, los cuales entrarán en operación dentro del periodo 2007-2010, este incremento va de acuerdo con el Programa de Obras de Infraestructura del Sector Eléctrico 2005 (POISE) [10].

La capacidad hidráulica instalada al inicio del periodo de planificación es de 10,486 MW, representada por 20 embalses, entre los cuales 9 corresponden con embalses de regulación semanal y 11 con embalses de regulación anual. Entre los proyectos hidráulicos comprometidos, se consideraron los embalses de *El Cajón* y *La Yesca* cada uno con una capacidad de 746 MW y que entrarán en operación en los años 2008 y 2011 respectivamente, conforme a lo especificado dentro del POISE 2005.

El sistema de transmisión está formado por 42 enlaces que interconectan a las regiones del Sistema Eléctrico de Planificación cuya capacidad de transmisión y parámetros eléctricos de resistencia y reactancia corresponden con los valores equivalentes de las líneas de transmisión que representan. Para el año 2006 se considera una capacidad de transmisión total en el sistema de 50,380 MW.

Figura1. Diagrama esquemático del sistema eléctrico de planificación.




## *3.2.- Opciones de Tecnologías de Generación Convencionales para la Expansión del Sistemas Eléctrico.*

Los tipos de tecnologías térmicas convencionales consideradas dentro del catálogo de opciones de expansión del sistema de generación son las tecnologías Convencional de Vapor, Carbón Supercrítica, Nuclear, Geotérmica, Turbogás, Ciclo Combinado y Ciclo Combinado de Gasificación Integrada (IGCC). Las características básicas y los costos de las tecnologías se extrajeron del *Informe sobre Costos y Parámetros de Referencia para la Formulación de Proyectos de Inversión en el Sector Eléctrico* (COPAR de Generación) de

2004 [9], a excepción de la tecnología IGCC cuya información se extrajo de un documento del EPRI [19].

*4.- Tecnologías de Aprovechamiento de Energías Renovables (TAER) No Convencionales.*

Para el presente estudio se utilizaron ocho tipos de Tecnologías de Aprovechamiento de Energías Renovables (TAER) No Convencionales entre las cuales se encuentran cuatro tecnologías de Biomasa que utilizan la basura, la madera y los residuos pecuarios como fuente primaria de energía. Dos tipos de tecnologías termosolares que aprovechan la energía calorífica de las radiaciones solares para la generación de energía eléctrica, cuya configuración está basada en un sistema de concentración de canal parabólico, la primera de ellas para la conversión puramente de la energía calorífica y la segunda dentro de un esquema híbrido Ciclo Combinado-Termosolar que utiliza como fuente de energía primaria el Gas Natural. Las restantes tecnologías corresponden a los tipos Eólica y Fotovoltaica que aprovechan la energía del viento y la energía luminosa de las radiaciones solares respectivamente para la transformación de energía eléctrica.

Los datos de carácter técnico–económico de las TAER se extrajeron de la referencia *Parámetros Técnico-Económicos y Potencial Regional de Fuentes Renovables* [13], el cual fue elaborado como parte de las actividades programadas de este proyecto. La Tabla 1 muestra las características básicas de las TAER utilizadas como opciones de expansión en el estudio. La Tabla 2 muestra los costos de Inversión y de Operación y Mantenimiento de las TAER consideradas como opciones para la expansión del sistema eléctrico.

Tabla 1 Catálogo de Tecnologías de Aprovechamiento de Energía Renovable No Convencionales.

| Tecnología | Capacidad Nominal (MW) | Vida útil (años) | Carga Mínima (p.u.) | Disponibilidad (p.u.) | Requerimiento de Mantto. (semanas/año) | Tipo de Combustible | Eficiencia térmica (%) |
|---|---|---|---|---|---|---|---|
| Biodigestores | 0.5 | 20 | 0.00 | 0.90 | 1.00 | Biogás | 47.60 |
| Rellenos Sanitarios | 1 | 20 | 0.00 | 0.90 | 1.00 | Biogás | 47.60 |
| Incineración de Residuos Sólidos Urbanos | 12 | 30 | 0.24 | 0.85 | 1.00 | Basura | 25.00 |
| Gasificación de Reservas Forestales | 15 | 20 | 0.00 | 0.90 | 2.00 | Madera | 25.00 |
| Eólicas | 30 | 25 | 0.00 | 0.95 | 2.00 | Viento | 14.58 |
| Fotovoltaicas | 10 | 25 | 0.00 | 0.95 | 2.00 | Luminosidad | 100.00 |
| Termosolar de | 50 | 30 | 0.00 | 0.96 | 3.00 | Radiación | 100.00 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Canal parabólico | | | | | | solar | |
| Híbrida: Solar - Ciclo Combinado | 286 | 25 | 0.45 | 0.96 | 3.00 | Gas Natural Nacional | 53.10 |

Tabla 2 Costos de Inversión y de Operación y Mantenimiento de las TAER.

| Tecnología | Costo de Inversión (Millones USD/MW) | Costo Fijo O&M (USD/MW-año) | Costo Variable O&M (USD/MWh) |
|---|---|---|---|
| Biodigestores | 2.000 | 60,000 | 0.000 |
| Rellenos Sanitarios | 0.775 | 42,700 | 0.260 |
| Incineración de Residuos Sólidos Urbanos | 2.870 | 51,724 | 0.260 |
| Gasificación de Reservas Forestales | 1.370 | 10,000 | 0.650 |
| Eólicas | 1.150 | 30,000 | 0.000 |
| Fotovoltaicas | 5.400 | 42,000 | 0.000 |
| Termosolar de Canal parabólico | 3.000 | 80,000 | 0.000 |
| Híbrida: Solar - Ciclo Combinado | 0.838 | 24,456 | 0.260 |

Las limitaciones al crecimiento de las TAER están directamente relacionadas con la información del Potencial Nacional de Energía Renovable presentado en el reporte *Parámetros Técnico-Económicos y Potencial Regional de Fuentes Renovables* [13], en el cual se especifica la distribución regional del potencial y el aprovechamiento cronológico del mismo.

La mayor parte del potencial de energía renovable esta conformada por las Reservas Forestales con una capacidad disponible de 12,525 MW, siendo Durango, Grijalva, Temascal y Chihuahua las regiones que concentran el 60% del potencial forestal.

El potencial de Energía Eólica en el país se estima en 7,500 MW, capacidad que se encuentra distribuida en las regiones de Mazatlán, Juárez, Nuevo Laredo, Reynosa, Huasteca, Veracruz y Temascal, en esta última región (que incluye a la estación La Ventosa) además de concentrar el 25% del potencial eólico, cuenta con excelentes condiciones de viento que se reflejan en altos factores de planta de la tecnología, situación que favorece la instalación en esta región de tecnologías de aprovechamiento del potencial eólico por encima del resto de las regiones del sistema.

Con respecto al potencial de Energía Fotovoltaica, se estima una capacidad máxima disponible de 7,140 MW siendo la disponibilidad de superficie la principal limitación para la instalación de las tecnologías de aprovechamiento del potencial fotovoltaico. En el estudio se considera que todas las regiones del sistema tienen las mismas posibilidades de instalación de dichas tecnologías.

Respecto al potencial Termosolar, éste se estima en 2,580 MW distribuido en las regiones de Aguascalientes, Cananea, Chihuahua, Culiacán, Durango, Hermosillo, Juárez, Laguna, Mochis, Moctezuma, Obregón, San Luís Potosí y Puebla, las cuales poseen altos índices de radiación solar. Las anteriores regiones son además, los sitios potenciales para la instalación de las tecnologías Híbridas Solar-Ciclo Combinado.

La consideración de la Basura como energía renovable da como resultado un potencial de 2,980 MW el cual se distribuye entre la tecnología de Rellenos Sanitarios y la tecnología de Incineración de Residuos Sólidos Urbanos, siendo esta última las que concentran el 80% del total de este potencial energético. Este tipo de energía renovable se concentra en las regiones con altas concentraciones urbanas siendo las regiones Central, Guadalajara y Monterrey las que mayor aporte tienen al mismo.

Tabla 3 Potencial de Energía Renovable y Limitaciones de Expansión de TAER

| Tecnologías | Potencial | | Tasa Máxima de Instalación (MW/año) |
|---|---|---|---|
| | MW | Periodo | |
| Centrales Eólicas | 7,500 | 2010-2026 | 500 |
| Rellenos Sanitarios | 448 | 2010-2026 | 32 |
| Biodigestores | 460 | 2010-2026 | 31 |
| Gasificación de Reservas Forestales | 12,525 | 2009-2026 | 750 |
| Incineracióndе Residuos Sólidos Urbanos | 2,352 | 2010-2026 | 312 |
| Centrales Termosolares | 2,750 | 2010-2026 | 250 |
| Centrales Híbridas CCTS | 12,298 | 2010-2026 | 1,000 |
| Plantas Fotovoltaico | 7,560 | 2009-2026 | 420 |
| TOTAL | 45,893 | | |

La tecnología de Biodigestores utiliza como fuente de energía el biogás que resulta del proceso de descomposición de los residuos producidos por el ganado en las modalidades de ganado bovino lechero, ganado bovino para carne, y ganado porcino. El potencial de este tipo de fuente de energía renovable se estima en 460 MW, siendo las regiones de Guadalajara, Central, Salamanca, Grijalva, Poza Rica, y Obregón las que concentran el 50% del potencial nacional de este tipo de energía renovable. La Tabla 3 muestra un resumen de las limitaciones de aprovechamiento del potencial de energía renovable utilizado para el presente estudio.

4.- La Preparación de los Escenarios.

El Horizonte de Planificación y su División.

El horizonte de planificación comprende un periodo de 21 años iniciando en el año 2006 y terminando en el año 2026. Cada año está dividido en 3 estaciones (cuatrimestres). La división estacional del año se realiza para representar la disponibilidad de energía hidráulica y las condiciones cambiantes de la demanda que ocurren a lo largo del año. Para lograr este último punto, cada cuatrimestre se divide en cinco modos de operación, los cuales reflejan el comportamiento de la curva de duración de carga característica de cada estación.

Tasa de Descuento, Costo de la Energía no Suministrada y Requerimiento de Reserva.

Se utilizó una Tasa Anual de Retorno del 12%, un costo para la Energía no Suministrada de 1,500 dólares/MWh. El requerimiento de margen de reserva es del 25% de la demanda pico.

Escenario de Crecimiento de la Demanda de Energía y Capacidad.

La información de los escenarios de crecimiento de la demanda de electricidad se obtuvieron del *Capítulo 1: Evolución del Mercado Eléctrico,* del POISE 2005 [10]. Las proyecciones de la demanda eléctrica, presentadas en el POISE se determinan a partir de modelos econométricos sectoriales y de estimación regional que utilizan análisis de tendencias y estudios de cargas. Para el cálculo de las proyecciones de consumo de energía, se utilizan las proyecciones anuales del producto interno Bruto (PIB), el consumo de electricidad y el precio medio de venta.

Escenarios de Evolución de los Precios Futuros de los Combustibles.

El conjunto de futuros de precios de combustibles, con el que se caracteriza la incertidumbre en esta materia, se estableció a partir de las proyecciones presentadas en el Informe *Annual Energy Outlook (AOE) 2007* [11] que publica el Departamento de Energía (DOE) de los Estados Unidos. Estas proyecciones se elaboran con base a las tendencias tecnológicas y demográficas actuales, asumiendo que las regulaciones vigentes se mantienen a lo largo de todo el horizonte de estudio. Las proyecciones en el AEO 2007, intentan proveer una referencia neutral que puede usarse para la evaluación de iniciativas y políticas energéticas de las administraciones de energía públicas, sin la intención de especular o influenciar en cuestiones regulatorias o legislativas.

5.- Resultados de la Planificación de la Expansión de Mínimo Costo.

Se presentan los resultados del Modelo de Planificación PEGyT en su versión determinista, que se utilizó para obtener el plan de expansión de mínimo costo (óptimo) para el escenario correspondiente a cada futuro de precios de los combustibles. Los planes de expansión de mínimo costo u óptimos son aquellos que se obtienen de la minimización de los costos de inversión más los de producción para un escenario previamente determinado, sin considerar la incertidumbre inherente de los parámetros de planificación. En la Tabla 4 se muestran los resultados de costos en Millones de Dólares para los planes de expansión óptimos para cada uno de los futuros de precios tratados en este estudio.

Tabla 4 Costos Totales en Millones de Dólares de los Planes de Expansión Óptimos para los Futuros de Evolución de Precios de los Combustibles.

| CONCEPTO | Plan de Expansión Óptimo para el Futuro de Precios | | |
|---|---|---|---|
| | Bajos | de Referencia | Altos |
| Inversión Térmica | 6,936 | 9,126 | 12,754 |
| Inversión Hidráulica | 1,694 | 1,870 | 1,885 |
| Inversión Transmisión | 137 | 217 | 379 |
| Subtotal Inversión | 8,767 | 11,213 | 15,019 |
| | | | |
| Consumo Combustible | 78,948 | 84,364 | 94,352 |
| Operación. y mantenimiento | 11,598 | 12,052 | 12,841 |
| Subtotal Producción | 90,546 | 96,416 | 107,193 |
| | | | |
| Total | 99,313 | 107,629 | 122,213 |

Capacidad de Generación agregada por los Planes de Expansión de Mínimo Costo.

En la capacidad de generación agregada por el Plan de Expansión que es Óptimo para el escenario que comprende al *futuro de precios de referencia*, la tecnología de Ciclo Combinado es la de mayor participación con un 65.7% (39,890 MW) de la capacidad total agregada. La tecnología Nuclear es la segunda tecnología con una participación del 15.6% (9,442 MW) y en tercer lugar la capacidad Hidráulica con un 12% (7,268 MW). El 6.7% restante está formado por capacidad de Carbón (655 MW), IGCC (220 MW), Turbogás (332 MW), Biodigestores (460 MW), Rellenos Sanitarios (448 MW) y Eólica (1980 MW).

Respecto a la participación de las TAER, el plan propone la instalación de 2,888 MW de capacidad, que corresponden con el 100% del potencial disponible por las tecnologías de Rellenos Sanitarios y Biodigestores. Respecto a la capacidad de generación Eólica, el plan de expansión propone la instalación del 100% de la capacidad disponible en la región de Temascal (que incorpora al sitio La Ventosa). El potencial eólico en el resto de las regiones del país no se ve favorecido por este plan de expansión.

El plan de expansión que es óptimo para el escenario que considera el *futuro de precios bajos*, favorece la instalación de unidades de Ciclo Combinado ya que dicha tecnología representa un 80% (47,700 MW) de la capacidad total propuesta. La capacidad de generación hidráulica ocupa un segundo lugar de preferencia con un 12% (6,932 MW) de la capacidad total propuesta y el 8% restante está formado por capacidad Nuclear (2,314 MW), Carbón (655 MW), IGCC (238 MW), Turbogás (332 MW) y Biomasa (908 MW). Respecto a la instalación de las TAER, el plan de expansión aprovecha el 100% del potencial de energía renovable disponible por las tecnologías no convencionales de Rellenos Sanitarios y Biodigestores. En este plan, la tecnología eólica no se ve favorecida a comparación con el resultado que presentó el plan que es óptimo para el futuro de precios de referencia.

El Plan de Expansión que es Óptimo para el escenario que considera el *futuro de precios Altos* presenta una mayor diversidad en la composición de la capacidad de generación agregada siendo las tecnologías con mayor participación, las siguientes: Ciclo Combinado (22,254 MW), Nuclear (10,403 MW), IGCC (10,360 MW), Carbón (8,370 MW) e Hidráulica (7,341 MW) que representan el 94% de la capacidad de generación total agregada por el plan de expansión, el 5.5% está formado por las TAER y el 0.5% restante por turbotas. La composición de las TAER en este plan de expansión está formada por las tecnologías Eólica (1,980 MW), Biodigestores (460 MW), Rellenos Sanitarios (448 MW), Incineración de Residuos Sólidos Urbanos (433 MW) y Gasificación de Residuos Forestales (151 MW).

Análisis de Incertidumbre de los Planes de Expansión de Mínimo Costo.

El criterio de decisión utilizado en el presente estudio es el criterio que Minimiza el Máximo Arrepentimiento [21], el cual traduce las posibles consecuencias de una decisión dada en una medida del perjuicio económico real (arrepentimiento) de una decisión en particular con respecto a la mejor decisión que pudo haberse tomado para el escenario que realmente se presenta.

El arrepentimiento para cualquier decisión tomada con respecto a un escenario, está definido como la diferencia entre el costo de la decisión y el costo de la decisión “óptima” para dicho escenario. El procedimiento consiste en determinar el máximo arrepentimiento asociado a cada plan de expansión. El plan que posea el mínimo de éstos representará el plan de menor máximo arrepentimiento, que para los fines del presente estudio se interpreta como el plan de mínimo riesgo, estableciendo al máximo arrepentimiento como una medida cuantitativa de los riesgos económicos derivados de la incertidumbre en la evolución de los precios de los combustibles.

Tabla 5 Análisis de Incertidumbre de los Planes de Expansión Óptimos.

| | Plan de Expansión Óptimo para el Futuro de Precios Bajos | | | Plan de Expansión Óptimo para el Futuro de Precios de Referencia | | | Plan de Expansión Óptimo para el Futuro de Precios Altos | | |
|---|---|---|---|---|---|---|---|---|---|
| Futuro de Precios → | BAJO | REF | ALTO | BAJO | REF | ALTO | BAJO | REF | ALTO |
| Inversión | 8,767 | | | 11,213 | | | 15,019 | | |
| Producción | 90,546 | 99,209 | 116,251 | 88,486 | 96,416 | 111,995 | 86,537 | 93,636 | 107,193 |
| Costo Total | 99,313 | 107,976 | 125,018 | 99,698 | 107,629 | 123,208 | 101,556 | 108,655 | 122,213 |
| Arrepentimiento | 0 | 347 | 2,806 | 385 | 0 | 996 | 2,243 | 1,026 | 0 |
| Máximo Arrepentimiento | 2,806 | | | 996 | | | 2,243 | | |
| Menor Máximo Arrepentimiento | | | | 996 | | | | | |

La Tabla 5 muestra los costos asociados a cada uno de los planes de expansión para los tres futuros de precios de combustibles analizados. El primer componente de costo asociado a cada plan es el costo de inversión que se relaciona directamente con los programas de instalación de capacidad que cada plan propone. El segundo componente es el costo de producción el cual es dependiente de los futuros de precios de los combustibles y es determinado por un programa que determina el despacho óptimo de la capacidad de generación (la existente más la agregada por cada plan).

Si se pudiera conocer a priori el futuro de precios que se presentará, la mejor decisión sería elegir el plan de expansión que minimiza los costos totales de inversión más producción para el futuro "conocido", es decir, el plan óptimo para cada futuro (en la Tabla 5 los costos totales óptimos para cada futuro se muestran con número azules). Como esta situación no es posible, en todo momento existirá el riesgo de un sobrecosto provocado por decisiones equivocadas. Bajo estas circunstancias, una mejor decisión sería aquella que minimiza dicho riesgo.

En la Tabla 5, el máximo arrepentimiento representa la cuantificación del riesgo económico de los planes de expansión siendo el Plan de Expansión Óptimo para el Futuro de Referencia la mejor de las decisiones debido a que arroja el menor de éstos. La anterior conclusión es la única que puede concretarse de un análisis de incertidumbre con herramientas deterministas. Estudios realizados con herramientas modernas [4, 6] han comprobado la existencia de un conjunto de planes eficientes con mejores argumentos para enfrentar de manera eficaz la incertidumbre en los escenarios de planificación.

6.- Resultados de la Planificación de la Expansión de Mínimo Riesgo.

Para la obtención del Plan de Expansión de Mínimo Riesgo se utilizó el módulo de acotamiento de riesgo del Modelo de Planificación PEGyT/AR. En la Tabla 6 se muestran los resultados de costos del Plan de Expansión de Mínimo Riesgo encontrado. En dicha tabla aparece además el correspondiente valor de arrepentimiento por futuro de precios, siendo el máximo arrepentimiento de 643 Millones de dólares. Este es menor que el que arroja el Análisis de Incertidumbre sobre los planes de expansión deterministas.

Tabla 6 Resultados de Costos y Análisis de Incertidumbre

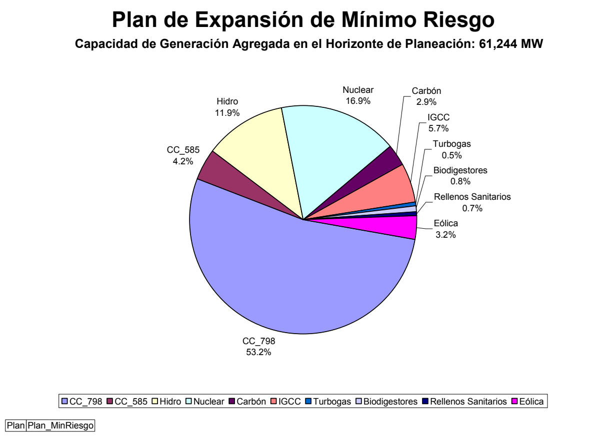
del Plan de Expansión de Mínimo Riesgo.

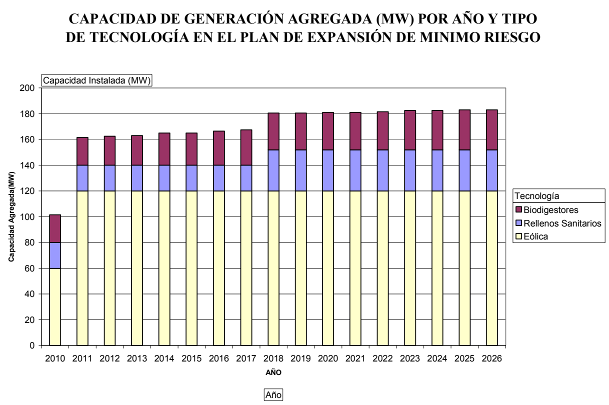
| CONCEPTO | Costos del Plan de Expansión de Mínimo Riesgo (Millones USD) | | |
|---|---|---|---|
| Futuro de Precios → | BAJO | REF | ALTO |
| Inversión Térmica | 9,870 | | |
| Inversión Hidráulica | 1,899 | | |
| Inversión Transmisión | 226 | | |
| Subtotal Inversión | 11,995 | | |
| Consumo Combustible | 75,734 | 83,486 | 98,590 |
| Operación. Y mantenimiento | 12,227 | 12,227 | 12,229 |
| Subtotal Producción | 87,961 | 95,713 | 110,818 |
| Total | 99,956 | 107,708 | 122,813 |
| Arrepentimiento | 643 | 80 | 601 |
| Máximo Arrepentimiento | 643 | | |

La Figura 2 muestra la composición de la capacidad de generación agregada por el plan de expansión *de mínimo riesgo*. Dicho plan de expansión propone una capacidad de generación de 61,244 MW, la cual esta compuesta por las tecnologías de Ciclo Combinado con un 57.4% (35,096 MW), Nuclear 16.9% (10,342 MW), Hidráulica 11.9% (7,283 MW), Carbón 2.9% (1,759 MW), IGCC 5.7% (3,469 MW), Turbogás (332 MW) y el 4.7% (2,888 MW) restante está formado por las TAER.

La composición de las TAER en este plan de expansión está formada por las tecnologías Eólica (1,980 MW), Biodigestores (460 MW) y Rellenos Sanitarios (448 MW). La Figura 3 muestra la evolución de dicha capacidad de Generación de las TAER.

Figura 2. Figura 3

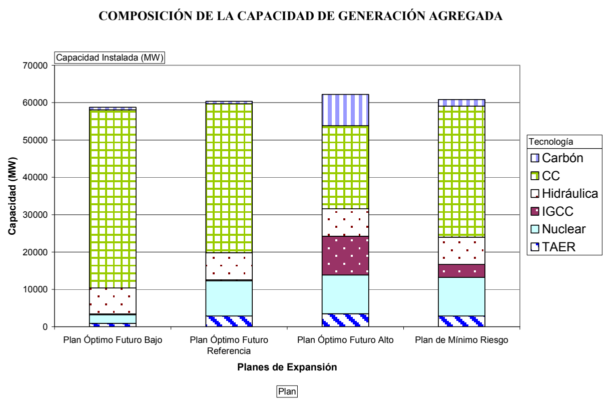


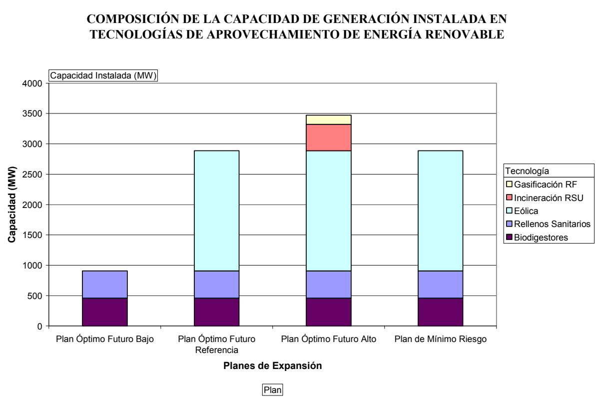




La Figura 4 muestra una comparación de la composición de la capacidad de generación agregada por los 4 planes de expansión determinados en este estudio. La variedad de la mezcla de tecnologías varía en cada plan. Se observa una mayor similitud entre el plan de mínimo riesgo y el plan que es óptimo para el futuro de precios de referencia, siendo la principal diferencia que el plan de mínimo riesgo propone 4,800 MW de capacidad de IGCC y Carbón, en lugar de capacidad de Ciclo Combinado que se proponen en el plan óptimo para el futuro de referencia.

La Figura 5 muestra una comparación de la composición de la capacidad de generación de TAER agregada por los 4 planes de expansión. Se observa que los cuatro planes de expansión coinciden en instalar el 100% del potencial disponible por las tecnologías de Rellenos Sanitarios (448 MW) y Biodigestores (460 MW). A excepción del plan de expansión que es óptimo para el futuro de precios bajos, la capacidad de generación eólica se propone por el resto de los planes aunque únicamente un 25% del potencial nacional que corresponde con la capacidad disponible en el nodo de Temascal (1,980 MW). El plan que es óptimo para el futuro de precios altos propone en su programa de expansión a las tecnologías de Incineración de Residuos Sólidos Urbanos (433 MW), y Gasificación de Reservas Forestales (151 MW).

Figura 4.    Figura 5.



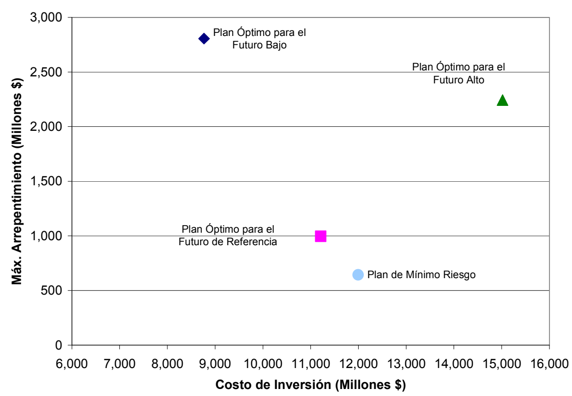

Análisis de la Relación de Riesgo-Costo de los planes de expansión.

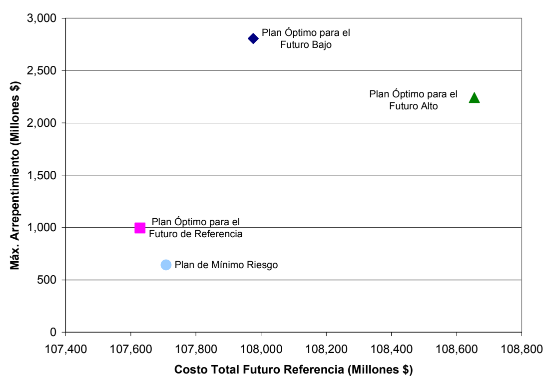
En la planificación de la expansión con incertidumbre, la minimización de los riesgos da como resultado un aumento en los costos totales de inversión más producción. En tal situación, se puede afirmar que no existe una solución óptima al problema de planificación, ya que el mejor plan para un ente tomador de decisiones dependerá de su propio grado de aversión al riesgo y de los recursos financieros que tenga disponibles para inversión.

Para ilustrar esta situación, en las gráficas de la Figuras 6 y 7 se comparan dos atributos de los planes de expansión obtenidos hasta el momento: el Riesgo (Máximo Arrepentimiento) contra el Costo de Inversión; y el Riesgo contra el Costo Total de Inversión más Producción en el Futuro de Referencia, respectivamente.

Figura 6

Figura 7




El Plan de Mínimo Riesgo arroja un riesgo de 643 Millones de USD, que representa 353 Millones de USD menos que el correspondiente al plan de menor costo en el futuro de Referencia. El beneficio que acarrea la reducción del riesgo se logra a costa de una inversión adicional valuada en 782 Millones de USD, pero sólo 80 Millones de USD adicionales en el costo total de inversión más producción en el futuro de referencia.

Si el criterio de mayor peso para la toma de la decisión es el Costo Total de futuro de referencia, entonces la solución presentada por el Plan de Mínimo Riesgo es la más atractiva debido a que los riesgos económicos evitados son mayores que el correspondiente incremento en los costos totales. Si el criterio más importante para tomar la decisión es el costo de inversión, entonces el planificador deberá analizar si las ventajas de la reducción del riesgo justifican el aumento en los costos de inversión.

Acotamiento de Riesgo en la Planificación de la Expansión.

El Modelo de Planificación PEGyT/AR, además de determinar el Plan de Expansión de Mínimo Riesgo, cuenta con las siguientes opciones:

a) Opción para determinar la familia de planes de expansión que se ubican en la frontera eficiente de decisiones, en el contexto de los dos criterios de interés: el riesgo económico derivado de la incertidumbre de los precios de combustibles, y el costo de inversión.

b) Opción para determinar la familia de planes de expansión que se ubican en la frontera eficiente de decisiones, en el contexto de los dos criterios de interés: el riesgo económico derivado de la incertidumbre de los precios de combustibles, y el costo total (inversión más producción) correspondiente a un escenario de referencia.

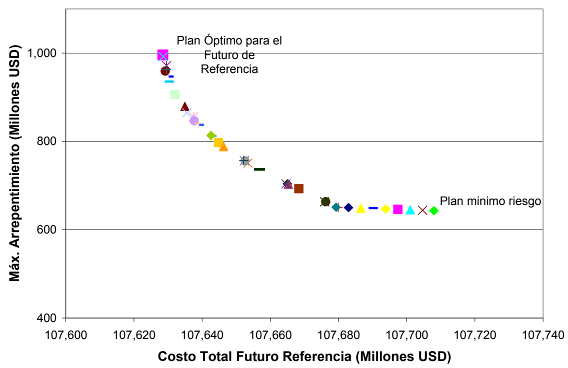
Ambas fronteras eficientes corresponden con el conjunto de soluciones no dominadas en el contexto de Pareto [12] que resultan del tratamiento multiobjetivo del problema de minimización de riesgos en el Modelo PEGyT/AR. Las fronteras eficientes amplían las alternativas de decisión del planificador permitiendo la elección de soluciones con diferentes niveles de riesgo y costos, estableciendo además una referencia útil para la evaluación de la eficiencia de otros planes de expansión ubicados fuera de dicha frontera (soluciones dominadas).

En la gráfica de la Figura 8 se muestra el conjunto de planes de expansión que conforman la *frontera eficiente en el contexto de Riesgo contra Costo Total en el Futuro de Referencia*. La frontera tiene como punto de partida el plan que es óptimo en el Futuro de Referencia y como punto de llegada el plan que minimiza el riesgo. Con esta información, el planificador puede elegir el plan o los planes sobre la frontera eficiente que vayan acorde con sus criterios de decisión, con la certeza de que dentro del universo de solución no existen planes de expansión con una mejor relación Costo-Riesgo que superen a los planes que conforman a la frontera eficiente.

En la Figura 9 se muestra la mezcla de la capacidad de generación instalada por cada uno de los planes de expansión en la frontera eficiente. Se observa poca variación en la mezcla de tecnologías de los planes de expansión con la diferencia de que los planes cercanos al plan de mínimo riesgo consideran la instalación de la Tecnología IGCC.

En la Figura 10 se muestra la mezcla de capacidad correspondiente a las TAER, en la cual se observa que en toda la frontera, la decisión de instalación de Rellenos Sanitarios, Biodigestores y Eólica se mantiene firme.

Figura 8 Figura 9




**Planes de Expansión en la Frontera Eficiente:**
**Riesgo vs. Costo Total en el Futuro de Referencia**

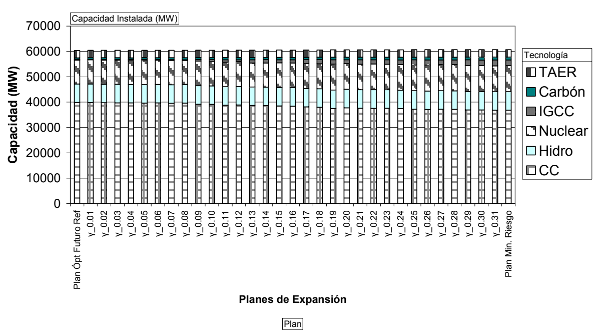
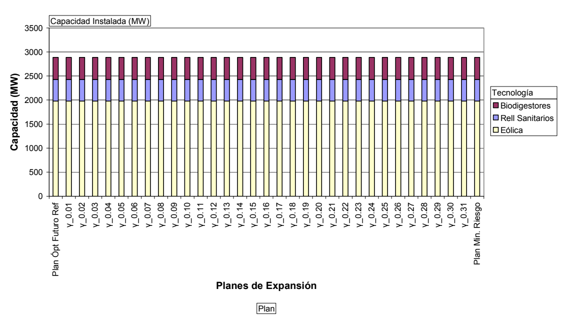



Figura 10

**PLANES DE EXPANSION EN LA FRONTERA EFICIENTE:**
**RIESGO vs. COSTO TOTAL EN EL FUTURO DE REFERENCIA**




En la gráfica de la Figura 11 se muestra el conjunto de planes de expansión que conforman la *frontera eficiente en el contexto de Riesgo contra Costo de Inversión*. La frontera eficiente tiene su punto de partida en el plan de expansión de mínimo riesgo y su punto de llegada en el plan de expansión que presenta como resultado la menor inversión posible. En este análisis no se observa el costo de producción, por lo que una decisión tomada bajo este criterio exclusivamente podría resultar desafortunada, pues el riesgo de precios de combustibles crece rápidamente, a medida que se prefieran los planes de menor inversión.

En la Figura 12 se muestra la mezcla de la capacidad de generación instalada por cada uno de los planes de expansión en la frontera eficiente. Puede observarse la variación en la composición de la mezcla de tecnología de tal forma que a menores costos de inversión la tecnología de Ciclo Combinado es la tecnología predominante.

En la Figura 13 se muestra la mezcla de capacidad correspondiente a las TAER, en la cual se observa que en toda la frontera la tecnología de Rellenos Sanitarios es firme en toda la frontera. A medida que se minimiza el riesgo las tecnologías de Biodigestores y Eólica se hacen presentes.

Figura 11.

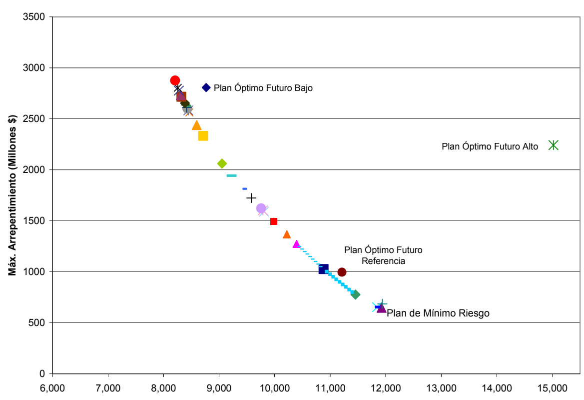



Figura 12

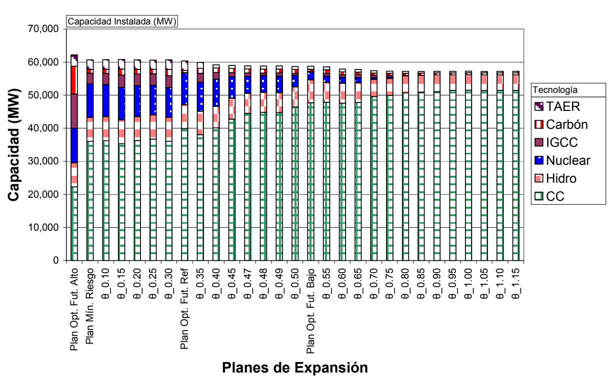
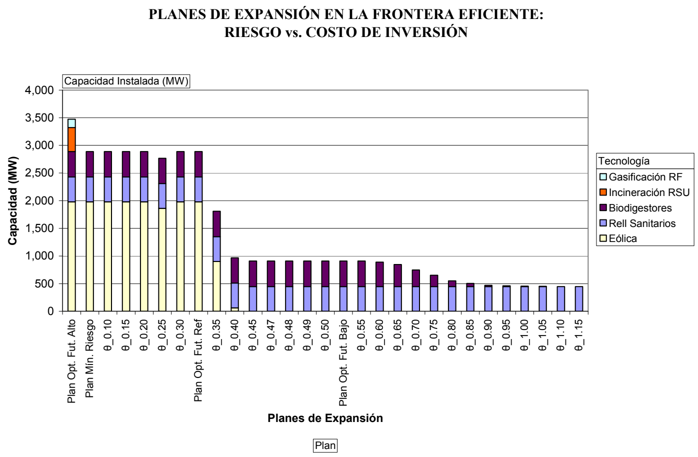


Figura 13.




## 7.- Conclusiones y Observaciones Finales.

Los resultados muestran que la participación de fuentes de aprovechamiento de energías renovables en la expansión del sistema eléctrico es pequeña, en términos de capacidad agregada, ya que del total del potencial disponible, sólo son economicamente atractivas las tecnologías de Biomasa de Rellenos Sanitarios y de Biodigestores; y las Plantas Eólicas.

Los principales factores que explican la baja penetración de las fuentes de aprovechamiento energía renovable no convencional son sus altos costos de inversión; y para algunas tecnologías la relativamente baja disponibilidad de su energía primaria, que en este estudio se representa mediante factores de planta regionales, que varían por tipo de tecnología y por estación del año.

En el caso de las centrales termosolares, centrales fotovoltaicas, plantas de incineración de residuos sólidos urbanos, centrales de gasificación de reservas forestales y centrales híbridas CCTS, los altos costos de inversión de las mismas desincentivan su desarrollo.

Respecto a las plantas eólicas, el factor decisivo es el factor de planta. Del total del potencial nacional (8,000 MW), los planes de expansión sólo proponen el 25% de éste, que es el disponible en la región de La Ventosa. El potencial eólico en La Ventosa se estima con un factor de planta promedio anual del 45%, mientras que en el resto de las regiones el factor de planta promedio anual fue del 25%.

Por otro lado, también es justo señalar que en este estudio no se toman en cuenta externalidades y consideraciones que pueden hacer más atractivas las TAER No convencionales. Entre estas destacan las siguientes:

El valor económico de la reducción de emisiones de efecto invernadero (bonos de carbono y certificados de reducción de emisiones).

Las posibles cotas que el gobierno y/o la sociedad imponga a las emisiones agregadas de contaminantes y gases de efecto invernadero.

Los posibles ahorros en los costos de inversión en transmisión, subtransmisión y distribución; así como la reducción de pérdidas por transmisión y distribución que son consecuencia de la utilización de la microgeneración distribuida urbana (fotovoltaica, celdas de combustible, etc).

Las cadenas de valor relacionadas con la adopción de tecnologías de generación que permiten un alto contenido de desarrollo y empleo nacional (la industria de fabricación de máquinas eólicas por ejemplo).

## 8.- Referencias.


[1] "Prospectiva y ruta tecnológica de procesos clave de CFE, Reporte Técnico, IIE, julio 2004.

[2] "Prospectiva sobre la Utilización de la Energías Renovables en México; una Visión al año 2030", SENER – Banco Mundial, 2005.

[3] "Energías renovables para el desarrollo sustentable de México", SENER – GTZ, 2006.

[4] J. A. Hernández, R. Nieva, "Acotamiento de Riesgo en la Planeación de la Expansión de Sistemas Eléctricos", IEEE Sección México, RVP-AI/2005, 10-16 de julio 2005, Acapulco Guerrero.

[5] R. Nieva, "Riesgos económicos de la expansión de la capacidad de generación: impacto de la energía nuclear", Seminario Internacional: El resurgimiento de la energía nuclear: ¿una opción para el cambio climático y para países emergentes? IIE-UNAM, EDF, AMEDES; Unidad de seminarios Dr. Chávez, Cd. Universitaria, México D. F., 19-20 de abril, 2006.

[6] R. Nieva, J. A. Hernández, “A Model for Long Term Generation Planning Under Uncertainty”, paper S4-9, IERE 5th General Meeting and South East Asia Forum, 20-25 November 2005, Kuala Lumpur.

[7] R. Nieva, “Metodología de planeación con acotamiento de riesgo”, Reporte técnico, Gerencia de Análisis de Redes, IIE, agosto 2006.

[8] Prospectiva del Sector Eléctrico 2006-2015, Primera Edición ISBN 968-874-203-1, Dirección General de Planeación Energética, Secretaria de Energía, México, D.F., 2006.

[9] “Costos y Parámetros de Referencia Para la Formulación de Proyectos de Inversión en el Sector Eléctrico (COPAR)”, Gerencia de Evaluación y Programación de Inversiones, Subdirección de Programación, CFE.

[10] Programa de Obras e Inversiones del Sector Eléctrico (POISE) 2994-2013, Gerencia de Programación de Sistemas Eléctricos, Subdirección de Programación, Comisión Federal de Electricidad, México, D. F: Enero 2005.

[11] Annual Energy Outlook 2007 with projections to 2030, www.eia.doe.gov/oiaf/aeo/ DOE/EIA-0383(2007), Energy Information Administration (EIA), Department of Energy (DOE), Washington, D.C., United States, February 2007.

[12] A. D. Athanassopoulos and V. V. Podinovsky, “Dominance and Potential Optimality in Multiple Criteria Decision Análysis with Imprecise Information”, Journal of the Operational Research Society, 48, pp: 142-150, 1997.

[13] J. Agredano, J. L. Arvizu, H. Romero, R. Saldaña, C. Ramos, "Parámetros Técnico-Económicos y Potencial Regional de Fuentes Renovables”, Reporte Técnico IIE/01/14/13242 A /I001/F/DC, Gerencia de Energías No Convencionales, Instituto de Investigaciones Eléctricas, Julio 2007.

[14] Manuel Ruiz, et. al, “PEGyT: Una herramienta Para la Planeación de la Expansión de los Sistemas de Generación y Transmisión”, Boletín IIE, vol. 18, núm. 5, 1994, pp. 223-231.

[15] J.A. Hernández, L.E. Altamirano, M. Ruiz, R. Nieva “Modelo de Planeación de la Expansión de los Medios de Generación y Transmisión PEGyT, Versión PC”, CIGRÉ Comisión Nacional México, 4to Congreso Bienal y Expo Industrial del 22 al 24 de Junio 2005, Irapuato Gto. México.

[16] R. Nieva, "Metodología de Planeación con Acotamiento de Riesgo", Reporte Técnico GAR-13069-MET-Planeación, Gerencia de Análisis de Redes, Instituto de Investigaciones Eléctricas, agosto 2006.

[17] Nieva R., "Riesgos Económicos de la Expansión de la Capacidad de Generación: Impacto de la Energía Nuclear", Seminario Internacional: El resurgimiento de la energía nuclear: ¿una opción para el cambio climático y para países emergentes? Unidad de seminarios Dr. Chavez, IIEc-UNAM, EDF, AMEDES,WEC; México D. F.., 20 abril 2006.

[18] Nieva R., Hernández G. J. A., "A Model for Long Term Generation Planning Under Uncertainty", IERE 5th General Meeting and South East Asia Forum, November 2005.

[19] N. Holt, IGCC Power Plants – EPRI Design & Cost Studies, EPRI – Energy Conversion Division, San Francisco, CA, October 6, 1999 .

[20] H. P. St. Clair; "Practical Concepts in Capability and Performance of Transmision Lines"; AIEE Transactions on Power Apparatus and Systems, Vol. 72, Part III, pp. 1152-1157, December 1953.

[21] International Atomic Energy Agency; “Uncertainty Analysis” in Expansion Planning for Electrical Generating Systems. A Guidebook; Technical Report Series No.241, IAEA Ed, Vienna, 1984

# 49. “Process and Product Technological Innovations in Natural Monopolies”

**Ricardo Raineri Bernain – Carlos Salamanca García**

The aim of this research is clarified the way in which a regular monopoly takes decisions of technological innovation in consumers' presence with heterogeneous preferences. It takes as a base the use of a conventional technology to produce a product A. The introduction of a new technology allows produce a product B that differs from the product A that it have a better quality but having a cost of major production. It is provoked then, a dichotomy for the monopolist who sublies in the dynamics of interaction of the new technology with the traditional one: the penetration of the new technology improves also the quality of the Product A and as consequence of it, there is discouraged the penetration of the Product B. ¿Which is the efficient decision of penetration of the new technology in such a way that the monopolist reduces the cost of production with the traditional technology (process innovation) and simultaneously extracts more consumer surplus by quality improvements with the new technology (innovation of product)?

To solve this question there has appeared a problem of dynamic optimization solved in a dynamic game of two stages limited to a distribution market of electric power produced by a regular monopoly. The conventional technology corresponds then to the generation of energy produced by conventional plants long away from the centers of consumption whereas the new technology corresponds to Distributed Generation located nearby to the consumer.

In this work, it appears that depending on the preferences and the spatial distribution of the consumers, it is possible to find an efficient border of penetration of the new technology for both a social planner and the monopoly. One concludes that for the social planner, the penetration of the new technology is less invasive than for the monopoly since the improvement of the quality of the Product A (with a regulated price) allows to reduce the extraction of consuming surplus achieved across the Product B (free price). In both cases, it is convenient to stimulate the penetration of the new technology.

Key words: Technological Innovation, Process Innovation, Product Innovation, Natural Monopoly, Electric Power Distribution.

# 50. Rent Taxation for Nonrenewable Resources A Critical Review of the Literature

**Diderik Lund**

University of Oslo, Norway, October 30, 2008

diderik.lund@econ.uio.no

Abstract for the IAEE Latin American meeting, Santiago, Chile, March 2009

The paper is a critical review of the literature since 1975 on rent taxation of nonrenewable natural resources. Ideally, this literature builds on economic theory, includes uncertainty in models, explains important real-world phenomena, and leads to clear policy recommendations. Much of the literature falls short of the ideal. There are also conflicting assumptions on companies' behavior towards risk. Some studies assume risk aversion, while others assume that companies maximize market value.

Dasgupta and Heal (1979), chapter 12, introduce taxes in Hotelling-type models with endogenous resource prices. This has not been influential, in particular since it does not offer much in terms of policy advice. The results assume that identical taxes apply world-wide. Moreover, there is some evidence that Hotelling-type models do not explain prices very well. Also, there is no accepted equilibrium model which extends Hotelling to conditions of uncertainty.

The proposal of the Resource Rent Tax by Garnaut and Clunies Ross (1975) has been influential. The system is neutral under conditions of certainty. But to find the correct rate of interest accumulation at which to carry forward deductions is a problem. This has to do with the authorities' ignorance, but also with different conditions for different companies and projects. Under uncertainty this becomes more pronounced, in particular since bad outcomes mean that the full value of deductions will not be earned. Models from financial economics have been used to quantify the effects of insufficient loss offset, which may be substantial. Similar models have been applied in public economics since Fane (1987), who derived principles for neutral taxation under uncertainty.

Some studies discuss combinations of taxes and fixed fees set through auctions. Mead (1994) is a notable spokesperson for using auctions only, which has not gained widespread following outside the U.S.A. Leland (1978) is a seminal paper on combination with taxes. Implementation requires knowledge of risk aversion parameters for companies and governments.

With high tax rates the problem of transfer pricing, or more generally, income shifting, is exacerbated. In particular costs are difficult to monitor. Solutions based on principal-agent models or a combination of rent taxes and royalties are discussed.

Whether tax competition between countries should be a concern in this literature, is not obvious. After all, natural resources are often viewed as immobile. Multinational companies, and some researchers, claim that companies have unique resources which they will only apply where they get the highest rewards after tax.

# 51. Dynamic of biodiesel price's formation on Brazilian market

**Inessa L. Salomão, Maria Clara Lippi**

Inessa Salomão is MSc Production Engineer, Economist, Assistant Professor from GEOS/DEPRO/CEFET-RJ; Maria Clara Lippi is student at CEFET-RJ

Av. Maracanã, 229, Bloco E, DEPRO, Rio de Janeiro, Brazil, + 55 21 2566-3015, 8269-1041, Fax + 55 21 2566-3120, inessa2@gmail.com

Key Words: Brazilian Biodiesel market, price-cost dynamic, ANP auctions

ABSTRACT : The market of Biodiesel is still developing in Brazil. Biodiesel's price on Brazilian market is regulated. Legislation determines the binding blend, granting demand. The supply of biodiesel depends on the supply chain consolidation. Commercial prices are determined on the auctions promoted by National Agency of Petroleum, Natural Gas and Biofuels (ANP), from a reference price established by the agency. Moreover, the raw material (vegetable oil) supply is showing a behavior that depends on the prices of others markets that use vegetable oil as raw material too, oscillations.

This article analyzes the price-cost dynamics of biodiesel production on Brazilian market. The relation among price determination and institutional regulation model is assessed. And are observed the linkage between raw materials costs and the governmental politic that promotes the introduction of this combustible in national energetic matrix is assed – instituted on National Program of Production and Use of Biodiesel (PNPB) rules.

RESUMO: O mercado do biodiesel ainda está se desenvolvendo no Brasil. O preço do biodiesel no mercado brasileiro é regulado. A demanda é garantida pela legislação que determina o percentual de mistura obrigatória. A oferta do biodiesel depende da consolidação de sua cadeia produtiva. O preço de comercialização é determinado em leilões de venda promovidos pela ANP a partir de um preço de referência estabelecido por esta agência. Além disso, o fornecimento de matéria–prima (óleo vegetal) vem se mostrando dependente das oscilações dos preços praticados em outros mercados que também utilizam óleo vegetal como insumo.

Assim, este artigo analisa a dinâmica preço-custo da produção de biodiesel no mercado Brasileiro. Avalia-se a relação da formação de preço com o modelo institucional de regulação. E são observadas as relações entre o custo da matéria-prima e a política governamental de incentivo à introdução deste combustível na matriz energética nacional, instituída através das normas do Programa Nacional de Produção e Uso do Biodiesel (PNPB).

## 1.- Introdução

Em 2003, o governo federal brasileiro iniciou o Programa Nacional de Produção e Uso de Biodiesel (PNPB) visando à consolidação de uma nova cadeia produtiva, como estratégia para promover a redução da importação de diesel fóssil e o desenvolvimento regional. Após cinco anos desta iniciativa o mercado do biodiesel no Brasil começa a se consolidar.

Este artigo analisa a dinâmica de formação de preço do biodiesel comercializado nos leilões públicos, considerando o modelo institucional de regulação e a política de incentivo estabelecida pelo PNPB.

O artigo está organizado como se segue: a seção 2 discute a estratégia de introdução do biodiesel na matriz energética brasileira; a seção 3 apresenta as determinações formais de regulação para a cadeia de produção do biodiesel; a seção 4 analisa os primeiros resultados obtidos no leilões públicos ocorridos até 2008; na seção 5, são discutidos os elementos que influenciam a formação de preço; a seção 6 apresenta as considerações finais e aponta novos objetos para estudo e aprofundamento da questão.

## 2.- Introdução do Biodiesel na Matriz Energética Brasileira

O mercado brasileiro de biodiesel é muito recente e se encontra em franco desenvolvimento. Em todos os elos da cadeia produtiva existem oportunidades de negócio e lacunas não preenchidas, pois as próprias relações comerciais não estão completamente maduras e estabelecidas. O ano de 2005 é um marco histórico do início das operações desta cadeia, principalmente pelas definições que ocorreram quanto ao marco jurídico inicial de produção, à regulação da cadeia de biodiesel, e pela realização do primeiro leilão de B100 (diesel vegetal em 100% de volume) promovido pela Agência Nacional de Petróleo, Gás Natural e Biocombustíveis (ANP).

O aumento de oferta do biodiesel foi induzido pela garantia de demanda instituída pelo Programa Nacional de Produção e Uso de Biodiesel (PNPB). O governo brasileiro instituiu PNPB, como um programa interministerial, visando implementar a produção e o uso do Biodiesel de forma sustentável, técnica e economicamente, tendo como foco a inclusão social e o desenvolvimento regional, via geração de emprego e renda.

O PNPB foi concebido a partir de três principais diretrizes: a) implantar um programa sustentável, promovendo inclusão social; b) garantir preços competitivos, qualidade e suprimento; c) produzir o biodiesel a partir de diferentes fontes oleaginosas e em regiões diversas (CEIB, 2005).

O biodiesel, aqui tratado de forma genérica, não é um produto único, representa um produto de origem não fóssil, proveniente da transesterificação ou esterificação de óleos vegetais ou gorduras animais. A política brasileira não define ou privilegia qualquer rota tecnológica, permite o uso de diferentes tipos de óleos provenientes de fontes renováveis como matéria-prima: sejam óleos vegetais crus (soja, mamona, algodão, palma, girassol, amendoim, entre outros); sejam óleos vegetais de cozimento reutilizados; ou mesmo o sebo animal e as gorduras de esgoto.

O programa é voltado à inclusão social, tendo por objetivo a geração de trabalho e renda nas regiões mais pobres do país, introduzindo o agricultor familiar na cadeia de produção.

Em conjunto com o PNPB, o governo federal estabeleceu um cronograma para adoção de misturas de biodiesel ao diesel de petróleo por força de lei. Segundo a determinação do governo federal, o biodiesel foi introduzido na matriz energética brasileira, sendo fixada a meta de 5% em volume, o percentual mínimo obrigatório de *blend* comercializado ao consumidor final, em um período de 8 anos da data de publicação da Lei 11097 de 2005 (Brasil, 2005).

A mesma lei determinou metas intermediárias de mistura. Inicialmente, o *blend*, estabelecido em 2% (diesel B2), apresentava caráter autorizativo, tornando-se obrigatório a partir de janeiro de 2006. Em julho de 2008, a Resolução nº 2 do Conselho Nacional de Política Energética (CNPE) ampliou para 3% o volume mínimo obrigatório de biodiesel na mistura.

A determinação do volume obrigatório atua como um impulso ao crescimento da oferta, na medida em que garante um patamar mínimo de demanda que, para ser atendida, exige um aumento progressivo da capacidade instalada das usinas e da produção de matérias-primas, em médio prazo, induzindo a formação da cadeia produtiva. Favoravelmente a esta política, o crescimento autônomo da demanda pelo diesel, como combustível, também tem impacto positivo sobre a demanda pelo biodiesel. Para garantir a efetividade desta medida, a comercialização em território nacional da mistura está sujeita a fiscalização e aplicação de sanções baseadas nas normas de regulação, em caso de descumprimento da obrigatoriedade.

3.- Regulação da oferta

A cadeia produtiva do biodiesel tem como elo inicial o produtor de matéria-prima, seguido das usinas de transesterificação/produção do biodiesel. O biocombustível puro (B100) segue para o distribuidor monopsonista e deste para a comercialização, através de novos distribuidores e varejistas.

O produtor de matéria-prima é o fornecedor dos grãos e/ou do óleo vegetal que entrará no processo produtivo da usina. No Brasil, o mercado de matéria-prima apresenta uma estrutura concorrencial da qual fazem parte os produtores de oleaginosas em pequena escala, assim como os grandes agronegócios, os produtores de óleo vegetal, e os recicladores de óleo vegetal de cozimento, e outros fornecedores de gordura animal.

Já as usinas de produção de biodiesel se encontram em um mercado regulado. A ANP possui competências legais para regular e autorizar as atividades relacionadas à produção de biodiesel, que abrangem a construção, modificação, ampliação de capacidade, operação de planta produtora e a comercialização de biodiesel; condicionadas à prévia e expressa autorização. (BRASIL, 2005)

A partir da aceitação do pedido de autorização e da conclusão das obras, a firma requerente do registro de produtor deve solicitar à ANP a vistoria das instalações visando obter a Autorização para Operação. A partir da emissão do Laudo Técnico de Vistoria, e da aprovação das instalações industriais pela ANP, a Autorização para Operação é concedida.

É fato que muitos empreendimentos têm iniciado seus projetos de construção antes mesmo de iniciarem este processo de pedido de autorização junto à agência reguladora, porém a legislação é bastante restritiva quanto à entrada em operação e comercialização. As requerentes autorizadas para o exercício da atividade de operação de plantas produtoras de biodiesel somente poderão comercializar sua produção após a publicação da Autorização para Comercialização do biodiesel produzido, condicionada à comprovação de sua qualidade.

A comprovação da qualidade ocorre através do envio do Certificado de Qualidade do produto, contendo todas as características estabelecidas na especificação vigente (Resolução ANP n.º 7 de 19/03/2008), firmado pelo responsável técnico pelas análises laboratoriais efetivadas em laboratórios cadastrados junto à ANP. As firmas com produção voltada para o consumo próprio ou para fins de pesquisa são desobrigadas a solicitar Autorização para Comercialização (Brasil, 2008).

Durante a operação, cabe ao produtor de biodiesel enviar à ANP, mensalmente, informações sobre processamento, movimentação, estoque, discriminação de recebimento de entrega de matérias-primas e sobre produção, movimentação, estoque, discriminação de recebimento e entrega de produtos referentes à sua atividade (Resolução ANP n.º 17 de 31/08/2004). Cabe também, manter espaço de armazenamento de produto final acabado, compatível com, no mínimo, cinco dias de autonomia de produção, tendo como base a capacidade máxima de produção autorizada pela ANP (Brasil, 2004b).

Para que as autorizações concedidas ao produtor permaneçam em vigência, é necessário haver continuidade de produção por um período superior a doze meses e que sejam atendidos os requisitos de qualidade do produto e as recomendações técnicas para assegurar os aspectos relacionados à segurança operacional, saúde dos trabalhadores e prevenção dos impactos ao meio ambiente.

Aprovado o pedido de Autorização de Comercialização, o biodiesel só poderá ser comercializado com exportador, refinaria e central petroquímica autorizada pela ANP; ou com distribuidor autorizado de combustíveis líquidos derivados de petróleo, álcool combustível, biodiesel, mistura óleo diesel e biodiesel especificada ou autorizada pela ANP; e com o mercado externo - no caso do produtor estar autorizado ao exercício da atividade de exportação de biodiesel. Para atender ao percentual mínimo obrigatório de mistura do diesel mineral, a agência realiza Leilões Públicos para aquisição de biodiesel.

Por meio dos leilões, são implementados os procedimentos necessários para formação de estoques de biodiesel, com ênfase na garantia do suprimento deste combustível, e na proteção dos interesses dos consumidores quanto a preço, qualidade e oferta do produto, segundo a Resolução CNPE nº 7 (Brasil, 2007). Estão aptos a adquirir biodiesel nos leilões produtores de óleo diesel que possuem participação no mercado de diesel superior a 1%.

A cada leilão, do tipo reverso, é fixado o valor do preço máximo, cabendo aos produtores de biodiesel oferecer preços iguais ou abaixo daquele estabelecido pela agência. Os editais dos leilões determinam, ainda, os compradores de biodiesel autorizados, os requisitos para fornecimento pelos produtores e indicam as quantidades de combustível que serão adquiridos no lote. (Prates et alii, 2007).

Os produtores de óleo diesel, Petróleo Brasileiro S/A. – PETROBRAS e Alberto Pasqualini – REFAP S/A., compram biodiesel nos leilões com o intuito de formar estoque em volume (de acordo com suas participações no mercado) correspondente a, pelo menos, a demanda mensal desse produto para atendimento ao percentual de adição obrigatória ao óleo diesel. No Brasil, o principal produtor e importador de diesel é a Petrobras – empresa estatal de economia mista – que detém acima de 90% do mercado, atuando como comprador monopsonista nos leilões.

Nos leilões públicos, as usinas produtoras de biodiesel que possuem o Selo Combustível Social, possuem preferência para ofertar o combustível no primeiro lote de compra. Cada produtor autorizado realiza três ofertas por lance e os lotes com preços mais baixos são arrematados até que seja completado o volume total do leilão (ANP, 2008b). Os valores dos lances devem, obrigatoriamente, ser menores ou iguais ao preço FOB de referência estabelecido pela ANP, a fim de que haja maior competitividade entre os produtores e, conseqüentemente, menor preço para os compradores.

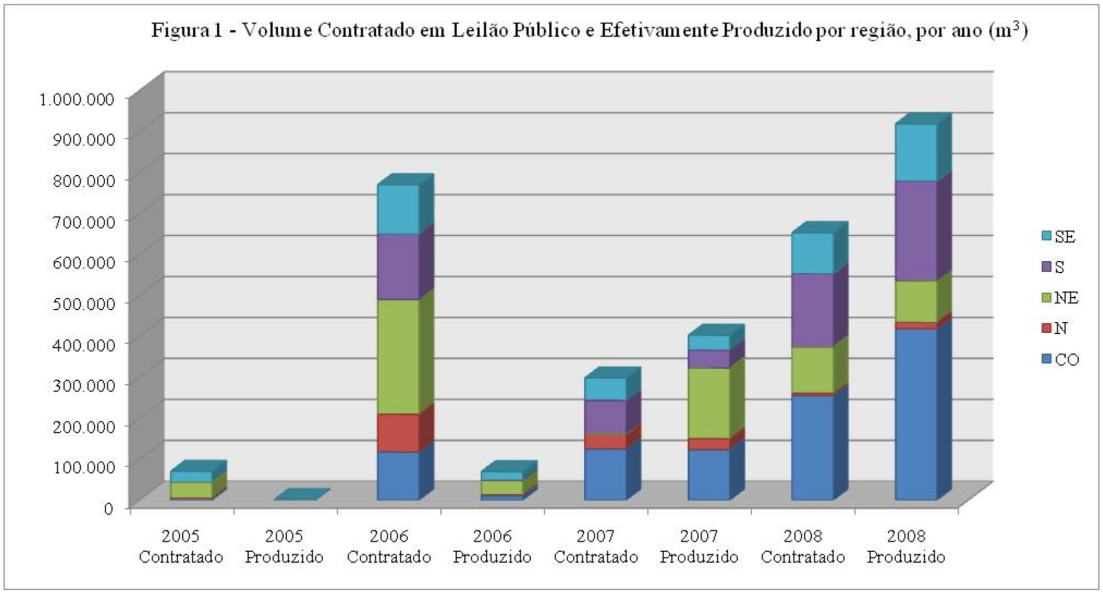
A distribuidora de combustíveis líquidos adquirente comercializa para as demais distribuidoras, que atuam no mercado nacional de combustíveis líquidos, a quantidade de B100 necessária para que todo diesel comercializado esteja dentro do estabelecido como mistura mínima obrigatória. O fornecimento dos pedidos mensais de diesel está condicionado à apresentação de documento formal que ateste a aquisição de biodiesel pelas distribuidoras em volume limitado às suas necessidades. Assim, o volume adquirido de biodiesel por distribuidor retalhista deverá ser compatível com sua participação no mercado de diesel – também regulado pela ANP.

A aquisição direta de biodiesel pelas distribuidoras para formação de estoque operacional, além das quantidades mínimas necessárias para a comercialização do B3, é permitida e regulada. Estas aquisições, suplementares não substituem o combustível adquirido em leilão. Isto é, não é permitido que seja adquirida quantidade menor do biodiesel de leilão que aquela que será comercializada regularmente no período. Caso isto ocorra, a distribuidora está sujeita às sanções legais. As aquisições suplementares já realizadas pela Petrobras ocorreram nos mesmos moldes dos leilões públicos, através de leilão reverso, mas utilizando como referência o preço CIF ( com o valor do frete incluído). (ANP, 2008a)

## 4.- Resultados dos leilões

O mercado do biodiesel começou a operar a partir da instituição do PNPB. No período compreendido entre os anos de 2005 e 2008 ocorreram 12 leilões públicos de biodiesel. No primeiro leilão, foram arrematados 70.000 $m^3$ e, no ano seguinte, 770.000 $m^3$.

Figura 1




Fonte: ANP, 2005; 2006 a, b, c; 2007 a, b, c; 2008 c, d, e, f, g.

A obrigatoriedade do B2, instituída pelo Decreto n.º 5297, iniciada a partir do dia 01/01/2006, gerou uma incrível demanda pelo combustível. No entanto, a oferta não acompanhou este crescimento. Em 2006, o volume de biodiesel contratado nos leilões foi 11 vezes maior do que o volume produzido no mesmo ano. Apesar do resultado positivo dos leilões e dos incentivos à produção oferecidos pelo governo federal, através de linhas de crédito para a construção de usinas e do financiamento de projetos agrícolas, em 2006, a produção total ficou muito abaixo das expectativas geradas pelo PNPB.

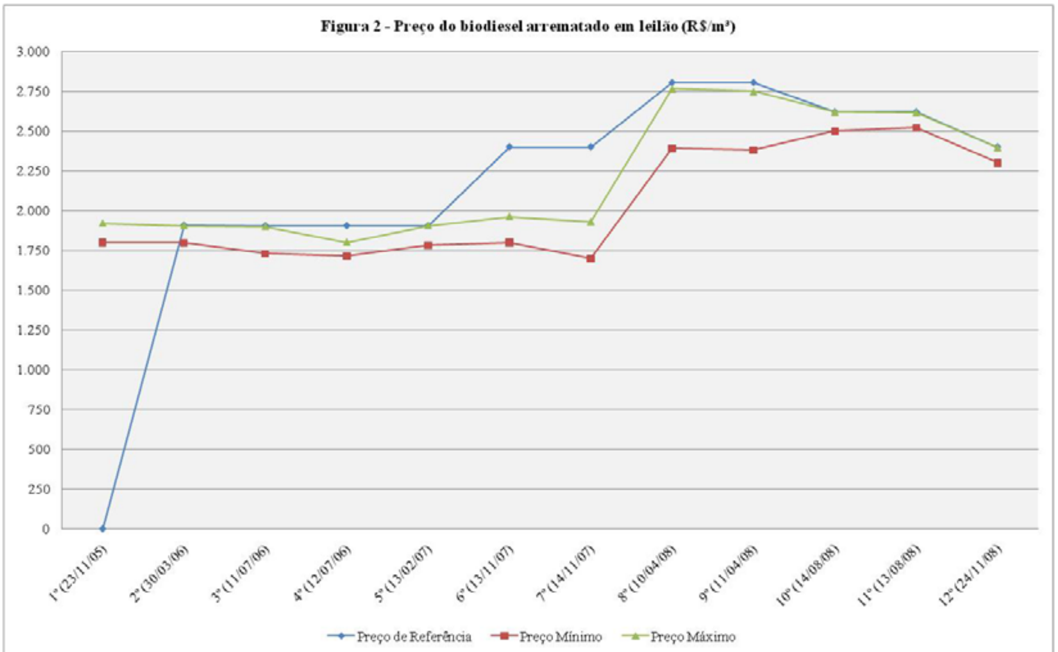
A maior parte dos contratos foi firmada com produtores do Nordeste e Semi-árido. E problemas ocorridos nos programas de plantio de mamona e de agricultura familiar impactaram negativamente o início da operação da cadeia. A produtividade não se confirmou e outros problemas logísticos e técnicos fizeram com que muitos contratos não fossem honrados.

A partir de 2007, a oferta passou a crescer com maior vigor e o volume de biodiesel produzido superou o volume contratado, estabilizando o mercado. Apesar da produção do Nordeste ter mantido o crescimento, o volume contratado nesta região diminuiu, assinalando a tendência, confirmada em 2008, de migração da oferta para outras regiões.

Em 2008, o patamar de contratação cresceu vigorosamente, apesar de não ter superado o volume atingido nos leilões de 2006. Este crescimento foi acompanhado pela expansão da oferta, desta vez baseada na cadeia produtiva, já estabelecida, da soja. O Centro-Oeste tornou-se o principal produtor de biodiesel, sendo responsável por aproximadamente 45% do total do volume produzido.

Embora a produção tenha crescido significativamente também nas regiões Sul e Sudeste, no Norte e Nordeste houve retração, conforme pode ser visto na figura 1.

Figura 2




Fonte: ANP, 2005; 2006 a, b, c; 2007 a, b, c; 2008 d, e, f, g, h.

No primeiro leilão realizado pela ANP não foi estabelecido um preço de referência. Nos demais leilões, onde foi estabelecido o preço de referência, os preços médios de contratação ficaram muito próximos ao teto estipulado, conforme mostra a figura 2. Nos leilões de 2007, os valores dos lances mantiveram o patamar dos leilões anteriores gerando o maior deságio do período, houve lotes arrematados a preços 29% mais baixos que o preço de referência. Em 2008, a tendência de alta apontada pelo preço de referência foi seguida de perto pelos produtores resultando em preços médios com deságio máximo de 15%. A ampliação do teto funcionou como mais um atrativo à ampliação da produção.

Segundo dados da ANP, até o ano de 2008, 71 produtores foram autorizados à produção de biodiesel no país, com capacidade nominal total em torno de 3,8 bilhões de $m^3$/ano, capacidade suficiente para atender à demanda de B5 do mercado nacional (ANP, 2009).

## 5.- Preço, custo e regulação

O leilão reverso permite que haja competitividade entre os diversos produtores a partir dos fatores qualidade e preço. Os critérios de qualidade são, principalmente, o cumprimento de contratos anteriores e a adequação do combustível fornecido às especificações técnicas exigidas. Estes critérios determinam que o produtor seja habilitado ou não para o leilão.

O produtor de biodiesel é um tomador de preços no mercado de seu produto, assim como na cadeia de suprimento de matéria-prima. O preço de venda, com teto determinado ex-ante, e a pulverização da oferta não permitem que haja grande influência sobre o preço FOB. Apesar de não haver notas oficiais da ANP que especifiquem as bases do preço de referência, é possível indicar que entre os principais fatores que podem interferir no preço máximo de leilão estão: o preço da matéria-prima, o custo com o processo de fabricação, o custo com a entrega e até quanto o comprador está disposto a pagar.

O valor do lance, portanto, é limitado pela posição do monopsonista por um lado, e pelos elementos de formação de preço por outro. O preço do produto é constituído pelo seu custo de fabricação, impostos sobre a venda, despesas e margem de lucro. Produtores com custos muito altos podem não conseguir vender seu produto, assim como a prática de preços muito baixos pode gerar margens de lucro muito apertadas, que tendem a ser nocivas à sustentabilidade do negócio. Para se manter competitivo o produtor deve buscar minimizar custos médios, a carga tributária, e manter uma margem de lucro conservadora próxima à de seus concorrentes. Isto é, deve adequar seus custos ao nível médio de preços praticados, que têm variado pouco nos leilões.

O principal fator de adequação de custos dos produtores é o suprimento de matéria-prima vis-à-vis a carga tributária determinada pelo PNPB. Considerando predeterminadas a estrutura produtiva e a rota tecnológica, a redução de custos do produtor individual recai sobre critérios operacionais muito influenciados pelo custo da matéria-prima.

O modelo brasileiro de regulação, através do Selo Combustível Social, visa equacionar disparidades regionais de desenvolvimento e permitir o ingresso do agricultor familiar na cadeia produtiva como fornecedor de matéria-prima. O governo federal oferece incentivo a uma parcela dos produtores no intuito de equiparar a competitividade entre os que contratam fornecimento de oleaginosas de pequenos agricultores, e aqueles que compram do agronegócio. Tais incentivos influenciam principalmente nos impostos, desta forma, a seleção da oleaginosa influencia fortemente a formação de preço, por impactar custos e tributos.

Aos produtores detentores do Selo Combustível Social é concedida prioridade nos leilões e redução de alíquotas de impostos - que pode chegar à isenção em determinados casos. Para manter a certificação do Selo, os produtores devem adquirir matéria-prima de agricultores familiares atendidos pelo PRONAF

(Programa Nacional de Agricultura Familiar), prestar-lhes assistência técnica, e estabelecer contratos de fornecimento claros.

A redução tributária varia conforme a região e a oleaginosa utilizada, e está condicionada à aquisição de um percentual mínimo de volume de matéria-prima, que corresponde a 50% na região Nordeste e Semi-árido; 10% nas regiões Norte e Centro-Oeste e, 30% nas regiões Sudeste e Sul (MDA, 2007). A redução de alíquota é aplicada ao lote produzido com a matéria-prima adquirida nos moldes descritos acima.

A legislação estabelece coeficiente de redução 0,775 sobre PIS/PASEP e COFINS para o biodiesel fabricado a partir de mamona ou fruto, caroço ou amêndoa de palma, e de 0,896, para o biodiesel fabricado a partir de matérias-primas adquiridas de agricultor familiar enquadrado no PRONAF (BRASIL, 2004a). Nas regiões Norte, Nordeste e Semi-árido, inicialmente a desoneração de tributos esteve atrelada à produção de biodiesel a partir da palma e da mamona. Uma nova regulamentação, decretada em 2008, permite a desoneração para quaisquer oleaginosas provenientes da agricultura familiar. Esta medida buscou minimizar os entraves logísticos e técnicos existentes, e ineficiências de escala, responsáveis pela elevação dos custos de matéria-prima proveniente da agricultura familiar, que reduziam sua competitividade.

Os produtores das regiões Norte e Centro-Oeste se beneficiam de reduções tributárias de menor magnitude, no entanto, estão menos sujeitos às ineficiências causadas pela introdução de oleaginosas na pauta da agricultura familiar. Enquanto no Nordeste e no Semi-árido, a isenção de tributos reduz os preços finais dos produtores significativamente, porém persistem entraves relacionados a gargalos logísticos e de produtividade. A estabilização do fornecimento de biodiesel, ocorrida a partir de 2008, reflete, em parte, a migração da produção contratada em leilão para o Centro-Oeste, e a afirmação da soja como principal matéria-prima devido à sua disponibilidade.

Segundo dados do Ministério de Minas e Energia (MME), a produção histórica da soja superou a dos demais óleos vegetais significativamente durante os últimos trinta anos. A soja é uma matéria-prima cuja cadeia produtiva encontra-se madura, e com disponibilidade de excedentes que permitem fornecimento contínuo. As demais oleaginosas com participação significativa na produção de biodiesel provêm de cadeias produtivas tradicionais que já têm destino para seu produto, e disponibilidade significativamente menor.

Apesar de ter ocorrido avanço dos principais óleos vegetais produzidos no país – algodão, amendoim, girassol e mamona – a produção atual não é suficiente para atender a demanda para a produção do biodiesel (MME, 2008). O produtor tradicional de oleaginosas e de óleo vegetal tem a opção de arbitrar entre fornecer para o produtor de biodiesel ou exportar.

Este é um modelo muito parecido com o caso da indústria sucroalcooleira no país que, na década de 1980, levou à ruptura do abastecimento de etanol. A depender das cotações internacionais do preço do açúcar, uma commodity assim como as oleaginosas e seus derivados, as usinas produzem quantidade maior ou menor de álcool combustível, regulando seu nível de produção, estoque e preço.

Da mesma forma, na indústria do biodiesel, quando há queda na cotação das oleaginosas e do óleo, o fornecedor de matéria-prima tem a possibilidade de regular seus estoques desviando parte de sua produção para a cadeia do biodiesel, agindo de forma inversa na alta. Assim, o custo da matéria-prima e a regularidade de seu fornecimento estão atrelados ao mercado internacional de commodities o que pode gerar descontinuidade de fornecimento.

Os incentivos legais fomentaram nos últimos anos o interesse dos produtores de biodiesel pelo Selo, uma vez que isso garantiria menores preços finais, e maior competitividade aos seus produtos. No entanto, estas vantagens podem não ser suficientes se consideradas as ações de arbitragem ocorridas dentro de cadeias tradicionais e as ineficiências inerentes à agricultura familiar, que oferecem risco de ruptura de estoque de matéria-prima, e dada a liquidez e abundância da soja.

Em termos da indústria, o risco de desabastecimento é muito baixo. A legislação impõe flexibilidade sobre os níveis de mistura, pois permite ao CNPE reduzir a quantidade de biodiesel adicionado ao diesel em caso de escassez de matéria-prima para que não haja ruptura de abastecimento.

Considerando que os contratos de suprimento devem ocorrer anteriormente ao lance para que o produtor faça jus ao Selo, a dinâmica preço-custo depende dos níveis de custo gerados pelas várias alternativas, e de escolhas intertemporais que devem considerar em que medida a redução de tributo compensa os riscos de ruptura de fornecimento.

6.- Considerações finais

A introdução do biodiesel na matriz energética brasileira criou uma nova cadeia de produção. No modelo adotado, a demanda tem papel fundamental ao fomentar o desenvolvimento do elo produtivo da cadeia.

As análises preliminares desta política pública mostram que o mercado inicialmente incipiente respondeu com rapidez e vigor às pressões de demanda. No entanto, as relações comerciais da cadeia de suprimentos ainda precisam amadurecer.

As relações comerciais em conjunto com o modelo de regulação e o marco jurídico-fiscal são os principais fatores que influenciam a dinâmica de formação de preço para os leilões. Pois todos impactam diretamente o custo do produto e a margem de lucro do produtor.

A estabilização do mercado a partir da migração para a soja, como principal matéria-prima, não impede que se mantenha o modelo de desenvolvimento regional baseado na agricultura familiar preconizado pelo PNPB. No entanto, o produtor sujeito às regras do leilão reverso busca minimizar seus custos para ampliar a margem de lucro, o que depende das decisões operacionais de curto prazo.

A queda de custos, em longo prazo, deverá ocorrer na medida em que surgirem oleaginosas energeticamente mais eficientes, em escala que garanta a continuidade de suprimento e com preços competitivos em relação à soja. Por outro lado, a rápida expansão da capacidade produtiva pode exercer ainda maior pressão sobre a margem, se houver queda de preços ocasionada por excesso de oferta de biodiesel no mercado.

É importante avaliar mais detidamente estes e outros alguns aspectos. O mercado de biodiesel no Brasil ainda é muito recente, as tendências apresentadas são de curto prazo e precisam ser avaliadas ao longo do tempo. Devem ser aprofundados os estudos quanto ao reflexo desta dinâmica sobre o preço ao consumidor final e sobre a margem de lucro setorial; e quantificados os impactos das oscilações das commodities, da influência das diversas rotas tecnológicas sobre o preço.

7.- Referências

ANP (Agência Nacional de Petróleo, Gás Natural e Biocombustíveis), *Aquisição direta de biodiesel para formação de estoque operacional*, 2008a. Disponível em: http://www.anp.gov.br/petro/aquisicao_biodiesel.asp Acessado em 26/12/2008.

_____, *Capacidade Autorizada*, 2009. Disponível em: http://www.anp.gov.br/biocombustiveis/capacidade_plantas.asp Acessado em 03/01/2009.

_____, *Edital de Pregão*, 2008b. Disponível em: http://www.anp.gov.br/doc/biodiesel/Edital_Pregao_48_08_ANP.pdf Acessado em 10/10/2008.

_____, *Resultado do 1o. Leilão de Biodiesel*, Brasília, 2005

_____, *Resultado do 2o. Leilão de Biodiesel*, Brasília, 2006 a

_____, *Resultado do 3o. Leilão de Biodiesel*, Brasília, 2006 b

_____, *Resultado do 4o. Leilão de Biodiesel*, Brasília, 2006 c

_____, *Resultado do 5o. Leilão de Biodiesel*, Brasília, 2007 a

_____, *Resultado do 6o. Leilão de Biodiesel*, Brasília, 2007 b

_____, *Resultado do 7o. Leilão de Biodiesel*, Brasília, 2007 c

_____, *Produção de Biodiesel – B100 por Produtor* , Brasília, 2008 c

_____, *Resultado do 8o. Leilão de Biodiesel*, Brasília, 2008 d

_____, *Resultado do 9o. Leilão de Biodiesel*, Brasília, 2008 e

_____, *Resultado do 10o. Leilão de Biodiesel*, Brasília, 2008 f

_____, *Resultado do 11o. Leilão de Biodiesel*, Brasília, 2008 g

_____, *Resultado do 12o. Leilão de Biodiesel*, Brasília, 2008 h

BRASIL, ***Decreto Nº 5.297 de 6 de dezembro de 2004*.** Dispõe sobre os coeficientes de redução das alíquotas da Contribuição para o PIS/PASEP e da COFINS incidentes na produção e na comercialização de biodiesel, sobre os termos e as condições para a utilização das alíquotas diferenciadas, e dá outras providências, Diário Oficial [da República Federativa do Brasil], Brasília, 2004a.

________, *Lei n.º 11.097, de 13 de janeiro de 2005*. Dispõe sobre a introdução do biodiesel na matriz energética brasileira; altera as Leis nºˢ 9.478, de 6 de agosto de 1997, 9.847, de 26 de outubro de 1999 e 10.636, de 30 de dezembro de 2002; e dá outras providências. Diário Oficial [da República Federativa do Brasil], Brasília, 2005.

________, *Resolução ANP n.º 7*, de 19 de março de 2008. Diário Oficial [da República Federativa do Brasil], Brasília, 2008.

________, *Resolução ANP n.º 17*, de 31 de agosto de 2004. Diário Oficial [da República Federativa do Brasil], Brasília, 2004b.

________, *Resolução CNPA n.º 7*, de 05 de dezembro de 2007. Diário Oficial [da República Federativa do Brasil], Brasília, 2007.

CEIB (Comissão Executiva Interministerial), *Programa Nacional de Produção e Uso do Biodiesel*, Brasília, 2005. Disponível em www.biodiesel.gov.br , Acesso em 15/11/2006

MDA (Ministério do Desenvolvimento Agrário), *Biodiesel no Braisl: Resultados socioeconômicos e expectativa futura*, 2007. www.mda.gov.br/saf/arquivos/0705113220.doc Acesso em: 23/08/2007

MME (Ministério de Minas e Energia), *Boletim Mensal dos Combustíveis Renováveis*, Brasília, n.8, agosto. 2008.

Prates, C.P.T., Pierobon, E.C., Costa, R.C., *Formação do Mercado de Biodiesel no Brasil*, BNDES Setorial, Rio de Janeiro, n. 25, p. 39-64, mar. 2007.

# 52. Evaluación Costo-Beneficio del Uso de Colectores Solares como Alternativa Energética en Hospitales

**Verónica Kunze y Alberto Pizarro Chañilao**

(versión preliminar)

Departamento de Economía

Universidad de Chile

RESUMEN[191]

Este paper tiene como finalidad, realizar un análisis costo-beneficio de la utilización de colectores solares en el Hospital de Urgencia y Asistencia Pública "Dr. Alejandro del Río", más conocido como la "Posta Central", ubicado en la Región Metropolitana. Como resultado, se obtuvo un VAN de $ $1.098.266.059, lo cual hace altamente rentable invertir en este tipo de tecnologías limpias.

Además de los significativos beneficios económicos logrados con el uso de esta tecnología, que permiten recuperar la inversión al cabo de 2,5 años, se suman los beneficios ambientales producto de la disminución de las emisiones contaminantes, logrando por ejemplo, disminuciones del orden de 132,33 toneladas de CO2 al año.

Lo anteriormente descrito, abre posibilidades de transformar iniciativas de este tipo en un proyecto de MDL (mecanismo de desarrollo limpio) con lo cual se podrían vender certificados de reducción de emisiones (CRE), generando con esto recursos que harían al proyecto más rentable, y por lo tanto, viable de realizar.

Palabras claves: paneles solares, análisis costo-beneficio

---

[191] Agradecemos la información facilitada por Carlos Infante de GEOSOLAR y Miguel Sánchez, profesional jefe de equipos industriales, del departamento de recursos físicos del hospital de urgencia asistencia pública, Dr. Alejandro del Río por Fuente: GEOSOLAR

ABSTRACT

This paper aims to conduct a cost-benefit analysis of the use of solar collectors in the Emergency and Public Assistance Hospital “Dr. Alejandro del Río”, better known as “Posta Central”, located in the Metropolitan Region, Chile. As a result, we obtained a NPV of $ $ 1,098,266,059, which makes it highly profitable to invest in this type of clean technologies.

In addition to the significant economic benefits achieved with the use of this technology, which allow to recover the investment within 2,5 years, we have to consider the environmental benefits given by the reduction of pollutant emissions, having for example a reduction of about 132,33 tonnes of $CO_2$ a year.

As described above, it opens possibilities of transforming initiatives of this type in a CDM project (Clean Development Mechanism) which would allow to sell certificates of reduction in emissions (CRE), which would provide resources that would make the project even more profitable, and therefore feasible to achieve.

Key words: solar panels, cost-benefit analysis

## INTRODUCCIÓN

La evolución del ser humano ha requerido crecientes cantidades de energía, las cuales empezaron a crecer aceleradamente luego de la revolución industrial iniciada hace ya más de 200 años. En este proceso, es que surge el petróleo a fines del siglo XIX, transformándose en el responsable de buena parte del desarrollo económico y del cambio en los hábitos de vida de nuestra sociedad.

Pero ésta herramienta que nos ha generado tanto bienestar, también nos ha hecho altamente vulnerables y dependientes, lo cual quedó en evidencia por primera vez en la crisis del petróleo de los años setenta. Lo anterior se ha convertido en algo aún más preocupante, luego que se ha confirmado un estancamiento en el descubrimiento de nuevos yacimientos, lo que trae como consecuencia una gran incertidumbre respecto a las reservas de combustibles fósiles con que podemos contar para mantener el estándar de vida moderno.

Este panorama requiere medidas urgentes para suplir los requerimientos energéticos y poder de esta forma mantener los niveles de vida como la conocemos hoy, lo cual implica diversificar la matriz energética y buscar alternativas que sean en lo posible renovables, con el fin de asegurar la sustentabilidad.

A la incertidumbre en la provisión de combustibles fósiles, es necesario agregar el daño que su uso genera en el medioambiente producto de las emisiones de dióxido de carbono y otros gases de efecto invernadero, lo cual ha sido ampliamente debatido en los últimos años, producto de la evidencia que existe respecto a la responsabilidad humana en el "cambio climático".

Todo lo anterior ha provocado que el tema energético y el medio ambiente se transformen en dos ejes de la política mundial y nacional, lo que implica la necesidad de generar políticas públicas que ayuden a resolver la encrucijada en que nos encontramos.

A lo anterior hay que sumarle, en el caso particular de Chile, el hecho de que las reservas de combustibles fósiles son escasas, lo cual queda en evidencia si se considera que se importa gran parte del petróleo y del gas natural que se consume, lo que nos trasforma en un país especialmente vulnerable a los vaivenes en la producción, y porque no decirlo de la estabilidad política de nuestros proveedores.

Una alternativa viable, pero que requiere de un fuerte compromiso y visión estratégica de parte del Estado, es fomentar el desarrollo y utilización de las energías renovables no convencionales (ERNC), entre las que se cuentan la geotérmica, biomasa, mareomotriz, eólica, solar fotovoltaica y solar térmica, entre otras.

Esta opción es especialmente válida en Chile, pues nuestro país cuenta con enormes potencialidades en el uso de ERNC, debido a sus particulares características geográficas y climáticas, lo cual nos transforma en un potencial usuario de este tipo de energías con un gran campo por desarrollar en la investigación y aplicación de este tipo de tecnologías.

Al respecto, ya se han tomado medidas que van en esa dirección, pues a inicios del mes de Octubre de 2008 el gobierno anunció que se subsidiará[192], vía franquicia tributaria, la instalación de colectores solares para producir agua caliente en las viviendas nuevas, encontrándose en estudio el porcentaje de este subsidio dependiendo del valor de los inmuebles.

Considerando lo anteriormente descrito, y siguiendo esta misma línea en el sentido de que el Estado debe asumir un rol protagónico en el fomento de este tipo de tecnologías, es que este paper tiene por objeto explorar el uso de colectores solares en edificios públicos, más específicamente en hospitales, debido a que por sus características de funcionamiento, requiere de grandes cantidades de agua caliente en forma continua.

Para evaluar la conveniencia de implementar este tipo de tecnología, se propone hacer un análisis costo-beneficio que contemple los ahorros monetarios, además de considerar el impacto en la disminución de las emisiones de dióxido de carbono. Con la disminución de contaminantes esta iniciativa puede ser susceptible de transformarse en un proyecto de MDL (mecanismo de desarrollo limpio) con lo cual se podrían vender certificados de reducción de emisiones (CRE), generando con esto recursos que harían al proyecto más rentable, y por lo tanto, viable de realizar.

## IDENTIFICACIÓN DEL PROBLEMA

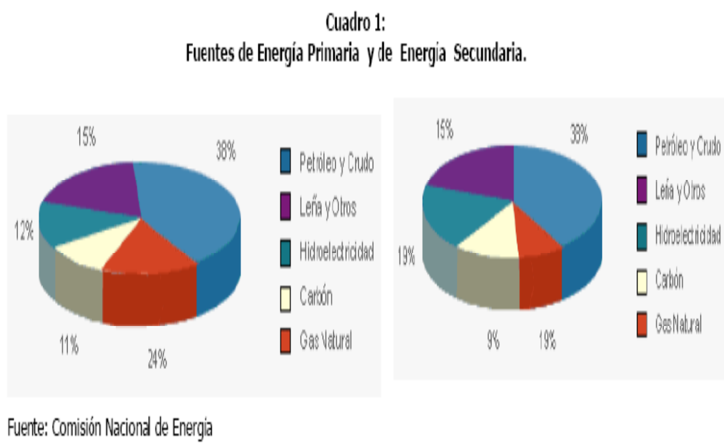
La crisis de abastecimiento energético en Chile y, particularmente, la vulnerabilidad que se evidencia en el sector eléctrico, muestran con claridad los factores de inseguridad y las falencias de la política energética desarrollada históricamente. Además, el año pasado se hizo evidente la falta de gas natural no solo para la generación eléctrica y usos industriales, sino también para uso doméstico.

[192] www.latercera.cl

A continuación se mencionan algunas causas de la vulnerabilidad energética en Chile, las cuales corresponden a:

Excesiva dependencia de combustibles externos. Ello es evidente en el caso del petróleo y lo es también en el caso del gas natural. Hoy, tanto la matriz primaria como secundaria muestran niveles sobre 70% de dependencia externa, lo cual se puede apreciar con más detalle en los siguientes gráficos.

Gráfico 1. Fuentes de energía primaria y secundaria (2008)[193].




Se denomina energía primaria a los recursos naturales disponibles en forma directa o indirecta para su uso energético. Se consideran cinco productos primarios: petróleo, gas natural, carbón, hidroelectricidad y biomasa (leña y derivados). No se consideran otros tipos de energía (geotérmica, eólica, nuclear, solar y otras) ya que estos no se han desarrollado en el país o se encuentran en etapa experimental, a excepción de la energía solar, usada marginalmente en el sector residencial e industrial.

A su vez, se denomina energía secundaria al conjunto de productos energéticos disponibles en forma apta para su utilización final. Se consideran 19 productos secundarios: Petróleos Combustibles, Petróleo Diesel, Gasolina 93, 95 y 97 octanos, Kerosene, Gas Licuado , Gasolina de Aviación, Kerosene de Aviación, Gas de Refinería, Electricidad, Carbón, Coke y Alquitrán, Gas Corriente, Gas de Altos Hornos, Gas Natural, Metanol, Leña y Otros.

Analizando las cifras presentadas cobra especial relevancia la diversificación de la matriz energética, donde las energías renovables no convencionales (ERNC) debieran cumplir un rol fundamental.

Vulnerabilidad eléctrica, expresada inicialmente por excesiva dependencia de la hidroelectricidad. En este punto cabe señalar, que la crisis energética sufrida por el país en los años 80 y 90, fue provocada por prolongados períodos de sequía, trayendo consigo racionamientos de electricidad. Con el fin de resolver ésta situación, el gobierno de la época tomó la determinación de negociar con Argentina el aprovisionamiento de gas natural, lo cual funcionó relativamente bien hasta hace unos años, en los que la producción de gas del país vecino se

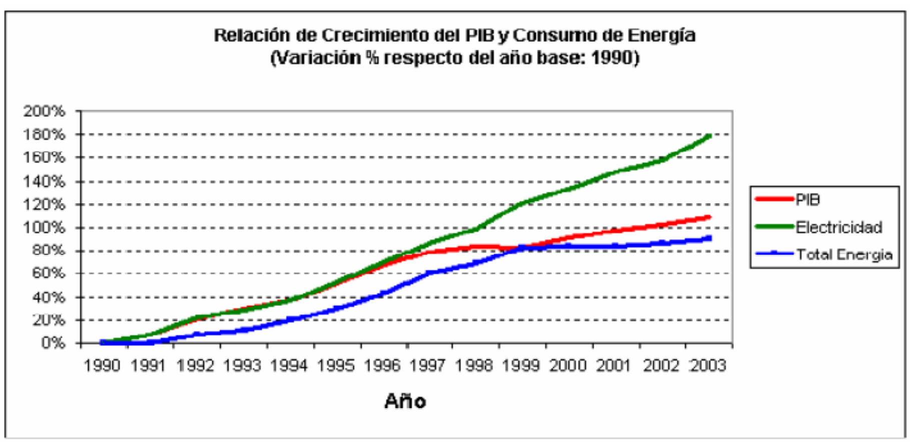
[193] www.cne.cl

estancó, y hubo un aumento sostenido del consumo interno, producto de una política de fijación de precios del gobierno Argentino que ha mantenido artificialmente bajo el valor del gas natural, lo que a su vez ha impedido la inversión en prospección y desarrollo de nuevos proyectos de extracción. Todo lo anterior provocó la "crisis del gas" que tuvo su momento más álgido el año 2007.

Ineficiencia energética. Chile es un país intensivo en uso de energía, es decir, el crecimiento energético es superior al crecimiento económico, lo cual se explica debido a que la economía del país está basada en la explotación de recursos naturales altamente demandantes de energía (minería principalmente), además del uso ineficiente de ésta. Lo anterior se puede apreciar en la siguiente figura.

Figura 1. Relación crecimiento del PIB y de la demanda energética en Chile (1990 al 2003)[194]

Figura 1. Relación crecimiento del PIB y de la demanda energética en Chile




Fuente: Comisión Nacional de Energía CNE

Rol secundario del Estado: Este ha sido un factor fundamental para explicar la vulnerabilidad energética de Chile y la razón final de la crisis de nuestra política energética. Lo anterior se inició con la liberalización de la economía en los años 70, en la que el Estado fue relegado por el mercado, en el supuesto de que este

[194] www.cne.cl

por si solo resolvería la crisis por la que atravesaba el país, lo cual en cierta medida ocurrió, pues el desempeño macroeconómico de Chile mejoró notablemente, exhibiéndose niveles de crecimiento económico por sobre la media mundial a partir de mediados de los años 80.

Sin embargo, este razonamiento no considera las llamadas fallas de mercado, entre las que se cuentan los mercados no competitivos, donde el Estado debe cumplir una función regulatoria. Respecto a esto último, en Chile existe una excesiva concentración de la gestión energética en pocos actores privados, lo cual ha quedado de manifiesto en el último tiempo, donde producto del debate por la construcción de las centrales hidroeléctricas de Aysén, se ha difundido que Endesa y Colbún concentran más del 70% de la generación eléctrica del sistema interconectado central (SIC). Esto es un elemento preocupante, ya que esto deja de manifiesto la poca maniobrabilidad del Estado para planificar u orientar la política energética, pues estas empresas además de controlar gran parte de la producción también lo hacen con la distribución, lo cual ejerce presiones que evitan el fomento y búsqueda de nuevas fuentes energéticas, que pudieran aportar al SIC (problema que quedó en evidencia con la tramitación de las leyes cortas I y II del Ministerio de Minería y Energía, ahora separados).

Adicionalmente, y según lo señalado por la Comisión Nacional de Energía se puede agregar que la dependencia energética de Chile se resume de la siguiente manera:

Tabla 1. Balance de energía primaria (cifras en teracalorías, 2007)[195]

| ENERGÉTICO | PRODUCCIÓN BRUTA | IMPORTACIÓN | EXPORTACIÓN | V. STOCK + PERD + CIERRE | CONSUMO BRUTO (1) |
|---|---|---|---|---|---|
| PETRÓLEO CRUDO (2) | 1.347 | 109.631 | 0 | 4.822 | 106.155 |
| GAS NATURAL (3) | 19.282 | 25.997 | 0 | 2.561 | 42.718 |

[195] www.cne.cl

| | | | | | |
|---|---|---|---|---|---|
| CARBÓN | 1.700 | 41.015 | 0 | 1.854 | 40.861 |
| HIDROELECTRICIDAD (4) | 19.604 | 0 | 0 | 28 | 19.576 |
| LEÑA Y OTROS (5) | 49.841 | 0 | 0 | 0 | 49.841 |
| TOTAL | 91.775 | 176.643 | 0 | 9.266 | 259.152 |

(1) Consumo Bruto = Producción Bruta + Importaciones -Exportaciones - Variación de Stock.

Representa la disponibilidad de energéticos primarios a la entrada de los Centros de Transformación.

(2) Producción Bruta Petróleo = Produccion Isla + Producción Continente + Producción Costa afuera = 607 + 371 + 370 =1.347

(3) Producción Bruta Gas Natural= Producción total - Reinyecciones = 19.282 - 0 = 19.282

Cierre : Gas lift + Gas quemado = 775 + 1786 = 2.561

Gas Absorbido (Diferencia Gas Primario y Secundario ) = 543.

(4) Cuadro generado con metodología Internacional de Balances de Energía, que utiliza el factor de conversión para la hidroelectricidad equivalente a 860 Kcal/Kwh.

(5) Otros incluye biogas, energía eólica y otros.

Fuente: Encuestas Balance de Energía a Empresas del Sector.

Elaboración: CNE (Septiembre, 2008)

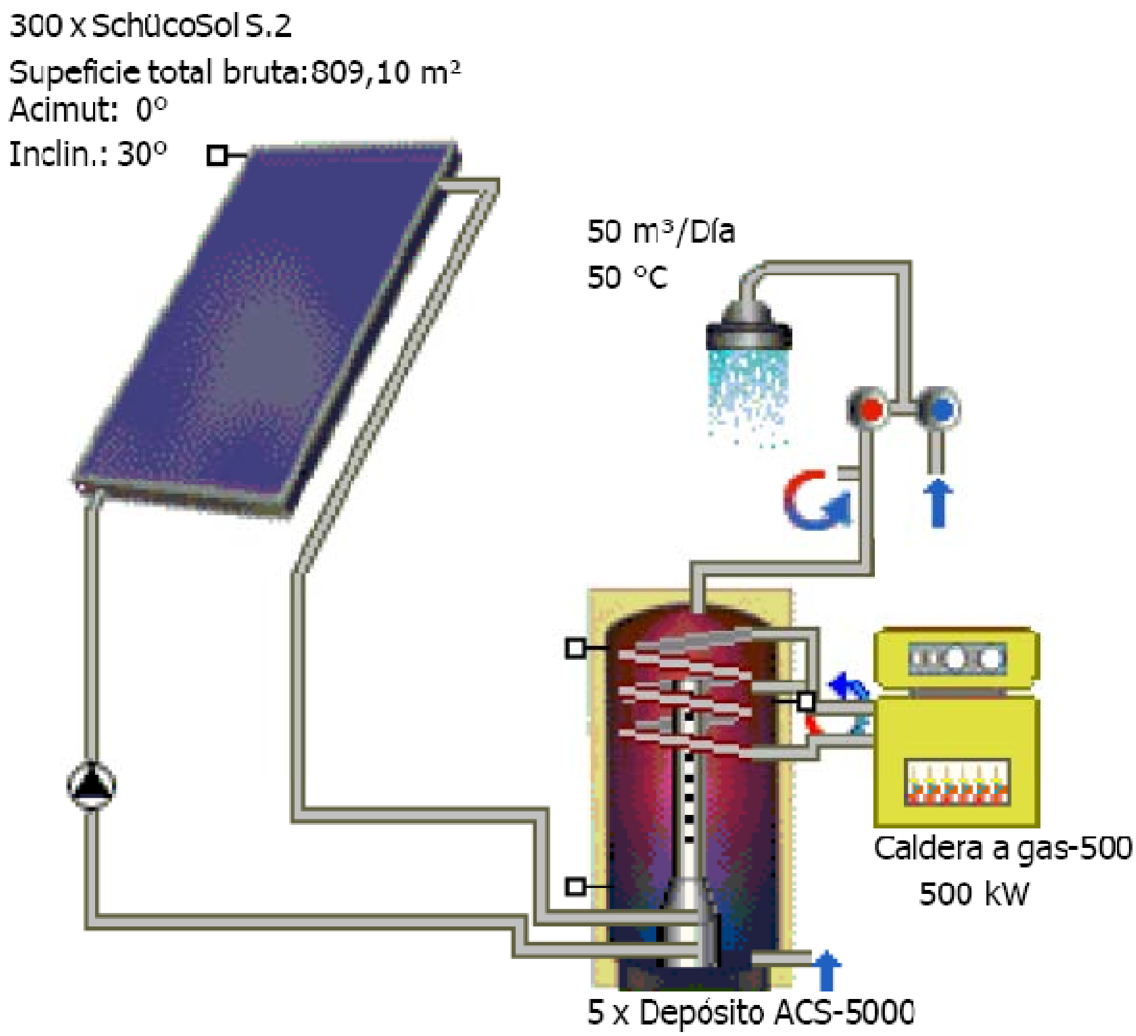
De lo anterior se desprende la alta dependencia energética de nuestro país, debido a que se importa gran parte de los combustibles más requeridos, no existiendo posibilidades que esto cambie en el corto o mediano plazo, aún cuando existe evidencia de yacimientos de gas natural en ciertas zonas de la costa chilena, pero con el inconveniente de que aún no existe la tecnología que haga viable la realización de un proyecto de explotación.

## PROPUESTA DE POLÍTICA PÚBLICA

Considerando lo expuesto en párrafos anteriores, es que se propone implementar una política pública que contribuya a disminuir la dependencia energética de Chile, además de aportar a la disminución de emisiones contaminantes por combustión de combustibles fósiles, a través del establecimiento de colectores solares. El ejercicio que se realizó en este artículo considera un "hospital tipo", ejemplificado en este caso con el Hospital de Urgencia y Asistencia Pública "Dr. Alejandro del Río", más conocido como la "Posta Central", ubicado en la Región Metropolitana. Es importante hacer esta distinción, pues los cálculos incorporan la variable radiación, la cual está relacionada al área geográfica del país en que nos encontremos.

Se considera para estos efectos un sistema de calentamiento de agua que funciona en base a energía solar con acumulador. El funcionamiento del sistema, se basa en el movimiento del fluido del colector al estanque por la parte superior y del estanque al colector por la parte inferior, causado por el principio de convección natural en que los fluidos más calientes, y por lo tanto más livianos, circulan libremente hacia arriba mientras que los más pesados tienden a bajar. Este sistema de circulación natural es conocido como Termo Sifón.

FIGURA 2. Configuración del sistema solar con respaldo.




Fuente: GEOSOLAR

La variable que define el comportamiento del sistema es la cantidad de radiación solar, de acuerdo a esto se tienen los siguientes escenarios:

Radiación solar acentuada: La superficie colectora es capaz de calentar la totalidad del fluido requerido a la temperatura final deseada.

Radiación solar moderada: La superficie colectora calienta una parte o la totalidad del fluido requerido a una temperatura menor que la necesaria. El calor que falta entregarle al fluido para que alcance la temperatura final es suministrado por un respaldo a gas. El equipo de respaldo aporta sólo la cantidad de calor necesaria para subir la temperatura a los grados deseados.

Radiación solar escasa: Casi la totalidad del fluido es elevado de temperatura mediante el calentador automático, esperando que exista mayor radiación solar en el lugar.

Dado que se trata de una aplicación de baja temperatura se está considerando un colector plano con buenas características técnicas y de construcción, y que no implique una inversión elevada.

Una instalación solar como la concebida, y que contempla la instalación de 300 colectores solares de 2 metros cuadrados de superficie aproximadamente cada uno, además de los estanques acumuladores correspondientes, se podría instalar en la superficie techada del hospital, donde existe el espacio y una estructura que la soporte.

## 3.1 Antecedentes y acciones de implementación

Con el fin de asegurar la implementación de ésta política pública, sería conveniente involucrar a los parlamentarios comprometidos con causas medioambientales, aprovechando que ésta iniciativa además de promover el ahorro energético, con los consiguientes beneficios económicos para el país, representa una potente señal de que el gobierno está comprometido con el medioambiente y la campaña mundial que existe relativa al cambio climático.

Lo anterior además, está en la misma línea del anuncio expresado por el Ministro de Energía Marcelo Tokman, quién dio a conocer los alcances del proyecto de ley que entrega una franquicia tributaria, que va entre un 20% a un 100% del valor del sistema solar térmico, a la instalación de dichos sistemas en viviendas nuevas, el que entrará próximamente al Congreso.

La iniciativa legal establece un crédito tributario para financiar sistemas solares térmicos (colectores solares), que sirvan para abastecer de agua potable sanitaria calentada con este tipo de energía a viviendas nuevas de hasta 4.500 UF, abaratando así la instalación de estos sistemas en los hogares de las familias de menores ingresos y de la clase media.

El ministro de Energía indicó que esto "tendrá un efecto doblemente positivo, ya que no sólo apunta al desarrollo de una fuente de energía renovable y de bajo costo, sino que también reducirá el gasto en gas de las familias, disminuyendo la dependencia de ese combustible, lo que redundará en una menor inflación y en una promoción del crecimiento económico"[196].

Además, el ministro señaló que podrán acceder a este beneficio las viviendas nuevas de hasta 4.500 UF. Las casas y departamentos cuyo valor no exceda de 2.000 UF recibirán un beneficio equivalente a la totalidad del valor del respectivo sistema solar térmico y su instalación, porcentaje que cambiará a medida que aumente el valor de la vivienda.

Esta franquicia tributaria tendrá un vigencia de cinco años, plazo en que se espera una desarrollo masivo del mercado de los colectores solares, con el consiguiente aumento en la oferta. Esto deberá ir asociado a un programa de capacitación de instaladores y servicio integral para terminar eventualmente con sistema de certificación como ocurre con otros combustibles como el gas, electricidad y recientemente la leña.

Lo anterior sin duda alguna permitirá que el uso de la energía solar se masifique, lo que generará una disminución en los costos de los equipos, haciendo más rentable su implementación en el futuro, contribuyendo con esto a la obtención de significativos ahorros por concepto de energía para el país, además de innegables beneficios para el medioambiente. Si bien es cierto que las descargas contaminantes de la combustión del gas licuado son menores a la leña o el petróleo, estas también contribuyen con gases de efecto invernadero y contaminación del aire que respiramos.

## 3.2 Características del sistema de salud público en Chile

Según datos obtenidos del ministerio de salud[197], la superficie construida en Chile equivale a 1.520.310 metros cuadrados, existiendo 183 hospitales a nivel nacional, los cuales tienen la siguiente distribución:

59 de alta complejidad

24 de mediana complejidad

100 de baja complejidad.

---

196 www.latercera.cl
197 www.minsal.cl

Cabe destacar, que el total de camas disponibles corresponde a 26.372. Este es un dato relevante si se considera que existen estimaciones realizadas por la Corporación de Desarrollo Tecnológico de la Cámara Chilena de la Construcción del año 2007, que señalan un requerimiento de agua caliente promedio entre 80 y 100 litros diarios por cama, lo cual nos arroja cifras de al menos 2 millones de litros de agua caliente requeridas diariamente. Esto involucra recursos económicos cuantiosos que podrían verse aminorados significativamente de implementarse alternativas de ERNC, como los colectores solares.

Adicionalmente, existen 1.803 establecimientos de atención primaria de salud, los cuales si bien es cierto no cuentan con camas para hospitalización, requieren igualmente grandes cantidades de agua caliente para las labores propias del servicio y para calefacción.

Debido a la diversidad de tamaños y requerimientos de cada uno de los establecimientos de salud, a continuación se realiza un análisis para un “hospital tipo”, con requerimientos de agua caliente de 50.000 litros diarios, teniendo como alternativa de combustible el petróleo que alimenta una caldera.

Características del hospital tipo[198]

El hospital de urgencia asistencia pública, Dr. Alejandro del Río, más conocido como "Posta Central", se encuentra ubicado en la intersección de las calles Portugal y Diagonal Paraguay en la comuna de Santiago centro. Este centro está clasificado como de alta complejidad, tipo 1, y administrativamente es dependiente del Servicio de Salud Metropolitano Central.

La población objetivo corresponde a la población que efectivamente utiliza las instalaciones de salud independiente de su afiliación previsional.

De acuerdo a lo anterior, para el cálculo se considera sólo la Población Usuaria de Atención Cerrada de la Región Metropolitana según el tipo de prestación de urgencia del hospital, asignada al Servicio de Salud Metropolitano Central, calculada con un porcentaje de "atencionalidad" según la encuesta CASEN 2006, correspondiente a un 64.89%. Lo anteriormente descrito se presenta en la siguiente table.

Tabla Nº 2: Población objetivo

| Año | Población OBJETIVO | Año | Población OBJETIVO | Año | Población OBJETIVO |
|---|---|---|---|---|---|
| 1994 | 243.285 | 2000 | 290.601 | 2007 | 542.909 |
| 1995 | 250.457 | 2002 | 309.106 | 2008 | 555.572 |
| 1996 | 257.921 | 2003 | 316.354 | 2009 | 567.775 |
| 1997 | 265.662 | 2004 | 502.617 | 2010 | 579.498 |
| 1998 | 273.746 | 2005 | 516.375 | 2011 | 590.651 |
| 1999 | 282.118 | 2006 | 529.825 | 2012 | 601.203 |

198 Información facilitada por Miguel Sánchez, profesional jefe de equipos industriales, del departamento de recursos físicos del hospital de urgencia asistencia pública, Dr. Alejandro del Río.

Fuente: Departamento de recursos físicos Hospital Dr. Alejandro del Río.

Respecto a los servicios y unidades de apoyo con que cuenta este centro asistencial estos corresponden a:

Servicios clínicos: Medicina, cirugía, quemados, traumatología, pensionado.

Unidades de apoyo diagnóstico: Laboratorio clínico, imagenología, anatomía patológica, endoscopía.

Unidades de apoyo terapeútico: UTI, urgencia, pabellones y anestesia, banco de sangre, kinesiterapia, nutrición parenteral, atención dental de urgencia, esterilización, servicio de ambulancias (SAMU, SMUR).

Los departamentos de Apoyo Administrativos, corresponden a:

Departamento de Recursos Humanos.

Departamento de Recursos Financieros.

Departamento de Recursos Físicos.

Departamento de Gestión en Salud.

En relación a la infraestructura, este hospital fue fundado el año 1911 y la construcción actual de hormigón armado fue inaugurada el año 1965.

Respecto a la dotación de camas, ésta se encuentra detallada en el siguiente cuadro.

Tabla N° 3. Dotación de Camas por servicio

| SERVICIO | DOTACIÓN CAMAS | PROM. DE CAMAS EN TRABAJO 2007 | INDICE OCUPACIONAL (%) |
|---|---|---|---|
| MEDICINA | 88 | 89 | 97,5 |
| CIRUGÍA | 68 | 65 | 90,9 |
| QUEMADOS | 28 | 24 | 58,8 |
| TRAUMATOLOGÍA | 40 | 38 | 86,3 |
| UTI | 14 | 13 | 89,7 |
| PENSIONADO | 31 | 14 | 48,8 |
| INTERMEDIO | 15 | 13 | 89,7 |
| TOTAL | 284 | 259 | 85,1 |

Fuente: Departamento de recursos físicos Hospital Dr. Alejandro del Río.

Análisis costo-beneficio

Con el fin de realizar un análisis costo-beneficio del uso de colectores solares, es necesario saber cuánto combustible se ahorra producto del uso de esta tecnología. En el caso específico de este hospital, el requerimiento promedio diario de combustible es de 1.500 litros de petróleo diesel[199]. Considerando un precio promedio de $650 por litro implica un gasto de $ 355.875.000 anuales.

A continuación se presenta un cálculo realizado con el programa de simulación para instalaciones solares térmicas T*SOL Pro 4.5[200]. Los resultados han sido calculados mediante un modelo de cálculo matemático con un intervalo de tiempo variable de máximo 6 minutos. Resulta necesario mencionar, que los resultados

[199] Oscila entre 1200 y 1800 litros diarios dependiendo de la época del año.
[200] Simulación realizada por Carlos Infante de GEOSOLAR, quien además cotizó el equipo necesario.

reales pueden mostrar variaciones debido a las variaciones meteorológicas, de consumo y por otras causas.

## 4.1 Resultados de la simulación anual

*Supuestos considerados:*

Potencia de colectores instalada: 566,37 kW

Superficie de colectores (bruta): 809,1 m²

Irradiación a la superficie colector: 980,34 MWh 1.307,11 kWh/m²

Energía suministrada por los colectores: 399,00 MWh 532,00 kWh/m²

Energía suministrada por los circuitos del colector: 390,77 MWh 521,03 kWh/m²

Suministro de energía para la producción del agua caliente: 804 MWh

Energía sistema solar para el ACS: 390,77 MWh

Energía suministrada por la calefacción auxiliar: 426,02 MWh

*Resultados:*

Emisión de CO2 evitada: 132.330,67 kg

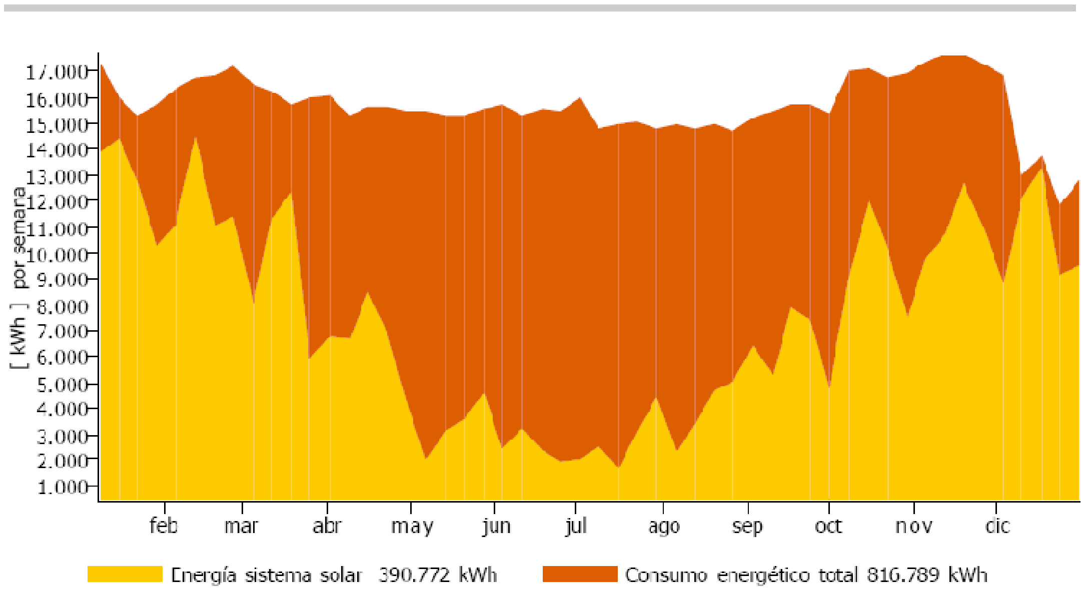
Fracción solar ACS: 47,8 %

Ahorro energético proporcional (EN 12976): 47,8 %

Grado de eficiencia del sistema: 39,9 %

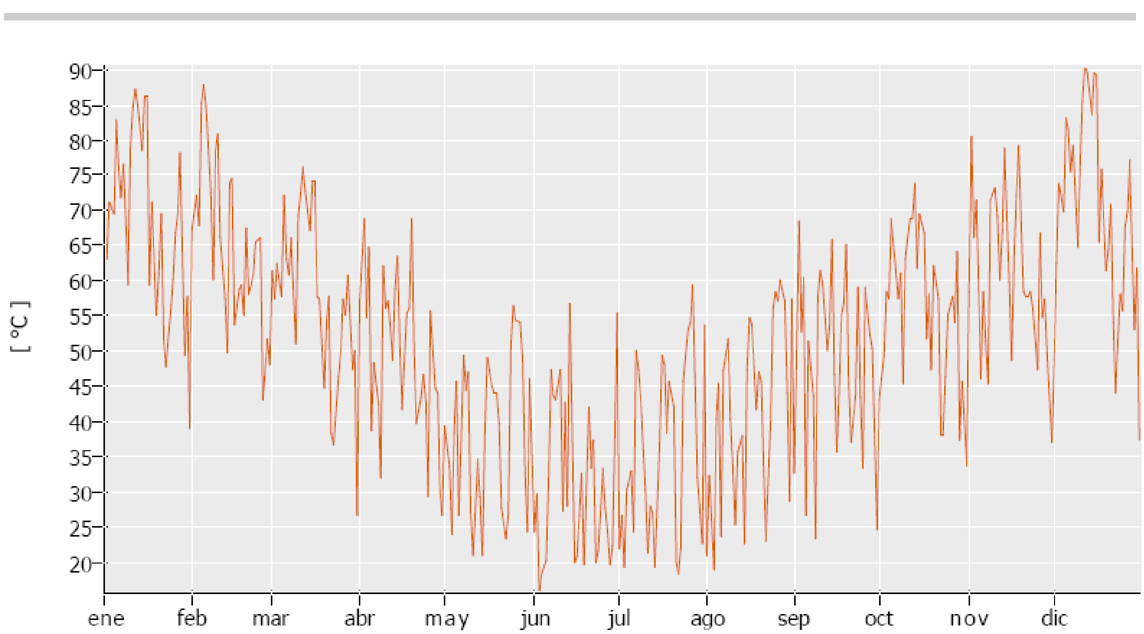
En lo que respecta a la fracción de la energía solar en el consumo energético y a las temperaturas máximas diarias en el colector, esto se puede apreciar gráficamente en las siguientes figuras:

Figura N° 3. Fracción de energía solar en el consumo energético




Fuente: GEOSOLAR

Figura N° 4. Temperaturas máximas diarias en el colector




Fuente: GEOSOLAR

En relación al costo del equipo que contempla 300 colectores solares y 5 estanques, este es de $ 350 millones[201].

Respecto al monto anual de ahorro en petróleo diesel, este equivale a:

$ 355.875.000 anuales x 0,478 (porcentaje de ahorro energético) = $ 170.108.250.

Teniendo la información expuesta, se puede proceder a calcular el valor presente neto de la inversión que se propone realizar. Para actualizar los flujos futuros de costos y beneficios se considera una tasa de un 10%.

Este aspecto es relevante de considerar para saber después de cuánto tiempo se recupera la inversión y justificar de este modo la adquisición de tecnología limpia.

Los resultados muestran que la inversión se recupera rápidamente y mucho antes del término de la vida útil de los paneles solares que se ha estimado en más de 20 años.

Para el análisis costo-beneficio se utiliza la tradicional fórmula de valor presente de los beneficios netos, a saber:

$$VPN = \sum_{t=0}^{n} \frac{B_t - C_t}{(1+r)^t}$$

Donde:

VPN: Valor presente neto

$t$: Vida útil de la inversión, que corresponde a 20 años

$B_t$: Beneficio en el tiempo t

[201] Cotización realizada por GEOSOLAR

$C_t$ : Costo en el tiempo t

$r$ : Tasa de interés, en este caso 10%

Para efectos de calcular la diferencia entre costo y beneficio en el tiempo, se utiliza el valor de ahorro generado por la utilización de ésta tecnología versus lo que se gasta en condiciones normales con equipos convencionales, que en este caso funcionan con petróleo diesel, valor que corresponde a $ 170.108.250 anuales.

Por lo tanto:

$$VPN = \frac{-350.000.000}{(1+0,1)^0} + \sum_{t=1}^{20} \frac{170.108.250}{(1+0,1)^t} = \$1.098.266.059$$

Resulta interesante analizar, con el fin de tomar la decisión de invertir, cuantos años es necesario esperar para recuperar la inversión y empezar a recibir los beneficios económicos. Lo anterior se puede apreciar con más detalle en la siguiente Tabla.

Tabla 4. Evolución del valor presente neto desde el año 0 al año 20.

| Año | Ahorro actualizado en pesos ($) | Acumulado($) |
|---|---|---|
| 0 | -350.000.000 | -350.000.000 |
| 1 | 154.643.863 | -195.356.137 |
| 2 | 140.585.330 | -54.770.807 |
| 3 | 127.804.846 | 73.034.039 |
| 4 | 116.186.224 | 189.220.263 |
| 5 | 105.624.496 | 294.844.759 |
| 6 | 96.024.979 | 390.869.738 |
| 7 | 87.293.195 | 478.162.933 |
| 8 | 79.360.042 | 557.522.975 |

| | | |
|---|---|---|
| 9 | 72.143.963 | 629.666.938 |
| 10 | 65.585.168 | 695.252.106 |
| 11 | 59.622.253 | 754.874.359 |
| 12 | 54.202.221 | 809.076.580 |
| 13 | 49.275.317 | 858.351.897 |
| 14 | 44.795.978 | 903.147.875 |
| 15 | 40.723.032 | 943.870.907 |
| 16 | 37.021.099 | 980.892.006 |
| 17 | 33.655.478 | 1.014.547.484 |
| 18 | 30.618.138 | 1.045.165.622 |
| 19 | 27.814.554 | 1.072.980.176 |
| 20 | 25.285.883 | 1.098.266.059 |

Fuente: Elaboración propia

De la tabla anterior se desprende que el valor presente neto de esta inversión, utilizando una tasa de interés del 10% y considerando una vida útil de 20 años es superior a $1.000 millones, cifra que se reduce a aproximadamente $700 millones si la vida útil del equipo fuera de sólo 10 años.

Además se puede agregar, que es necesaria una vida útil de al menos 3 años, con el fin de que la inversión se recupere y empiece a generar beneficios (tomando como base la tasa de interés de 10%, la cual refleja el costo de oportunidad del dinero invertido).

Disminución en las emisiones contaminantes

Además de las consideraciones económicas analizadas anteriormente, es posible cuantificar los beneficios ambientales producto de la disminución en las emisiones contaminantes, especialmente de CO2.

Lo anterior podría ser abordado desde distintas perspectivas, resultando más factible cuantificar las cantidades de contaminantes que se dejan de emitir a la atmósfera y asignarles un valor económico que podría estar dado, desde la disminución en la incidencia de enfermedades respiratorias en la población, hasta el valor económico que tiene disminuir las emisiones de CO2 a la atmósfera a través de la venta de certificados de reducción de emisiones (CRE), pudiendo transformarse en un proyecto de MDL (mecanismo de desarrollo limpio), generando con esto recursos que harían al proyecto más rentable, y por lo tanto, viable de realizar.

Para lograr lo anterior es necesario analizar las emisiones contaminantes antes y después de la implementación de los colectores y de esta forma estimar la reducción efectiva de $CO_2$ y demás elementos particulados.

Lo anterior se puede calcular utilizando el programa de simulación para instalaciones solares térmicas T*SOL Pro 4.5, el cual nos arroja un valor de emisiones de $CO_2$ evitadas de 132.330 kg.

Con estas estimaciones se podrían calcular los efectos o beneficios directos relacionados con la disminución de $CO_2$, por ejemplo, en mortalidad y morbilidad, así como otros beneficios más indirectos en estética, productividad agrícola, además de la posibilidad de comercializar certificados de reducción de emisiones (CRE). Si bien estos beneficios son importantes y ciertamente significativos, se considerarán en futuros trabajos de investigación.

## CONCLUSIONES Y PROYECCIONES

El valor presente neto de esta inversión, utilizando una tasa de interés del 10% y considerando una vida útil de 20 años, corresponde a $1.098.266.059, cifra que se reduce a $695.252.106  si la vida útil del equipo fuera de 10 años.

Además de los evidentes ahorros en recursos destinados a la adquisición de combustibles fósiles (en este caso de petróleo diesel), que permiten amortizar la inversión al cabo de 2,5 años, se encuentra el hecho de que el fomento de energías renovables no convencionales (ERNC), constituye un real aporte a la independencia energética de nuestro país, que no cuenta con recursos energéticos significativos provenientes de combustibles fósiles.

Otro efecto positivo de la implementación de esta política pública, corresponde a la disminución de las emisiones de gases de efecto invernadero y contaminantes del aire que respiramos, cuyos beneficios directos e indirectos se dejan para futuras investigaciones. En el caso específico de este estudio, se logran disminuciones de 132,33 toneladas de CO2 al año, al implementar colectores solares en el mencionado hospital. Cabe destacar eso sí, que los efectos se harán evidentes, en la medida que el uso de las ERNC se haga más masivo, lo cual puede ser potenciado por la implementación de políticas públicas que tengan esa dirección, como es el caso de esta iniciativa y las medidas ya comentadas por parte del Ministerio de Energía.

Es necesario considerar que los precios de los equipos instalados han presentado una tendencia a la baja en los últimos años, lo cual seguramente hará mucho más rentable su implementación en el futuro. En este punto, y relacionado a lo planteado en la conclusión anterior, se puede agregar que otra posible “externalidad positiva” de implementar esta política pública, pudiera ser el hecho de que esta iniciativa genere un incentivo en el uso de tecnología solar, lo cual traería evidentes reducciones en los costos de los equipos por las economías de escala que se generarían, contribuyendo con esto a la obtención de significativos ahorros por concepto de energía para el país, además de innegables beneficios para el medioambiente.

Además de los beneficios tangibles, también se encuentra el hecho de que un proyecto de este tipo puede generar “externalidades positivas”, en el sentido de fortalecer una visión más sustentable de desarrollo, contribuyendo con esto a generar “cultura ambiental” en el país.

Por último, esta propuesta y su posterior ampliación, pudiera ser susceptible de transformarse en un proyecto de MDL (mecanismo de desarrollo limpio) con lo cual se podrían vender certificados de reducción de emisiones (CRE), generando con esto recursos que harían al proyecto más rentable, y por lo tanto, viable de realizar.

## BIBLIOGRAFÍA

Boardman, A, D Greenberg, A Vining, D Weimer: "Cost Benefit Analysis. Concepts and Practice" Prentice Hall, segunda edición, 2001.

Corporación de desarrollo tecnológico, cámara chilena de la construcción (2007). Manual de diseño para el calentamiento de agua con sistemas solares térmicos, elaborado con la colaboración y patrocinio de: Programa País Eficiencia Energética, Facultad de ciencias Físicas y Matemáticas de la Universidad de Chile, PROCOBRE y GTZ.

## SITIOS WEB VISITADOS

Comisión nacional de energía, www.cne.cl

Instituto nacional de estadísticas, www.ine.cl

Programa de estudios e investigaciones en energía, www.prien.cl

Corporación nacional del medioambiente, www.conama.cl

Ministerio de Salud, www.minsal.cl

El Mercurio on-line, www.emol.com

La tercera on-line, www.latercera.cl

# 53. Relations between energy and economic growth

**Oscar Gonzalo Manrique Diaz**

Universidad Nacional de Colombia

Facultad de Ciencias Humanas y Económicas

Calle 59 No. 63-20, Medellín

Teléfono (574) 4-309231

Fax: (574) 2-604451

ogmanriq@unalmed.edu.co

Key words: Energy, Economic, Growth

Abstract: It is true that our degree of economic development is directly proportional at the level of energetic consumption. Nevertheless in the economic theory of the growth this fact passes definitively unnoticed. This paradox is accepted by the majority of economists without any discussion. At this moment, the humanity faces different phenomena derived from the intensive use of fossil, necessary resources to guarantee the production of goods and services: global warming, pollution of the air, and deforestation, among others. Additional, an increasing pressure exists on the renewable resources, like water and wood.

In this work, one seeks to establish clearly the strong and narrow existing relation between the energetic consumption and the economic growth. To manage to demonstrate the above mentioned relation, there is done a historical, technical, conceptual and economic approximation. Considering the quantity and variety of the resources that exist in Latin America, the determination of the above mentioned connection, allows to design and to define public policies of conservation and national or regional use, to support the future well-being of our societies.

# Does Energy Cost Affect Long Run Economic Growth? Time Series Evidence Using Chilean Data?

Gonzalo F. Blümel† , Ricardo A. Espinoza‡, María de la Luz Domper†

† Libertad y Desarrollo

Alcántara 498, Las Condes, +56 02 3774800, +56 02 3774853

‡ Facultad de Ingeniería, Universidad de los Andes, Santiago, Chile.

JEL classifications: C22; Q43; Q48; O13

Keywords: Energy; Economic growth; Cointegration, Granger causality.

Abstract: This paper investigates the long and short run relationship between energy prices and economic growth through cointegration and error correction (ECM) techniques, using quarterly Chilean data. The model is based on the dynamic interaction of output and its explanatory variables, extending the neoclassical production function with energy as a factor of production, as well as labor and capital.

The empirical evidence indicates that almost all series are individually non-stationary at levels and stationary at first differences. Furthermore, the variables cointegrate. In the long-run, output depends positively on capital and labor, but negatively on energy price. The suggested price elasticity of output to energy is between -0.085 and -0.16. We also estimate the parsimonious model of the dynamic ECM and check for the consistency of the estimated parameters.

The main implication of this paper is that in the long-term the higher the energy price the lower the output's growth rate of the Chilean economy. Energy strategies should consider the effects on aggregate output of such policies. Secondly, energy prices affect aggregate output only in the long-run. There are no observable effects in the short-run. Finally, the low speed of adjustment suggests a low degree of the economy to adjust shocks in the short-run.

## Introduction

Does energy price affect real economic activity? This paper investigates the relationship between economic growth and the price of energy, based on the Chilean context. We examine the dynamic interaction among those variables using a modified neoclassical production function. Estimations follow cointegration and error-correction approaches.

This discussion is specifically motivated by a new law, “Law 20.257”, which imposes fixed quotas of production from non-conventional renewable energies (NCRE) to electricity generators. Galetovic and Muñoz (2008) have estimated that the cost to consumers of the Central Interconnected System (CIS)[202] will increase by US$ 4000 millions in net present value, due to higher costs associated to NCRE generation. However, there are no official estimations about the impact of the law in the price of energy. Based on Galetovic and Muñoz, we estimate that without subsidies the issue of this bill could increase roughly the price of energy by 6% to 10% and residential tariffs by 3% to 5%.

The objective of this paper is to evaluate possible short and long-run effects on economic output of energy price variations. We extend earlier studies considering several energy price indices such as the proxy for energy in the production function, and additionally we consider different specifications for capital and labor series. This framework of analysis is of interest for low and mid-income countries which depend on adequate energy policies to foster industrialisation processes and development.

Section 2 describes briefly the Chilean electric context. Section 3 reviews theoretical and empirical research on energy and economic growth. In section 4 we present a macroeconomic growth model and the data considered into the analysis. Results of our empirical estimations are presented in section 5. Finally, we present the conclusions in section 6.

## The Chilean Context

The Chilean electric market is separated into three different segments: Generation, Distribution and Transmission. The current regulation comes from the earlier 80’s and it attempts to provide a competitive environment for generation activities, based on a system of prices that reflect the market conditions. Decisions and investments in this sector are not centrally planned, and respond fundamentally to market incentives. Generators establish long-term contracts to supply power and energy. However, contract term depends on the type of consumers: regulated or

[202] The Chilean Central Interconnected System is the main electricity system of the country (there are four separated systems in Chile). It serves the 93% of the total population which represents 71.12% of the 2007 installed capacity.

not. Regulated consumers are those who demand less than 2 MW[203]. Energy and power prices are regularly fixed by the National Energy Commission (NEC). Prices paid by consumers include transmission charges and the value added of distribution. Besides, regulated clients have different tariffs options according to the corresponding voltage level demanded. Free or not regulated consumers are those who demand more than 2 MW. They negotiate the prices for energy and power directly with generators based on market conditions. They also have to pay transmission charges. Transmission and distribution activities are regulated by the authority because of the specific characteristic of those markets. For a more detailed description of the Chilean electric market see Galetovic and Muñoz (2009).

Over the last years, strategic and environmental considerations have induced the local authorities to introduce changes in the regulatory framework, particularly in relationship with the NCRE. The so-called “Ley Corta I” and “Ley Corta II” laws established specials conditions for the development of NCRE (wind, solar, biomass, among others). The first law suppressed the charges for connecting to the transmission system to NCRE projects smaller than 9 MW. The second one established that distribution companies must auction its supply in competitive conditions. Furthermore, the authority published specific rules to limit the risk associated to the price volatility of these energies. All of these initiatives have induced NCRE generation. For instance, wind generation projects represent the 8% (1.463 MW) of the total power generation into the Environmental Impact Assessment (EIA) system (15.818 MW).

These policies will be reinforced with the new law 20.257, issued in April of 2008, defining a minimum generation quota of 5% from NCRE sources in 2010 until 2014; thereafter the quota must increase 0.5% each year until reaching the 10% of the total electric production in 2024. These quotas can be filled via own generation or subcontracted.

Economic Growth and Energy

Over the last decades, many researchers have attempted to study economic growth and its determinants. The basic model of economic growth, known as the neoclassical model, was presented by Solow (1956) and examines the evolution of output of an economy that produces goods using two factors of production: capital and labor. The neoclassical model assumes diminishing returns to capital, that is, output increases at a decreasing rate as capital stock rises. The dynamic of that model leads to a stationary equilibrium or steady state where depreciation is equal to savings, so higher level of capital stocks are not optimal, because there are no incentives to do so.

[203] Consumers that demand between 0.5 and 2 MW can choose freely between regulated or free regime.

According to that theory, the only source of sustained economic growth is technological change, defined as the efficiency by which capital and labor are combined to produce output. As the level of technology increases, the functional relationship between inputs changes and greater quantities of output may be produced using the same amount of inputs, leading to a sustained output per capita growth in the long-run.

Thereafter, many extensions of this model were developed, incorporating different elements to allow a better description of the real economy. Nevertheless, the neoclassical framework misses the primary force that drives all economic activities: the energy. Energy from non-human sources, like oil, coal and others, are only incorporated in national accounts as intermediate inputs, ignoring that energy per se could be a main factor of production. Wolde-Rufeal (2009) pointed out that the role of energy as a separated factor input has been historically rejected because the cost of energy represents a minor proportion of total GDP compared to the cost of employment.

Since the neoclassical approach does not directly consider energy as a factor of production, many authors have developed different theories to incorporate it. Saunders (1984; 1992) includes energy as a factor of production and through simulations shows the output’s transition from the short to the long term. Stern and Cleveland (2004) and Alam (2006) also include energy in the production process. Alam argues that the economy consists of streams of energy-producing and energy-using activities, so ignoring the role of energy in the production process distorts the analysis of economic growth and its sources, making also difficult to define capital and labor, since they play only supporting roles in the economy that can only be understood in relation to energy. In the same way, Stern (1997) argues that energy is a crucial factor of production since all the production involves the transformation or movement of matter, where energy is required.

Finn (2000) presents a model of an economy with perfect competition that produces a final good from three factors of production: capital, labor and energy, where stochastic and exogenous shocks to technology and energy prices are two possible sources of fluctuation in the economy, providing the foundation for discriminating between the helpfulness of using perfect or imperfect economy's model. An increase in the energy price level would affect economic output through affecting energy usage, employment, and capital's future marginal productivity and return, inducing a decrease in the total return to investment, and so in investments and total capital stock. He also found an indirect transmission channel related to what he calls the capital’s marginal energy cost.

While no theoretical model can actually fully explain the growth process considering energy as a primary factor of production, many empirical researches have attempted to examine the role of energy in economic growth. Some of them test the causal relationship between energy consumption and economic growth. Others test the incidence of energy price level on aggregate output. This paper focuses on the effect of energy price level on Chilean's economic activity.

Historically, energy price increases has negatively affected the economic activity. Empirical evidence shows that in the U.S, the Solow residual tends to fall when energy price rises, implying a direct link between energy and production (Finn, 1995). Rotemberg and Woodford (1996) found that a 1 percent innovation in energy prices engenders a decline of 0.25 percent in real output and 0.09 in real wages, and presented a theory with imperfect competition that can successfully address that fact.

A vast macroeconomic literature suggests that there is also a negative relationship between energy price level and real output in the short and long-run (Darby, 1982; Burbidge and Harrison, 1984). Rasche an Tatoom (1981) using data from six developed countries (United States, United Kingdom, West Germany, France, Canada, and Japan) found a negative elasticity of output to real price of energy, based on an aggregate supply framework with energy as a factor of production. Hamilton (1983) and Boyd and Caporale (1996) extend those works adding an additional finding: output growth is significantly influenced by both energy price volatility and energy price level. Tatom (1987), Tatom (1988) and Tatom (1991) found an asymmetric response of output in oil price shocks, arguing that a shock alters the incentives to employ energy resources and alter the optimal methods of production in a different way. He also found that a positive oil price shock has a deeper impact on output than a negative one does.

On the other hand, Bohi (1989) using a classical static model of growth and cross-country data found that important energy price shocks have not had a significant importance explaining macroeconomic performance of the U.S and other developed countries.

Since ordinary linear regressions or correlation methods are not quite appropriate to establish causality between variables, many researchers have worked in the direction of finding new techniques to do so. Numerous empirical works have attempted to detect Granger causality and cointegration between energy consumption and aggregate output, by applying the procedures popularized by Engel and Granger (1987) and Johansen and Juselius (1990). Up to now, the results have been diverse. Kraft and Kraft (1978), using data for the period 1947-1974 found that for the US exists a causality effect running from GNP to energy consumption, result that was then supported by Akarca and Long (1979), who found unidirectional causality running from energy to employment, without feedback. Erol and You (1987) using data for a large set of industrialized countries found a causal relationship running from energy consumption to output. Yu and Choi (1985) found the same for the Philippines and found causality from GDP to energy use for South Korea. Asafu-Adjaye (2000) found unidirectional short-run Granger causality from energy to income for India and Indonesia and bidirectional short-run Granger causality for Thailand and the Philippines, suggesting that energy-dependant economies are more vulnerable to energy shocks. Recently, Akinlo (2008) examined the causal relationship between energy consumption and economic growth for eleven countries in sub-Saharan Africa and finds that energy consumption is cointegrated with economic growth in most of them. Moreover, Glasure and Lee (1997) found bidirectional causality among GDP and energy consumption for South Korea and Singapore. Similar result was found in Jumbe (2004) and Yang (2000) for Malawi and Taiwan respectively. Chontanawat et al. (2008) found that the causality relationship of energy consumption and economic growth is stronger in developed countries than in developing countries.

The bivariate approach has been criticized because its limitations to describe the real economic interactions. Some authors (Stern, 1997; Asafu-Adjaye, 2000; Glasure, 2002; Stern and Cleveland, 2004) have pointed out the importance of omitted variables. Yuan et al. (2008) argue that multivariate approach “can offer multiple causality channels which, under a bivariate approach, may remain hidden or can lead to spurious correlations and erroneous conclusions”. Many authors have addressed this issue by including energy as a separate factor of production in the neoclassical production function (see, Stern, 2000; Ghali and El-Sakka, 2004; Soytas and Sari, 2006; Lee and Chang, 2008; Lee et al., 2008; Narayan and Smyth, 2008; Wolde-Rufael, 2008; Wolde-Rufael, 2009). The main conclusion from these studies is that there exists long-run cointegration and causality among the variables.

Using a slightly different approach, Gardner and Joutz (1996) focused the multivariate approach on the energy price effect on output. They found that the real price of energy is negatively related to output. They also found that positive price shocks lead to a slowdown in economic growth while energy price declines have no significant impact on aggregate output. In this paper, following the above-mentioned authors we investigate the relationship between the price of energy and economic growth in a conventional neoclassical aggregate production model where capital, labor and energy are treated as separate factors of production.

## The Model and the Data

The aggregate supply channel states that positive energy price shocks affect negatively the output. In the last years, this framework of analysis has received a lot of attention among researchers (see the section above). Rasche and Tatom (1981), and Tatom (1987) present a detailed discussion about energy and its role in economic growth, discussing the different channels of possible influence.

The aggregate supply channel assumes that an energy price shock modifies the optimal usage of the existing stock of capital, promoting the use of less energy-intensive capital. Labor resources are redirected to economize on energy use, modifying the optimal capital-labor ratio. Subsequently, the output produced is lower than before due to an upward shift on the aggregate supply curve. This situation is usually referred as a decline in potential or natural output.

We employ a neoclassical aggregate production function where, in addition to capital and labor, energy is added as a factor of production.

$$Y_t = f(L_t, K_t, E_t) \qquad (1)$$

$Y_t$ is real GDP, $L_t$ is total employment, $K_t$ is real aggregate capital stock and $E_t$ is total energy consumption. The real price of energy enters into the equation through a *"first order condition"* for energy employment as in papers by Tatom (1987; 1988; 1991) and Bohi (1989). Thus, the log linear form can be expressed conveniently:

$$\ln Y = \alpha_0 + \alpha_1 \ln L + \alpha_2 \ln K + \alpha_3 \ln P_e$$

The term $P_e$ represents the real price of energy and the coefficient $\alpha_3$ can be interpreted as the elasticity of output to energy price.

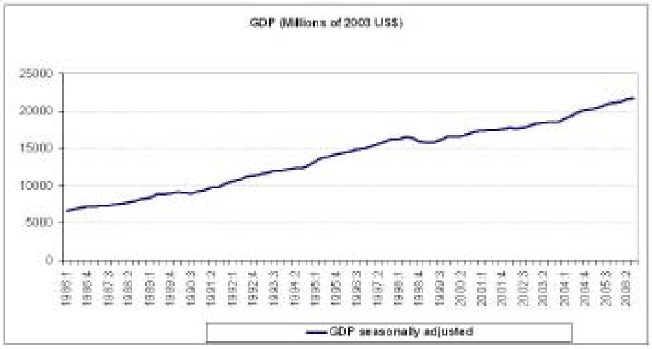
The early literature in energy price shocks and economic growth usually estimates this relation via OLS. However, regressions of non-stationary time series may produce spurious results by simply apply OLS. We address that point following an error-correction modeling framework.

In this paper, we use Chilean quarterly data from 1986 to 2006. The data series are GDP, total employment, capital stock and different energy price indices (see Figure 16). GDP data came from the Central Bank of Chile (2008). We use seasonally adjusted GDP in real 2003 Chilean pesos. Total employment data is taken from Chilean's National Institute of Statistics (INE). Employment is adjusted by seasonality and human capital level variations. We employ two series for capital stock: total capital stock and total capital stock adjusted by intensity of use. Series are annually constructed. We apply linear interpolations for getting quarterly data. Both series are taken from Chilean's Finance Ministry, and values are expressed in 2003 Chilean pesos. We use three proxies for energy price based on the annual reports of the National Energy Commission (CNE, 2008). The first two indices, the node energy price and the monomic price[204], are obtained from regulated consumers of the electric Chilean's market. They represent the 18.8% of the total secondary energy consumption in 2007. The third index is a weighted linear combination of several secondary energy prices (electricity, oil, coal and gas), and is constructed from the energy consumption surveys of the CNE (2008). This index represents the 72% of the total secondary energy consumption of Chile in 2007. All indices are computed in real values as January 1986 price=100.

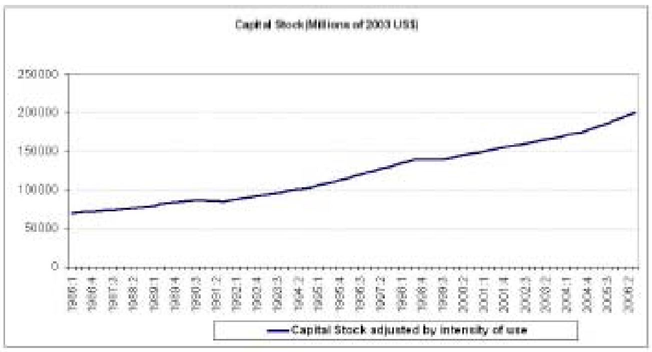
Next table details the nomenclature used for each variable. All variables are converted to natural logarithms.

Figure 16: Real GDP, capital stock, employment and energy price indices

[204] The monomic price, $p^{mon}$, is the equivalent in energy terms of energy and power prices.







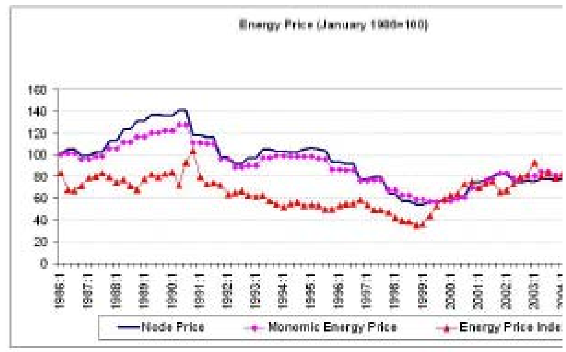




Table 15: Variable names and nomenclature

| Nomenclature | Variables Name |
|---|---|
| gdp | GDP |
| k | Capital stock without adjustments |
| $k^{in}$ | Capital stock adjusted by intensity of use |
| labor | Labor force without adjustments |
| $labor^{hc}$ | Labor force adjusted by human capital |
| $p^{ene}$ | The price of energy |
| $p^{mon}$ | The monomic price |
| $p^{index}$ | Index price |

The empirical strategy of this work is to analyze the short and long-run relationship of the variables using cointegration and the error-correction (ECM) approach, based on Engle-Granger and Johansen-Juselius methodologies, which is a conventional approach for this type of studies (Gardner and Joutz, 1996; Glasure and Lee, 1997; Asafu-Adjaye, 2000; Jumbe, 2004). The main contribution of this work is that we consider several energy prices indices such as the proxy for energy in the production function, looking for the effects of energy cost variations in economic growth, and additionally we consider different specifications for capital and labor series.

To analyze the possible existence of cointegration among the variables is necessary to examine the stationarity and the order of integration of the series. Table 16 presents the results for the Augmented Dickey-Fuller (ADF) and the Phillips-Perron (PP) unit roots tests, including a constant term in all of them. For ADF, the number of lags is selected according to Akaike's Information Criteria (AIC)[205]. And for PP, the optimal bandwidth is selected according to the Newey-West method for the spectral estimator. The table shows that the τ-statistics for all the variables at level form are greater than the critical values at any significant level both ADF and PP, excepting the PP τ-statistics for GDP at 10% of significance, showing that the null hypothesis of non-stationarity can not be rejected when the series are in their level form at 5% of significance.

Table 16: ADF and PP unit roots tests

| Variable | Augmented Dickey-Fuller test (ADF) | | Phillips - Perron test (PP) | |
|---|---|---|---|---|
| | Level Form | First Differences | Level Form | First Differences |
| gdp | -2.096 (1) | -7.032 (0)*** | -2.652 (3)* | -7.036 (3)*** |
| k | -0.690 (1) | -2.374 (0) | -0.973 (6) | -2.359 (2) |
| $k^{in}$ | -0.002 (9) | -2.016 (8) | 0.464 (5) | -3.376 (3)** |
| labor | -1.835 (1) | -5.589 (0)*** | -2.363 (3) | -5.589 (0)*** |

205 Patterson (2000) suggests that an adequate procedure to select the lag length is to choose the smallest values from Akaike (AIC) and Schwartz (SIC) criteria, subject to non-rejection of the null hypothesis of white noise innovations.

| | | | | |
|---|---|---|---|---|
| $labor^{hc}$ | -1.991 (0) | -7.810 (0)*** | -1.935 (3) | -7.792 (3)*** |
| $p^{ene}$ | -1.967 (4) | -2.700 (3)* | -1.189 (3) | -8.304 (1)*** |
| $p^{mon}$ | -1.975 (4) | -2.572 (3) | -1.174 (3) | -8.296 (2)*** |
| $p^{index}$ | -0.844 (3) | -4.323 (2)*** | -0.747 (3) | -8.103 (3)*** |

| *Significant Level* | *Critical Values* | |
|---|---|---|
| 1% | -3.515 | -3.512 |
| 5% | -2.899 | -2.897 |
| 10% | -2.587 | -2.586 |

Note: the reported value is the ADF and PP τ-statistic for the series. All the regressions include a constant term. The sample is 1986Q1 to 2006Q3. Here *** / ** / * denote rejection of the null at the 1%, 5 % or 10% significant level. The number inside the brackets corresponds to the optimum lag selection for ADF, and the optimal bandwidth for PP. Critical values are those reported by EViews from MacKinnon (1996) one-sided p-values.

When variables are first differenced, the τ-statistics from ADF test for GDP, labor (adjusted and not by human capital levels), and the energy price index are less than the critical value at 5%, suggesting stationarity or I(1) series. This is not the case for the stock of capital (with and without intensity of use adjustments), energy price and monomic price; the τ-statistics are higher than the critical values so we can not reject the null hypothesis of non-stationary variables. However, the τ-statistics from PP test at first differences are all of them less than the critical value at 5% of significance, excepting the stock of capital without adjusting for the intensity of use[206], implying stationarity. Based on these results, we can assume that in the most cases output, capital adjusted by intensity of use, labor and the energy price indices are I(1) at 5% of significance. These results were also contrasted with KPSS unit root tests, which tests the null hypothesis of stationarity,

[206] In fact, the log of the stock of capital without any adjustment is an I(2) variable. The τ-statistic from ADF is -9.265 and the optimal lag length specification according to AIC is 0.

obtaining similar conclusions to PP results. KPSS results are not reported for practical reasons.

Given that the majority of the series are I(1), we proceed to test for cointegration using Engle-Granger procedure. Basically, this procedure suggests that it is possible to construct a linear non-spurious combination of time series if all of them are integrated of the same order, even though individually the time series are non-stationary. If cointegration exists, the parameters of the regressions will represent the long-run, or equilibrium, relationship between the variables. The procedure to check for cointegration using Engle-Granger consists of regressing the contemporaneous value of one variable involved in the relationship against the contemporaneous value of the others, including a constant term. If the residuals obtained from the regressions are stationary, which can be checked with ADF test, the variables cointegrate. While ADF critical values are not quite appropriate to compare with the τ-statistics obtained from the regressions (Gujarati, 2004), in this study we consider critical values from Engle and Yoo (1987).

Table 17 presents the results of Engle-Granger cointegration test for several model specifications. We include only the I(1) variables into the analysis. The first three columns compare the variations in the results when the energy price proxy is modified (energy price, monomic price and the price index) keeping constant labor (adjusted by human capital) and capital (adjusted by intensity of use), and the second three columns present the results following the same procedure for the energy price proxy, but changing the labor variable by the not adjusted one.

Comparing the τ-statistic from the ADF on the residuals with the critical value at 5% of significance, which is 3.62, we can assume that the series cointegrate only if the price index is used as the energy price proxy, independently of the labor specification. At 10% of significance, the hypothesis of cointegration is not rejected in the second and the fourth case. In those cases, the τ-statistics are less than the critical values.

Table 17: Cointegration results from Engle-Granger procedure

| Variable | Dependent Variable (GDP) | | | | | |
|---|---|---|---|---|---|---|
| | Coefficients (1) | Coefficients (2) | Coefficients (3) | Coefficients (4) | Coefficients (5) | Coefficient s (6) |
| Constant | 2.279 | 2.346 | 0.503 | -2.927 | -2.791 | -4.212 |
| $k^{in}$ | 0.243 | 0.251 | 0.427 | 0.310 | 0.318 | 0.551 |

| | | | | | | |
|---|---|---|---|---|---|---|
| labor | | | | 1.636 | 1.617 | 1.252 |
| $labor^{hc}$ | 1.122 | 1.111 | 0.935 | | | |
| $p^{ene}$ | -0.090 | | | -0.137 | | |
| $p^{mon}$ | | -0.114 | | | -0.169 | |
| $p^{index}$ | | | -0.085 | | | -0.107 |
| ADF Test Statistic (Residuals) | -3.274 (0) | -3.334 (0)* | -3.631(0)** | -3.443 (1)* | -2.780 (0) | -3.801(1)** |
| $R^2$ | 0.994 | 0.994 | 0.995 | 0.994 | 0.994 | 0.994 |
| F-statistic | 4413.74 | 4803.37 | 5556.03 | 4077.18 | 4615.16 | 4442.32 |

| *Significant Level* | *Critical Values* |
|---|---|
| 1% | -4.22 |
| 5% | -3.62 |
| 10% | -3.32 |

Note: The sample is 1986Q1 to 2006Q3. Here *** / ** / * denote rejection of the null at the 1%, 5 % or 10% significant level. The number inside the brackets is the optimum lag selection determined using Akaike's Information Criteria. The ADF framework includes a constant term without trend.

The signs of the parameters are consistent with theoretical predictions, positive for labor and capital and negative for energy prices. Taking only the cases where cointegration hypothesis is not rejected, the suggested price elasticity of output to energy goes from -0.085 (model 3) to -0.137 (model 4), with an average value of -0.110. This means that, in the long-run, a 10% energy price increase reduces output's growth rate by 1.1%. The estimated elasticities are higher than previous findings for the U.S. (Tatom, 1987, Gardner, 1996), implying that the Chilean's output is more responsive to changes in the energy price.

Additionally, in the equilibrium output seems to be much more sensitive to changes in the labor force rather than changes in the capital stock, according to the observed elasticities. The average values of labor and capital coefficients in those cases where cointegration is not rejected are 1.279 and 0.350 respectively. Comparing to Gardner's estimations for the U.S., the suggested elasticity of output is higher in the case of labor, and lower in the case of capital. It is also interesting to note that the coefficients on labor are much higher when the series are not adjusted by human capital variations.

Another procedure to test for cointegration is the Johansen's multivariate maximum likelihood procedure (Johansen and Juselius, 1990), which has some advantages in relation to Engle-Granger residual approach[207]. The methodology is based on a VAR modeling framework:

$$y_t = A_1 y_{t-1} + \ldots + A_p y_{t-p} + Bx_t + \xi_t$$

Where $y_t$ is a $k$-vector of non-stationary I(1) variables, $x_t$ is a $d$-vector of deterministic variables, and $\xi_t$ is a vector of innovations. It is possible to rewrite the VAR as follows:

$$\Delta y_t = \Pi y_{t-1} + \Sigma \Gamma_i \Delta y_{t-i} + Bx_t + \xi_t$$

Where:

$$\Pi = \Sigma A_i - I, \Gamma_i = - \Sigma A_j$$

According to Granger's representation theorem if the coefficient matrix $\Pi$ has reduced rank $r < k$, then there exists $k \times r$ matrices $\alpha$ and $\beta$, each with rank r such that $\Pi = \alpha \beta'$, where $r$ is the number of cointegrating relationships, $\beta$ is the cointegrating vector and $\alpha$ is the speed of adjustment of the vector error-correction (VEC) model. Basically, Johansen's method consists of estimating the $\Pi$ matrix from an unrestricted VAR and testing whether or not we reject the restrictions implied by the reduced rank of $\Pi$. If the restrictions are not rejected, the expression $\beta' y_t$ is stationary and represents the long-run, or equilibrium, relationship among the variables.

Table 18 summarizes the results for Johansen's cointegration test for GDP, capital adjusted by intensity of use, labor adjusted by human capital variations, and the price of energy. It includes the eigenvalues, the Max and Trace statistics, the standardized estimated feedback coefficients α and the cointegrating vector β'. Trace and Max statistics suggest a single cointegration relationship at 5% of significance. The signs of the coefficients of the long-run relationship are according to theory predictions: labor and capital positively related to GDP and energy price negatively related to GDP.

---

[207] With Johansen's approach it is possible to detect multiple cointegration relationships among other advantages.

Comparing with our previous results, the coefficients from the cointegration relationship are relatively similar, excepting the case of the price of energy, which is higher in comparison to all Engle-Granger estimations. The estimated coefficient for energy price (-0.162) means that a 10% of energy price increase will decrease aggregate output' growth rate by 1.62% in the long-term. Johansen's cointegration equation is as follows:

$$gdp_t = 2.007 + 0.375\, k^{in}{}_t + 0.914\, labor^{hc}{}_t - 0.162\, p^{ene}{}_t$$

Table 18: Cointegration results from Johansen's procedure

| Unrestricted Cointegration Rank Test (Trace) | | | | |
|---|---|---|---|---|
| Hypothesized (Number of coint. eq.) | Eigenvalue | Trace Statistic | Critical Value (0.05) | Probability |
| None * | 0.340 | 61.877 | 47.856 | 0.001 |
| At most 1 | 0.222 | 29.462 | 29.797 | 0.055 |
| At most 2 | 0.119 | 9.859 | 15.495 | 0.292 |
| At most 3 | 0.000 | 0.013 | 3.841 | 0.908 |

| Unrestricted Cointegration Rank Test (Maximum Eigenvalue) | | | | |
|---|---|---|---|---|
| Hypothesized (Number of coint. eq.) | Eigenvalue | Trace Statistic | Critical Value (0.05) | Probability |
| None * | 0.340041 | 32.41506 | 27.58434 | 0.011 |
| At most 1 | 0.222224 | 19.60266 | 21.13162 | 0.0807 |
| At most 2 | 0.118586 | 9.845793 | 14.2646 | 0.2222 |
| At most 3 | 0.00017 | 0.013237 | 3.841466 | 0.9082 |

Unrestricted Cointegrating Coefficients (normalized):

| | | | | |
|---|---|---|---|---|
| gdp | $k^{in}$ | $labor^{hc}$ | $p^{ene}$ | |
| 57.138 | -21.435 | -52.226 | 9.252 | |
| 43.233 | -8.342 | -48.230 | 2.244 | |
| 3.095 | 10.374 | -22.745 | -0.200 | |
| 31.907 | -21.308 | -22.049 | -1.659 | |
| Unrestricted Adjustment Coefficients α: | | | | |
| Δgdp | 0.00268 | -0.00395 | -0.00031 | -0.00009 |
| $\Delta k^{in}$ | 0.00014 | 0.00052 | -0.00076 | -0.00003 |
| $\Delta labor^{hc}$ | 0.00071 | 0.00113 | 0.00225 | -0.00007 |
| $\Delta p^{ene}$ | -0.03056 | -0.00353 | 0.00021 | -0.00021 |
| Normalized cointegrating coefficients β (t statistic in parentheses) | | | | |
| gdp | $k^{in}$ | $labor^{hc}$ | $p^{ene}$ | constant |
| 1 | -0.375 | -0.914 | 0.162 | -2.007 |
| | [-7.10601] | [-12.7839] | [ 8.10303] | |
| Adjustment coefficients | | | | |
| Δgdp | 0.153 | | | |
| $\Delta k^{in}$ | 0.008 | | | |
| $\Delta labor^{hc}$ | 0.040 | | | |
| $\Delta p^{ene}$ | -1.746 | | | |

Note: The sample is 1987Q2 to 2006Q3. * denotes rejection of the hypothesis at the 0.05 level. Probability values are based on MacKinnon-Haug-Michelis (1999) reported by EViews. The VAR includes intercept and no trend. 4 lags were allowed in the VAR framework. The *t*-statistics are between square parentheses

From α coefficients (0.153, 0.008, 0.040, -1.746) we can infer that the highest average speed of adjustment towards the equilibrium corresponds to energy price. The estimated value (-1.746) means that a 1% deviation from the equilibrium will adjusts 1.746% each quarter toward the equilibrium. Labor and capital are characterized by a slow speed of adjustment, close to zero, indicating that any disequilibrium in the cointegrating relationship will not induce adjustments in those variables. This is confirmed by testing for weak exogeneity. Results indicate that labor and capital are weakly exogenous, while energy price and GDP (marginally) are not (see Table 19), confirming the idea that these variables are endogenously determined. In this context, weak exogeneity means that inference about the cointegrating vector can be performed on the conditional model without loss of information relative to the system analysis. Even though weak exogeneity is rejected for the case of energy price it is possible to develop a single-equation model following the ECM approach, considering the system estimates of the cointegrating vector as given (Ericsson et al., 1998; Metin, 1998).

Table 19: Weak exogeneity test statistics

| Variable | gdp | $k^{in}$ | $labor^{hc}$ | $p^{ene}$ |
|---|---|---|---|---|
| χ2 (1) | 2.289 | 0.099 | 0.381 | 12.511 |
| *p* value | 0.130 | 0.752 | 0.537 | 0.0004 |

The ECM approach, which is based on the Engle-Granger representation theorem (Engle and Granger, 1987), states that cointegrated variables can always be represented in an ECM model, which is stationary so that estimation and statistical inference can be performed following standard statistical methods. In this context, the ECM specification of the model is represented by the next equation:

$$\Delta GDP_t = \alpha + \sum_{i=1}^{4} \beta_i \Delta GDP_{t-i} + \sum_{i=0}^{4} \delta_i \Delta labor_{t-i}^{hc} + \sum_{i=0}^{4} \phi_i \Delta k_{t-i}^{in} + \sum_{i=0}^{4} \varphi_i p_{t-i}^{ene} + ecm_{t-1} + \xi_t$$

Where the lagged error-correction term is derived from Johansen's estimations:

$$ecm_{t-1} = \log GDP_{t-1} - 0.375\, k_{t-1}^{in} - 0.914\, labor_{t-1}^{hc} + 0.162\, p_{t-1}^{ene} - 2.07$$

This specification allows us to observe the dynamic relationship among the variables because the estimated coefficients are interpreted as short-run elasticities. In this framework, which includes only stationary variables at first differences, the growth rates of GDP is a function of its own lagged values and the current and lagged growth rates in labor, capital and the energy price plus the lagged error-correction term.

Table 20: Dynamic ECM Model of GDP

Dependent Variable Δlog_GDP / OLS Method

| Variable | Coefficient | Std.Error | t-value | t-prob |
|---|---|---|---|---|
| Δgdp(-1) | 0.224 | 0.131 | 1.706 | 0.094 |
| Δgdp(-2) | -0.077 | 0.133 | -0.576 | 0.567 |
| Δgdp(-3) | 0.099 | 0.142 | 0.702 | 0.486 |
| Δgdp(-4) | 0.058 | 0.140 | 0.415 | 0.680 |
| C | 0.011 | 0.006 | 1.975 | 0.053 |
| Δk | 0.905 | 0.427 | 2.119 | 0.038 |
| $\Delta k^{in}$ (-1) | -1.256 | 0.539 | -2.332 | 0.023 |
| $\Delta k^{in}$ (-2) | 0.771 | 0.585 | 1.319 | 0.193 |
| $\Delta k^{in}$ (-3) | 0.516 | 0.589 | 0.875 | 0.385 |
| $\Delta k^{in}$ (-4) | -1.216 | 0.478 | -2.543 | 0.014 |
| $\Delta labor^{hc}$ | 0.247 | 0.163 | 1.512 | 0.136 |
| $\Delta labor^{hc}$ (-1) | -0.077 | 0.161 | -0.477 | 0.635 |
| $\Delta labor^{hc}$ (-2) | -0.256 | 0.166 | -1.545 | 0.128 |
| $\Delta labor^{hc}$ (-3) | -0.109 | 0.147 | -0.743 | 0.461 |
| $\Delta labor^{hc}$ (-4) | 0.017 | 0.140 | 0.119 | 0.905 |
| $\Delta p^{ene}$ | -0.026 | 0.026 | -0.979 | 0.332 |
| $\Delta p^{ene}$ (-1) | 0.027 | 0.025 | 1.081 | 0.284 |
| $\Delta p^{ene}$ (-2) | -0.009 | 0.026 | -0.357 | 0.723 |
| $\Delta p^{ene}$ (-3) | -0.008 | 0.025 | -0.318 | 0.752 |
| $\Delta p^{ene}$ (-4) | 0.029 | 0.026 | 1.080 | 0.285 |
| ecm(-1) | -0.082 | 0.044 | -1.871 | 0.067 |

Breusch-Godfrey Serial Correlation LM Test: F-statistic 0.391[0.677]

ARCH Test: 0.096[0.756]

White Heteroscedasticity Test: F-statistic 0.587[0.949]

Normality Tests: Jarque Bera 1.683[0.431]

Ramsey RESET Test: F-statistic 0.0052[0.942]

Note: Four lags are allowed in each variable. The sample is 1987Q2 to 2006Q4 (n=38). $R^2$ = 0.369. F-statistic = 1.668 [0.068]. Standard error = 0.0127. DW = 2.034. Probability of the null is between square parentheses.

Estimation results and diagnostic statistics are reported in Table 20. The short-run version of the model has good properties according to diagnostic statistics and it does not suffer from autocorrelation, heteroscedasticity, misspecification or non-normality of the errors. However, the explanatory power is relatively low according to the $R^2$ value (0.36). The coefficient of the error term is negative, as theory predicts for the purpose of dynamic stability and cointegration, and significant at 10% but many of the coefficients are statistically not significant at any relevant level. The estimated value of the error term means that any movement from the equilibrium condition due to random shocks represents a significant determinant in the short-run dynamic behaviour, and disequilibrium is adjusted by 8.2% in each quarter. This value is lower to Gardner's (1996) estimation (0.29) for the US data. This result might reflect structural rigidities of the Chilean economy, possibly due to the existence of adjustment costs. This value could also be reflecting errors of agents from past decisions which seem reasonably in the energy market context.

To obtain a more interpretable and meaningful version of the dynamic model we follow a general to specific approach to develop a parsimonious equation, which consists of eliminating negligible and insignificant variables through a sequential reduction. The equation is again fitted over the same period, and *t*-statistics are reported between parentheses. The parsimonious version of the model suggests that the growth rate of output depends positively on the current growth rates of capital and labor, and negatively in the lagged growth rates of capital and labor (fourth and second respectively). Energy price is not present in the parsimonious estimation due to its low statistical significance, either current or lagged values. The error term is again negative and significant at 10% level, and the equation has good properties and does not suffer from autocorrelation, heteroscedasticity, misspecification or non-normality of the errors.

$$\Delta y_t = 0.012 + 0.658\Delta k_t - 0.790\Delta k_{t-4} + 0.149\Delta labor_t - 0.147\Delta labor_{t-2} - 0.065ecm_{t-1}$$

(2.454) (2.681) (-3.171) (1.218) (-1.248) (-1.688)

$R^2$ = 0.233, standard error = 0.012, F-statistic = 4.38 [0.001], DW = 1.68, Breusch-Godfrey Serial Correlation LM Test: F-statistic = 0.959 [0.435]; ARCH test: F-statistic = 0.958 [0.435], Normality test: Jarque-Bera Statistic $\chi^2(2)$ = 0.451 [0.798], White Heteroscedasticity Test (cross-terms): F-statistic = 1.584 [0.089]. Ramsey RESET Test: F-statistic 0.047[0.828].

To estimate the stability of the dynamic model we also use recursive least square estimation for the coefficients and the residuals. Using this tool we can investigate the constancy of the parameters from one-step innovations which is consistent in a dynamic process. The recursive coefficients all remain inside the two-standard error bands around the estimated ex-ante values, confirming reasonably stability of parameters (Figure 17). However, residual recursive estimation suggests a possible break in the latter quarters of the 90's (Figure 18). We contrast this result performing the CUSUM test (R.L.Brown et al., 1975) which is based on the cumulative sum of the recursive residuals. This option plots the cumulative sum together with the 5% critical lines. The test finds parameter instability if the cumulative sum goes outside the area between the two critical lines. Results indicate no significant structural disruptions (Figure 18), but breaks can not be totally discarded. Possibly, output and investments falls in the latter 90's levels due to Asian financial crisis post-effects are the main source of instability. To evaluate this possibility we include in the dynamic model a dummy variable to control for the external effects of the crisis in the local economy, from 1998:Q1 to 2000:Q2. Results with the dummy variable are much better than previous version of the model. The dummy variable itself is negative, as we expect, and highly significant with a *t*-value of -3.46 significant at 1% level. The coefficient of the error term (-0.12) imply a higher speed of adjustment and is significant at 1% level. The $R^2$ increase until 0.48 improving the explanatory power of the model, the *F*-statistic also increases until 2.46, significant at 5%, the standard error is lower than previous estimation (0.0116) and the DW value is 2.12. Based on these results we can assume that a good specification of the model must address the local effects of external shocks.

Figure 17: Recursive estimation of the dynamic model

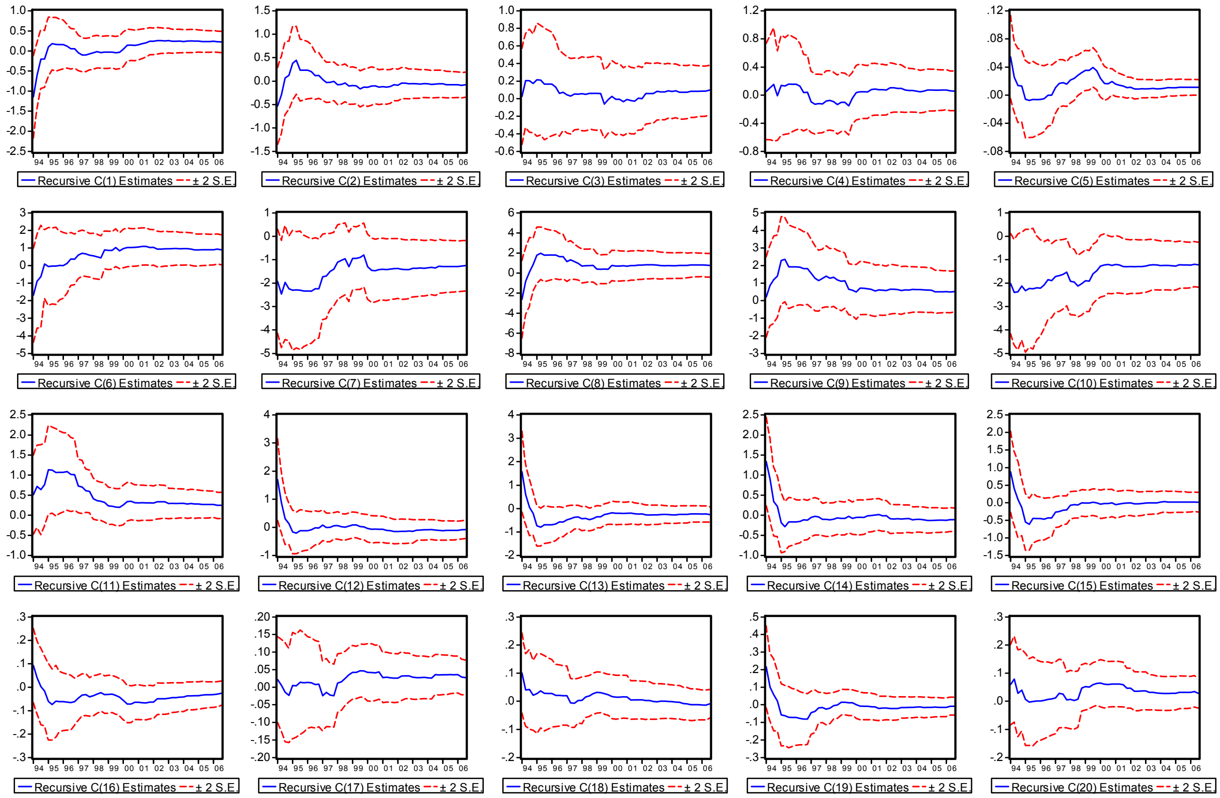
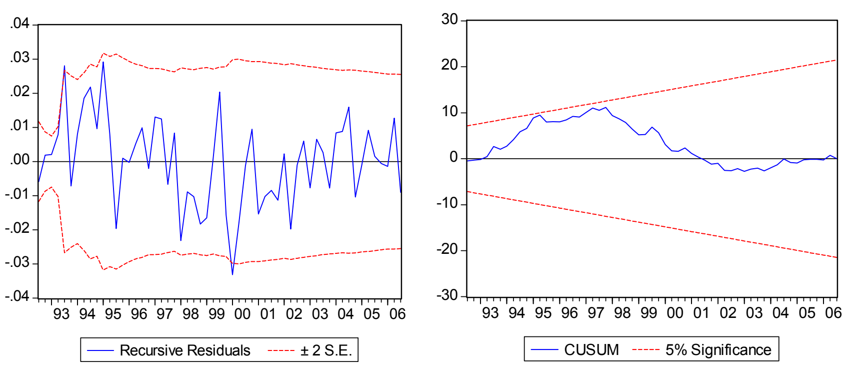



Figure 18: One step recursive residual estimation for the dynamic model




Note: The left panel shows the recursive residuals about the zero line. Plus and minus two standard errors are also shown. The right panel shows the CUSUM test. This option plots the cumulative sum together with the 5% critical lines.

## Conclusions

The purpose of this work was to test for the effects of energy price variations on aggregate output based on the Chilean context. The main contribution of this work is the use of several economic series for output, labor, capital and energy prices, in a neoclassical analysis framework. We use Engle-Granger and Johansen's multivariate maximum likelihood approaches to test and compare the existence of a long-run equilibrium between the variables.

The results of the tests indicate that most of the series are integrated of order one. We can also conclude that cointegration exist considering the different specifications of the model. Johansen's estimations suggest a single cointegration equation. This relationship states that in the long-run aggregate output depends positively on labor and capital, and negatively on energy price. The suggested price elasticity of output to energy price is between -0.085 and -0.16 depending on the model specification. Additionally, in the long-term output seems to be much more sensitive to changes in the labor force rather than changes in the capital stock. The low speed of adjustment suggests a low degree of the economy to correct disequilibrium in the short-run. Probably, a more flexible framework of the economy would generate more efficient adjustments to random shocks.

Policy-makers should be especially careful on designing energy policies. Even though the NREC law ("Ley 20.257") is based on environmental and strategic considerations, the implementation of this law might raise permanently energy prices by 10% which might decrease the log-run growth rate of output by roughly 1%. Energy price distortions due to energy policies should be avoided or, at least, the convenience of such policies must be evaluated considering the negative effects on the growth rate of aggregate output as well as the environmental implications. Future research on this field should also address the social implications across the population of having higher energy prices (employment, poverty and income distribution).

References

Akarca, A. T. and T. Long (1979). *"Energy and employment: a time-series analysis of the causal relationship."* Resources and Energy 2(2-3): 151-162.

Akinlo, A. E. (2008). *"Energy consumption and economic growth: Evidence from 11 Sub-Sahara African countries."* Energy Economics 30: 2391-2400.

Alam, M. S. (2006). *"Economic growth with energy."* MPRA paper: 1-25.

Asafu-Adjaye, J. (2000). *"The relationship between energy consumption, energy prices and economic growth: time series evidence from Asian developing countries."* Energy Economics 22(6): 615-625.

Bohi, D. R. (1989). *Energy price shocks and macroeconomic performance*. Washington.

Boyd, R. and T. Caporale (1996). *"Scarcity, resource price uncertainty, and economic growth."* Land Economics 72(3): 326-335.

Burbidge, J. and A. Harrison (1984). *"Testing for the effects of oil-price rises using vector autoregressions."* International Economic Review 25(2): 459-484.

Central Bank of Chile (2008). *Statistical Databases*.

CNE (2008). *Energy Statistics*, National Energy Commission,.

Chontanawat, J., L. C. Hunt, et al. (2008). *"Does energy consumption cause economic growth?: Evidence from a systematic study."* Journal of Policy Modeling 30(2): 209-220.

Darby, M. R. (1982). *"The price of oil and world inflation and recession."* The American Economic Review 72(4): 738-751.

Engle, R. F. and C. W. J. Granger (1987). *"Co-integration and error correction: representation, estimation, and testing."* Econometrica 55(2): 25.

Engle, R. F. and B. S. Yoo (1987). *"Forecasting and testing in co-integrated systems."* Journal of Econometrics 35(1).

Ericsson, N. R., D. F. Hendry, et al. (1998). *"Exogeneity, Cointegration, and Economic Policy Analysis."* Journal of Business & Economic Statistics 16(4): 370-387.

Erol, U. and E. S. H. Yu (1987). *"On the causal relationship between energy and income for industrialized countries."* Journal of Energy and Development 13: 113-122.

Finn, M. G. (1995). *"Variance properties of Solow's productivity residual and their cyclical implications."* Journal of Economic Dynamics and Control 19(5-7): 1249-1281.

Finn, M. G. (2000). *"Perfect Competition and the Effects of Energy Price Increases on Economic Activity."* Journal of Money, Credit and Banking 32(3): 400-416.

Galetovic, A. and C. Muñoz (2008). *"Energías renovables no convencionales: ¿cuánto nos van a costar?"* (1-46).

Galetovic, A. and C. Muñoz (2009). *"Estimating deficit probabilities with price-responsive demand in contract-based electricity markets."* Energy Policy 37(2): 560-569.

Gardner, T. A. and F. L. Joutz (1996). *"Economic growth, energy prices and technological innovation."* Southern Economic Journal 62(3): 653-666.

Ghali, K. H. and M. I. T. El-Sakka (2004). *"Energy use and output growth in Canada:a multivariate cointegration analysis."* Energy Economics 26(2): 225-238.

Glasure, Y. U. (2002). *"Energy and national income in Korea: further evidence on the role of omitted variables."* Energy Economics 24(4): 355-365.

Glasure, Y. U. and A.-R. Lee (1997). *"Cointegration, error-correction, and the relationship between GDP and energy: The case of South Korea and Singapore."* Resource and Energy Economics 20(1): 17-25.

Gujarati, D. N. (2004). *Basic Econometrics, Fourth Edition*, The McGraw-Hill Companies.

Hamilton, J. D. (1983). *"Oil and the macroeconomy since world war II."* The Journal of Political Economy 91(2): 228-248.

Johansen, S. and K. Juselius (1990). *"Maximum likelihood estimation and inference on cointegration - with applications to the demand for money."* Oxford Bulletin of Economics and Statistics 52(2): 43.

Jumbe, C. B. L. (2004). *"Cointegration and causality between electricity consumption and GDP: empirical evidence from Malawi."* Energy Economics 26(1): 61-68.

Kraft, J. and A. Kraft (1978). *"On the relationship between energy and GNP."* Journal of Energy and Development 3: 401-403.

Lee, C.-C. and C.-P. Chang (2008). *"Energy consumption and economic growth in Asian economies: A more comprehensive analysis using panel data."* Resource and Energy Economics 30(1): 50-65.

Lee, C.-C., C.-P. Chang, et al. (2008). *"Energy-income causality in OECD countries revisited: The key role of capital stock "* Energy Economics 30(5): 2359-2373.

Metin, K. (1998). *"The Relationship between Inflation and the Budget Deficit in Turkey."* Journal of Business & Economic Statistics 1998(16): 412-422.

Narayan, P. K. and R. Smyth (2008). *"Energy consumption and real GDP in G7 countries: New evidence from panel cointegration with structural breaks."* Energy Economics 30(5): 2331-2341.

Patterson, K. (2000). *An introduction to applied econometrics*, Palgrave.

R.L.Brown, J.Durbin, et al. (1975). *"Techniques for Testing the Constancy of Regression Relationships over Time "* Journal of the Royal Statistical Society 37(2): 149 - 192.

Rasche, R. H. and J. A. Tatom (1981). *Energy price shocks, aggregate supply and monetary policy: The theory and the international evidence*. Carnegie-Rochester Conference Series on Public Policy, North-Holland Publishing Company.

Rotemberg, J. and M. Woodford (1996). *"Imperfect competition and the effects of energy price increases on economic activity."* Journal of Money, Credit & Banking 28(4): 549-577.

Saunders, H. D. (1984). *"The macrodynamics of energy shocks, short- and long-run."* Energy Economics 6(1): 21-34.

Saunders, H. D. (1992). *"The khazzoom-brookes postulate and neoclassical growth."* The Energy Journal 13(4).

Solow, R. M. (1956). *"A contribution to the theory of economic growth."* The Quarterly Journal of Economics 70(1): 65-94.

Soytas, U. and R. Sari (2006). *"Can China contribute more to the fight against global warming?"* Journal of Policy Modeling 28(8): 837-846.

Stern, D. I. (1997). *"Limits to substitution and irreversibility in production and consumption: a neoclassical interpretation of ecological economics."* Ecological Economics 21(3): 197-215.

Stern, D. I. (2000). *"A multivariate cointegration analysis of the role of energy in the US macroeconomy."* Energy Economics 22(2): 267-283.

Stern, D. I. and C. J. Cleveland (2004). *"Energy and economic growth."* Working Papers in Economics(0410): 1-41.

Tatom, J. A. (1987). *"The macroeconomic effects of the recent fall in oil prices."* The Federal Reserve Bank of St. Louis Review June/July: 34-45.

Tatom, J. A. (1988). *"Macroeconomic Effects of the 1986 Oil Price Decline."* Contemporary Policy Issues VI.

Tatom, J. A. (1991). *"The 1990 oil price hike in perspective."* The Federal Reserve Bank of St. Louis Review November/December: 3-18.

Wolde-Rufael, Y. (2008). *"The long-run relationhsip between petroleum imports and economic growth: The case of Cyprus."* Resource, and Energy and Development 5: 95-103.

Wolde-Rufael, Y. (2009). *"Energy consumption and economic growth: The experience of African countries revisited."* Energy Economics 31(2): 217-224.

Yang, H.-Y. (2000). *"A note on the causal relationship between energy and GDP in Taiwan."* Energy Economics 20: 309-317.

Yu, E. S. H. and J. Y. Choi (1985). *"The causal relationship between energy and GNP: an international comparison."* Journal of Energy and Development 10: 249-272.

Yuan, J.-H., J.-G. Kang, et al. (2008). *"Energy consumption and economic growth: Evidence from China at both aggregated and disaggregated levels."* Energy Economics 30(6): 3077-3094.

# 54. Spatial analysis to optimize land use for bioenergy

**Stella Carballo[1], Alicia Anschau[1], Noelia Flores M.[2] Jorge Hilbert[2]**

Instituto Nacional de Tecnología Agropecuaria

(1) INTA-CIRN-Instituto de Clima y Agua – scarballo@cnia.inta.gov.ar

(2) INTA-CIA-Instituto de Ingeniería Rural – hilbert@cnia.inta.gov.ar

Palabras Clave: Sistemas de Información Geográfica, Biocombustibles, Bioenergía.

Resumen: La matriz energética argentina se caracteriza por estar basada en un 94% en combustibles fósiles, los cuales presentan en el contexto nacional, un horizonte de agotamiento cercano. Este hecho, muestra la necesidad de diversificarla incorporando paulatinamente fuentes de energía renovables (eólica, solar, hidráulica, biomasa, etc).

La aprobación de la ley 26093 de " Regulación y promoción para la producción y uso sustentable de biocombustibles" que obliga al corte paulatino del diesel y nafta con biocombustibles muestra la decisión del gobierno Argentino de encarar el tema..Por otra parte la ley 26190 que establece el "Régimen de fomento nacional para el uso de fuentes renovables de energía destinada a la producción de energía eléctrica" abre la posibilidad de incorporar la biomasa como recurso para la generación de bioelectricidad.

Argentina, es uno de los principales productores agrícolas en el mundo. Se estima, que el 10 % del biodiesel mundial, será producido en Argentina con gran parte de este porcentaje destinado a la exportación. En el 2008 la capacidad productiva de biodiesel pasó de 840.000 tn. a 1,4 millones de toneladas y se prevé un aumento sostenido hasta alcanzar una capacidad de producción en el 2011 de 3.947.000 tn.

En este contexto, se evidencia un aumento de presión agrícola sobre el territorio para expandir cultivos que puedan ser destinados a biocombustibles generando

competencia con otros usos y planteando dilemas éticos, ecológicos, y de sustentabilidad que deberán resolverse.

INTA se a abocado al análisis territorial elaborando un Atlas de Cultivos Bioenergéticos determinando las reales potencialidades y limitantes de los diversos cultivos para las diferentes ecorregiones del país

Por otro lado, nuestro país presenta cadenas agroindustriales y foresto industriales, en muchos casos de fuerte desarrollo local, de las que surgen residuos biomásicos en calidad y cantidad suficientes como para poder ser utilizados para la generación de energía eléctrica que permita el acceso al recurso a comunidades rurales desprovistas del mismo o bien genere ingresos adicionales a través de su venta a la red nacional.

Para abordar el estudio de los recursos biomásicos con este destino se ha generado un Sistema de Información Geográfica, para evaluar de forma espacializada el potencial de los recursos existentes e identificar áreas críticas de intervención contribuyendo al uso ordenado del territorio, desde la perspectiva de la sustentabilidad ecológica, económica, social, y medioambiental.

Los SIG desarrollados se han pensado como soporte técnico a decisiones gubernamentales y empresariales en bioenergía y como una herramienta de ordenamiento territorial y de gestión de los recursos.

Abstract: The Argentine energy matrix is composed by a height rate (94%) of fossil fuels, which display in the national context, a horizon of near exhaustion. This fact shows the necessity to diversify it through the gradual inclusion of other renewable energy sources (aeolian, solar, hydraulic, biomass, etc).

Argentine has a framework that regulates and promotes the use of biofuels since 2007. The law N 26093 of “Regulation and promotion for the production and sustainable use of biofuels”, mandates the gradual blending of diesel and gasoline with biofuels (5% by 2010). On the other hand the law Nº26190 establishes the “National promotion regime for the use of renewable energy sources destined to the production of electrical energy” opening the possibility to incorporate biomass as a source for electric generation.

Argentina is one of the main crop producers in the world. It is considered, that about 10% of the world-wide biodiesel, will be produced in Argentina, the greatest part for exportation. In the 2008 biodiesel production increased from 840,000 ton to 1.4 million tons and an increasing amount is expected for the next years until reaching a production around 4 million tons in the 2011.

An increasing pressure of agricultural land use is expected on the territory next years to expand cultures that can be destined to biofuels, intensifying the

competition with other uses and rising ethical, ecological and sustainability dilemmas, that will have to be analyzed and solved. INTA has been working in territorial analysis to estimate biomass potentials for energy supply in our country, assessing potential land availability for different biofuel crops or plantations to be made with ecological, economic and social sustainability criteria. The product obtained is a digital Atlas of Bioenergy Crops.

.INTA, also assumed the challenge to evaluate the wood- and agro-energy potential as renewable source for electrical generation. Our country presents agro-industrial and forest –industrial chains, in many cases with a strong local development, that would provide enough quality of biomass residues in the necessary amount to be used for electrical generation to supply rural communities improving their life standard or to sale to the national electrical net providing additional incomes for local economies..

Heterogeneous and fragmentized information was gathered and used to feed a GIS to estimate the biomass balance in our territory. The developed GIS could be considered as a strategic planning tool to support governmental and enterprise decisions about bioenergy and as an instrument for the territorial ordering and management of the resources.

1. - Introducción

Desde el año 2006 Argentina cuenta con un marco legal que regula y promueve la producción y uso de biocombustibles. La ley determina para el año 2010 un corte obligatorio del 5% de etanol en la nafta y 5% de biodiesel en el diesel. Para cumplir con este mandato, se estima que se necesitará un volumen de aproximadamente 250 millones de litros de etanol y 700 millones de litros de biodiesel (Hoff, 2007).

Las industrias productoras de biocombustibles tienen 3 alternativas:

1. Producir para el mercado doméstico, tomando ventajas de los incentivos impositivos,

2. Producir para el autoconsumo, con similares ventajas en los incentivos impositivos, y

3. Producir para el mercado externo, sujetos a controles gubernamentales, pero sin gozar de las ventajas impositivas.

El aumento del precio del petróleo que tuvo lugar en los años 2006, 2007 y primer semestre del 2008, impulsó la inversión privada en proyectos de producción de biocombustibles con destino a exportación. En la tabla 1 se resumen los proyectos existentes, con su estado de avance, tanto para el etanol, mientras que en la tabla 2 se resumen los proyectos para biodiesel.

| Empresa | Capacidad (m3/año) | Ubicación | Mat. Prima utilizada | Estado de Desarrollo |
|---|---|---|---|---|
| Los Balcanes SA | 126.000 | La Florida – Tucumán | Caña de azúcar | Operativo |
| Soros | 200.000 | V. Tuerto – Sta. Fé | Maiz | Proyecto |
| Ledesma SA | | Lib. S. Martín – Jujuy | Caña de azúcar | Construcción |
| Tabacal | | Orán – Salta | Caña – Sorgo | Construcción |
| ARCOR | 100.000 | San Pedro – Bs. As. | Maiz | Proyecto |
| Bioetanol Río Cuarto SA | 50.000 | Río IV – Córdoba | Maiz | Proyecto |
| San José | 100.000 | San Luis - SL | Maiz | Proyecto |

Tabla 1. Plantas de Bioetanol en Argentina

| Empresa | Capacidad (tn/año) | Ubicación | Mat. Prima utilizada | Estado de Desarrollo |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| Renova | 200.000 | San Lorenzo – Sta. Fé | | Operativo |
| Ecofuel | 200.000 | Pto. San Martín – Sta. Fé | | Operativo |
| Vicentín | 47.500 | Avellaneda – Sta. Fé | | Operativo |
| Biodiesel | 6.800 | Sancti Spiritu – Sta. Fé | | Operativo |
| Emp Sanluiseña Energía Ar | 30.000 | Vª. Mercedes – S. Luis | | Operativo |
| Biomadero | 72.000 | Vª. Madero – Bs. As. | | Operativo |
| Soy Energy | 32.400 | Vª Astolfi – Bs. As. | | Operativo |
| Adv. Organic Materials | 15.800 | PIP – Pilar – Bs. As. | | Operativo |
| Louis Dreyfus | 300.000 | Gral. Lagos – Sta. Fé | | Construcción |
| Patagonia Bioenergía | 250.000 | San Lorenzo – Sta. Fé | | Construcción |
| Renova | 200.000 | San Lorenzo – Sta. Fé | | Ampliación |
| Unitec Bio - Eurnekian | 200.000 | Pto. San Martín – Sta. Fé | | Construcción |
| Explora | 120.000 | Pto. San Martín – Sta. Fé | | Construcción |
| Molinos Río de la Plata | 100.000 | Rosario – Sta. Fé | | Construcción |
| Villuco | 100.000 | Pinto – Sgo. Del Estero | | Proyecto |
| Prarex | 100.000 | Pinto – Sgo. Del Estero | | Proyecto |
| Biocombustibles Federales | 20.000 | Pampa del Infierno – SE | | Proyecto |
| Patagonia Bioenergía | 250.000 | San Lorenzo – Sta. Fé | | Proyecto |
| Oil Fox | 250.000 | San Lorenzo – Sta. Fé | | Proyecto |
| Asoc. Coop. Argentinas | 200.000 | Pto. San Martín – Sta. Fé | | Proyecto |
| Raiser - Enarsa | 200.000 | Timbúes – Sta. Fé | | Proyecto |
| Cargill | 200.000 | Pto. San Martín – Sta. Fé | | Proyecto |
| Oil M&S | 200.000 | Rosario – Sta. Fé | | Proyecto |
| Saraceni | 200.000 | Rosario – Sta. Fé | | Proyecto |
| GEA | 200.000 | San Lorenzo – Sta. Fé | | Proyecto |
| Explora | 120.000 | Pto. San Martín – Sta. Fé | | Proyecto |
| Repsol YPF | 100.000 | San Lorenzo – Sta. Fé | | Proyecto |

| | | | | |
|---|---|---|---|---|
| Agric. Federados Arg. | 100.000 | Vª Constitución – Sta. Fé | | Proyecto |
| IBI | 60.000 | Rosario – Sta. Fé | | Proyecto |
| Agroindustrias Tejedor | 60.000 | San Lorenzo – Sta. Fé | | Proyecto |
| Rosario Bioenergy | 30.000 | Rosario – Sta. Fé | | Proyecto |
| Diferal | 30.000 | Rosario – Sta. Fé | | Proyecto |
| Energías Renovables Arg. | 1.000 | Piamonte – Sta. Fé | | Proyecto |
| Unitec Bio - Eurnekian | | Santa Fé | | Proyecto |
| Biooil Dynamotive | 70.000 | Misiones y Corrientes | | Proyecto |
| Goldaracena | 40.000 | Gualeguaychú – ER | | Proyecto |
| Louis Dreyfus | 300.000 | Bahía Blanca – Bs. As. | | Proyecto |
| Greenlife | 150.000 | Bahía Blanca – Bs. As. | | Proyecto |
| Oil Fox | 100.000 | San Nicolás – Bs. As. | | Proyecto |
| Bioenergía Bragado | 12.000 | Bragado – Bs. As. | | Proyecto |
| BGS Group | 200.000 | | | Proyecto |
| Pure Biodiesel | 200.000 | | | Proyecto |
| Imperial Renewables | 200.000 | | | Proyecto |
| Entaban | 100.000 | | | Proyecto |

Tabla 2. Plantas de Biodiesel en Argentina

La distribución y escala de los proyectos existentes para la producción de biodiesel se visualizan en el mapa de la Figura1 mostrando una marcada concentración en el área de molineras y puertos que se extienden desde Rosario hasta Santa Fe..

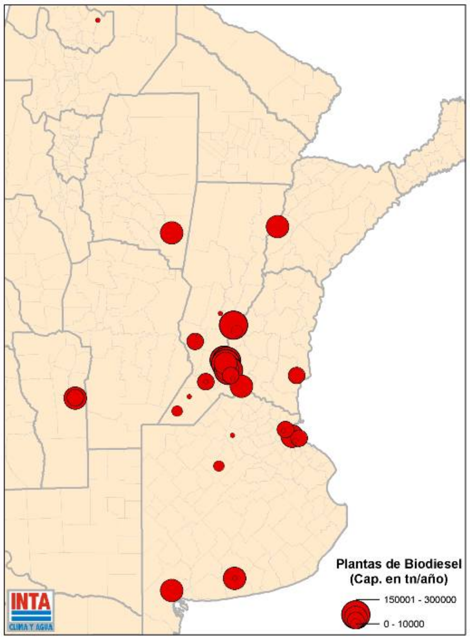



Figura 11. Plantas de producción de Biodiesel

Las exportaciones crecieron desde las 300.000 toneladas de biodiesel alcanzadas en el 2007, a las 1,4 millones de toneladas que se concretaron en el 2008. En cuanto al etanol, en el 2006 la producción total fue de 230.000 $m^3$, de los cuales el 40% fue exportado, siendo los principales destinos Estados Unidos y Unión Europea (CEADS-CAI, 2008).

Para incentivar los proyectos de etanol , con el objeto de alcanzar los volúmenes requeridos por el corte de naftas a nivel nacional en el 2010, el gobierno argentino anunció a fines del 2008, medidas que pretenden estimular inversiones por U$S 500 millones para el desarrollo de proyectos en las regiones del NOA y NEA. La inversión se repartirá entre las provincias de Tucumán, Salta, Jujuy, Chaco, Formosa, Misiones y Santa Fe.

Argentina posee diversos ecosistemas que le permiten producir un abanico de cultivos que le dan una gran flexibilidad a la hora de transformarlos en energías renovables.

Frente al aumento de la presión agrícola sobre el territorio y el planteo de dilemas éticos, ecológicos y de sustentabilidad que deben resolverse surge el Proyecto Nacional de Biocombustibles del INTA que intenta fijar los criterios técnicos necesarios para estimar el potencial de las diferentes alternativas a lo largo del territorio nacional. Dentro de este proyecto marco se ha comenzado con la construcción de un Atlas Nacional de Recursos Bioenergéticos, generado dentro de una estructura SIG y en el que converge toda la información relevante.

A la vez , se han establecido redes de evaluación de cultivos energéticos que cumplen con las condiciones de sustentabilidad ecológica, económica y social en las diferentes eco-regiones del país..En este sentido el INTA ha creado diversos programas para el desarrollo de paquetes tecnológicos destinados a la producción de biocombustibles a partir de cultivos tradicionales y no tradicionales, y está investigando el potencial de diferentes pasturas nativas y foráneas como el pasto varilla (switch grass). Se da particular importancia a los cultivos no tradicionales o pasturas que puedan desarrollarse en áreas no aptas para la agricultura, y que no representen una competencia por el uso de la tierra con la producción de alimentos.

## 2. – Materiales y Métodos

La metodología de trabajo combina el enfoque agro ecológico con técnicas de análisis de información satelital y uso de sistemas de información geográficos, para lograr la integración y poder evaluar los numerosos factores convergentes en la definición del potencial de expansión de cultivos aptos para la producción de biocombustibles y definir riesgos o vulnerabilidades en las distintas áreas.

Se comenzó por seleccionar aquellos cultivos que por sus antecedentes productivos puedan considerarse especialmente útiles para la producción de biocombustibles e identificar las exigencias, límites y tolerancias meteorológicas de cada uno de ellos, en función de las características climáticas de sus áreas de origen, donde el cultivo es exitoso a nivel mundial, y de la información disponible en trabajos previos de agro-climatología a nivel nacional e internacional.

Los principales cultivos seleccionados y analizados se detallan en la tabla 3.

| Biodiesel | Bioetanol |
|---|---|
| Algodón | Caña de Azúcar |
| Colza | Maíz |
| Girasol | Remolacha Azucarera |
| Jatropha | Sorgo Azucarero |
| Olivo | Arroz |
| Ricino | Pawlonia |
| Soja | Pasto Varilla |
| Cártamo | |

| | |
|---|---|
| Mani | |

Tabla 3. Cultivos analizados en el atlas de recursos bioenergéticos

Aptitud Agroclimática

La información acerca de los requerimientos agroclimáticos de los distintos cultivos fue analizada e incorporada al sistema de información geográfico, obteniéndose, a partir de las bases de datos meteorológicos disponibles a nivel nacional, los límites geográficos de las diferentes variables climáticas que definen y separan las condiciones de aptitud alta, media, baja y marginal de las zonas no aptas. Algunas de las variables analizadas fueron: requerimientos hídricos y térmicos, respuesta a la radiación solar, necesidades de fotoperíodo, efectos de las heladas y golpes de calor.

Como resultado se obtuvo una serie de mapas de Aptitud Agroclimática, en los que se definen áreas con diferentes grados de aptitud

A modo de ejemplo, se ilustran a continuación, los mapas de aptitud agroclimática de la soja, ya que es el principal cultivo en superficie de Argentina , con posibilidades de ser utilizado para la obtención de biodiesel y los correspondientes al sorgo azucarero y la caña de azúcar, con posible destino a biotanol. Como ejemplo de cultivos no tradicionales se ha elegido la Jatropha Curcas (Piñón manso), ya que es una especie poco conocida en Argentina que se pretende difundir y sobre la cual no existe mucha información ni experiencia en nuestro país.

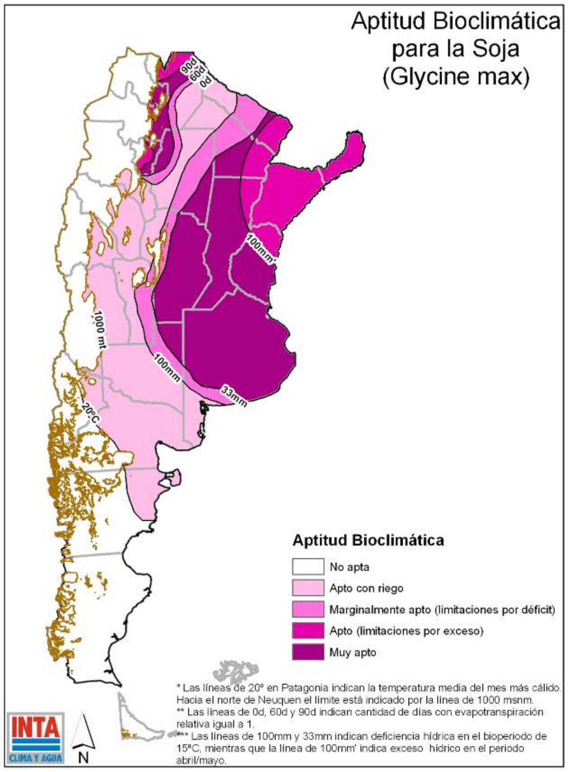



Figura 12. Aptitud Bioclimática para la SOJA

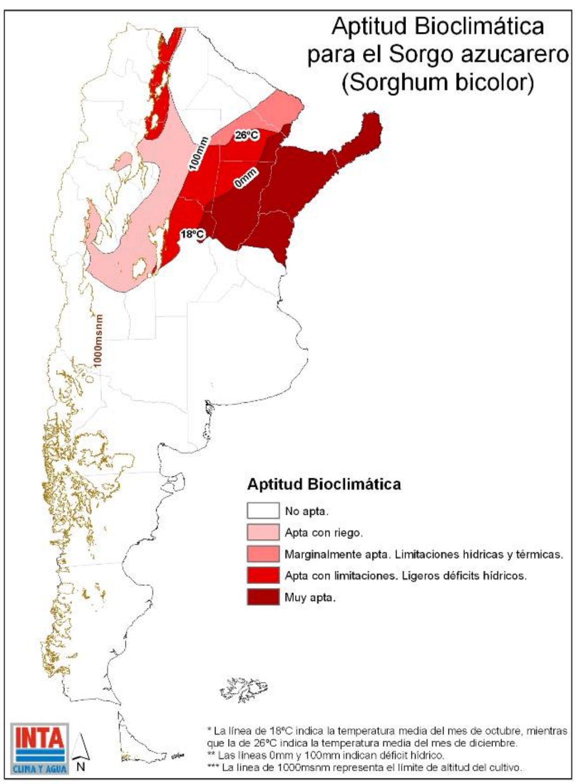
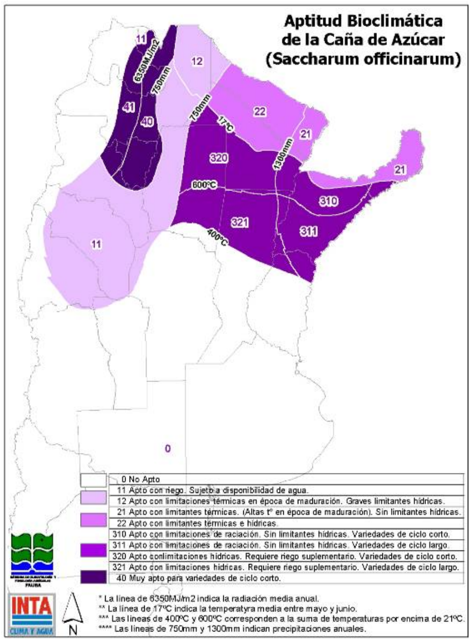



Figura 13. Aptitud bioclilmática para el SORGO AZUCARERO



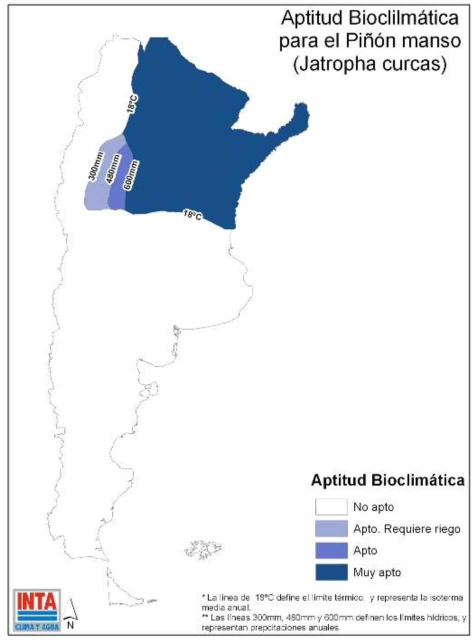




Figura 14. Apt. Bioclim CAÑA de AZÚCAR Figura 15. Apt. Bioclim JATROPHA

## Aptitud Edáfica

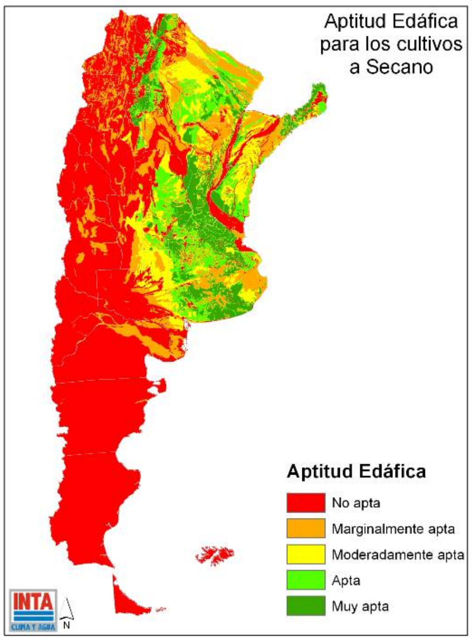
Se han analizado los requerimientos edáficos de cada cultivo, tales como textura, profundidad y relieve, y teniendo en cuenta estas características, se han confeccionado mapas de suelos para cada cultivo, clasificados según las clases de capacidad de uso de las tierras (USDA-SCS). Esta categorización asigna a las tierras aptas para cultivos valores que van desde el I al IV; y a las tierras de uso limitado o nulo, valores comprendidos entre V y VIII. A su vez establece subclases de capacidad de usos que obedecen a unidades con el mismo tipo de limitaciones dominantes para su uso agrario, provenientes del suelo y clima, siendo estas erosión (e), exceso de humedad, drenaje deficiente o peligro de inundación (w), limitaciones en la zona de actividad radical (s) y limitaciones climáticas (c).

En el presente trabajo se ha tomado como base el Atlas de Suelos de INTA levantado en las décadas del sesenta y setenta y digitalizado en 1996, el cual fue ajustado espacialmente con imágenes Landsat TM y Landsat ETM+. En algunos casos la capacidad de uso ha sido modificada teniendo en cuenta la información que ofrecen las imágenes de satélite y considerando los avances en materia de tecnología de los cultivos y genética que permitieron cambiar la capacidad de producción de ciertas áreas.

El resultado de esta etapa fue una serie de mapas de Aptitud Edáfica para cada cultivo analizado.

El mapa de la figura 6 refleja los distintos niveles de aptitud edáfica para cultivos a secano tradicionales, como por ejemplo soja o maíz..

La figura 7 ilustra las capacidades edáficas para uno de los cultivos no tradicionales analizados: la Jatropha, el cual presenta características de rusticidad que lo convierten en resistente aún en suelos marginales (Carballo, 2008).



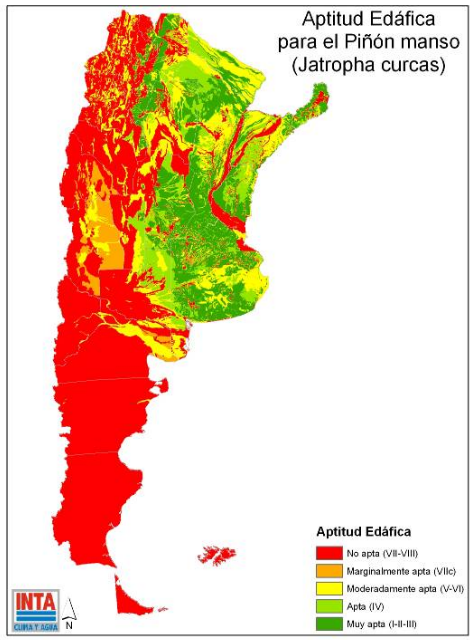
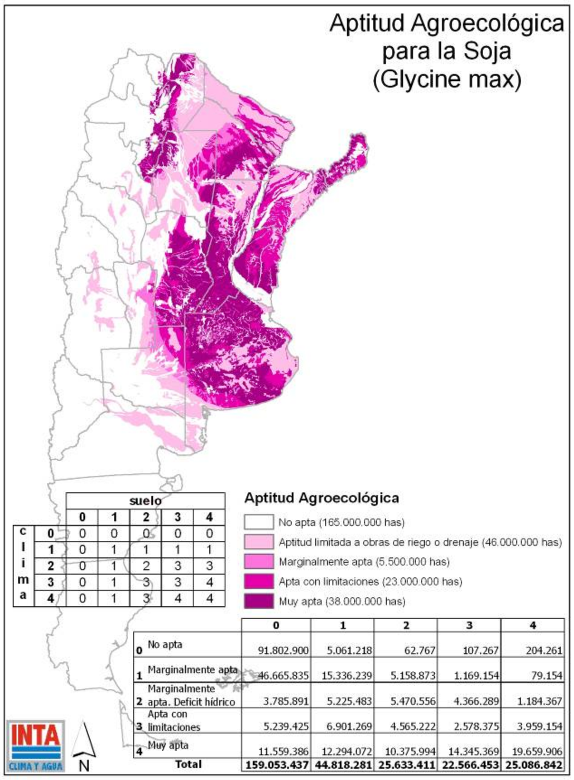




Figura 16. Apt. Edáfica SECANO Figura 17. Apt. Edáfica JATROPHA

Aptitud Agroecológica

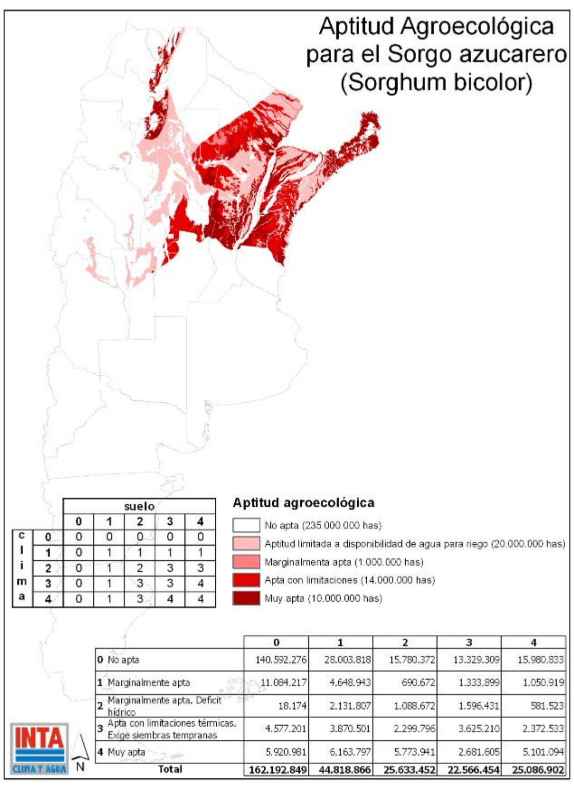
Una vez delimitadas las áreas tanto por su aptitud agroclimática, como por su aptitud edáfica, se han elaborado matrices para relacionar los requerimientos de los cultivos en ambos sentidos, y mediante técnicas de análisis espacial se ha obtenido una cartografía en la cual quedan expresadas distintas regiones con aptitudes agroecológicas diferenciadas.




| clima \ suelo | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 1 | 1 | 1 | 1 |
| 2 | 0 | 1 | 2 | 3 | 3 |
| 3 | 0 | 1 | 3 | 3 | 4 |
| 4 | 0 | 1 | 3 | 4 | 4 |

| | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 0 No apta | 91.802.900 | 5.061.218 | 62.767 | 107.267 | 204.261 |
| 1 Marginalmente apta | 46.665.835 | 15.336.239 | 5.158.873 | 1.169.154 | 79.154 |
| 2 Marginalmente apta. Deficit hídrico | 3.785.891 | 5.225.483 | 5.470.556 | 4.366.289 | 1.184.367 |
| 3 Apta con limitaciones | 5.239.425 | 6.901.269 | 4.565.222 | 2.578.375 | 3.959.154 |
| 4 Muy apta | 11.559.386 | 12.294.072 | 10.375.994 | 14.345.369 | 19.659.906 |
| Total | **159.053.437** | **44.818.281** | **25.633.411** | **22.566.453** | **25.086.842** |

Figura 18. Apt. Agroecológica SOJA




| clima \ suelo | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 0 |
| 1 | 0 | 1 | 1 | 1 | 1 |
| 2 | 0 | 1 | 2 | 3 | 3 |
| 3 | 0 | 1 | 3 | 3 | 4 |
| 4 | 0 | 1 | 3 | 4 | 4 |

| | 0 | 1 | 2 | 3 | 4 |
|---|---|---|---|---|---|
| 0 No apta | 140.592.276 | 28.003.818 | 15.780.372 | 13.329.309 | 15.980.833 |
| 1 Marginalmente apta | 11.084.217 | 4.648.943 | 690.672 | 1.333.899 | 1.050.919 |
| 2 Marginalmente apta. Deficit hídrico | 18.174 | 2.131.807 | 1.088.672 | 1.596.431 | 581.523 |
| 3 Apta con limitaciones térmicas. Exige siembras tempranas | 4.577.201 | 3.870.501 | 2.299.796 | 3.625.210 | 2.372.533 |
| 4 Muy apta | 5.920.981 | 6.163.797 | 5.773.941 | 2.681.605 | 5.101.094 |
| Total | **162.192.849** | **44.818.866** | **25.633.452** | **22.566.454** | **25.086.902** |

Figura 19. Apt. Agroecológica SORGO AZUCARERO

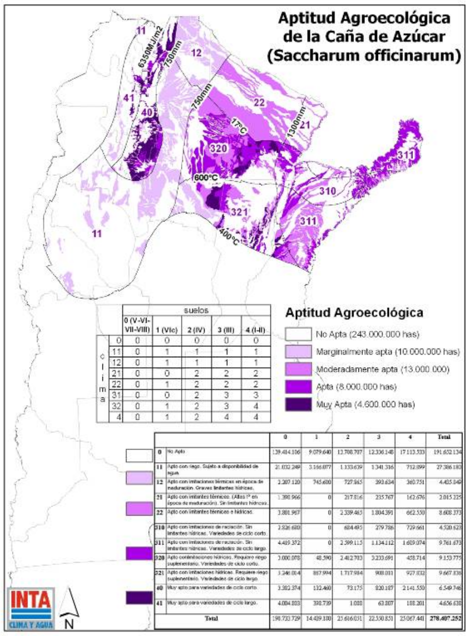



Figura 20. Apt. Agroecológica CAÑA

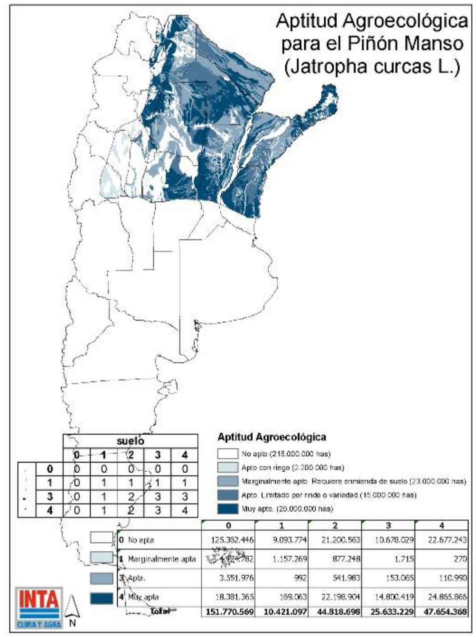



Figura 21. Apt. Agroecológica JATROPHA

Restricciones a la posible expansión de los cultivos.

Para poder determinar, con criterios de sustentabilidad, las áreas donde los diferentes cultivos podrían ser expandidos sin atentar con la biodiversidad, fue necesario recopilar información cartográfica que refleje aquellas zonas que presentan restricciones para su uso.

Se tomaron en cuenta las áreas cubiertas con bosques o montes nativos sobre las cuales la Ley de Pesupuestos Minímos aprobada durante el 2008 ha fijado restricciones de uso específicas, las forestaciones implantadas y las áreas protegidas.

A los fines de identificar las zonas de bosque o monte nativo se consideraron los datos de la Secretaría de Ambiente y Desarrollo Sustentable (SAyDS, 2007), donde se identifican las áreas correspondientes a tierras forestales nativas distribuidas en las distintas ecorregiones del territorio nacional. Para reconocer las tierras con plantaciones forestales, se incorporaron los datos provenientes del Inventario Nacional de Plantaciones Forestales de la Secretaría de Agricultura, Ganadería, Pesca y Alimentación (SAGPyA, 2001), sobre los cuales se realizó una actualización mediante técnicas de fotointerpretación sobre imágenes Landsat. Y finalmente, para identificar las áreas que están sometidas a algún régimen de protección jurídica, ya sean éstas parques nacionales o provinciales, reservas naturales o cualquier otra designación con objetivos específicos de conservación,  se hizo una recopilación de información existente a partir de diversas fuentes, tomando como referencia la documentación existente en el Sistema Federal de Áreas Protegidas (SIFAP) y del World Database on Protected Areas (WDPA), y toda esta información fue cartografiada y compilada para generar el mapa de áreas protegidas.

En la figura 12 se representan las áreas identificadas como áreas protegidas, plantaciones forestales o bosque nativos, las cuales posteriormente serán utilizadas para definir zonas de restricción de avance de las actividades agrícolas.

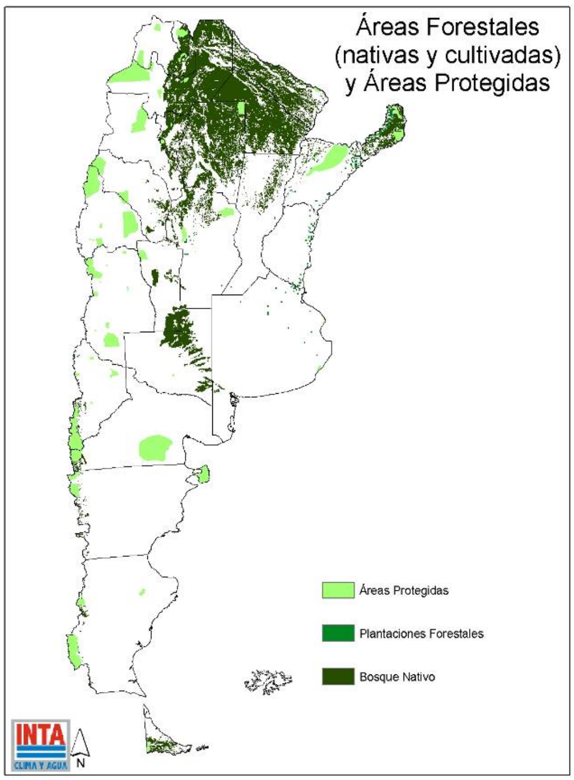



Figura 22. Áreas restringidas a la actividad agrícola

El mapa resultante del paso anterior fue combinado con los mapas de aptitud agroecológica para cada cultivo, para obtener de esta manera, los mapas de superficie de expansión potencial de cada uno de los cultivos.

## 3. - Resultados

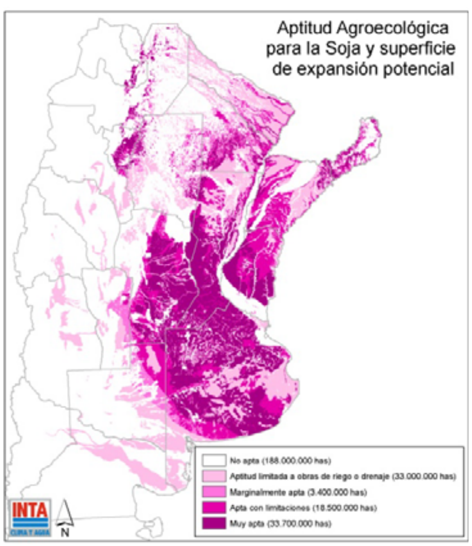
A través de esta metodología de trabajo, se han reconocido, a lo largo del territorio nacional, las áreas en las que potencialmente podrían desarrollarse o expandirse distintos cultivos destinados a la producción de biocombustibles con criterios de sustentabilidad agroecológica y ambiental.

A modo de ejemplo se detallan las superficies con diferente aptitud para cultivos tradicionales tales como soja, sorgo y caña de azúcar y no tradicionales como la Jatropha y se muestran los mapas obtenidos teniendo en cuenta restricciones ambientales a los procesos de expansión .

.

| | MUY APTO | APTO | MODERADAMENTE APTO | MARGINALMENTE APTO |
|---|---|---|---|---|
| SOJA | 33,7 | 18,5 | 3,4 | 33 |
| SORGO | 8 | 11 | 0,5 | 14 |
| CAÑA DE AZÚCAR | 2,5 | 5,2 | 7,4 | 4,7 |
| JATROPHA | - | 2,8 | 0,8 | 1,7 |

Tabla 4. Superficies de expansión potencial (millones de hectáreas)



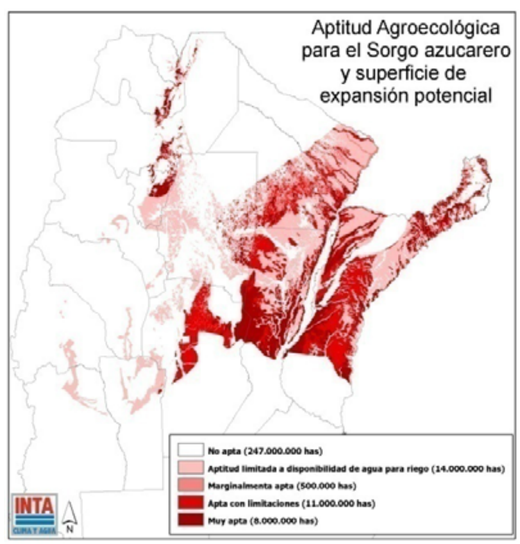
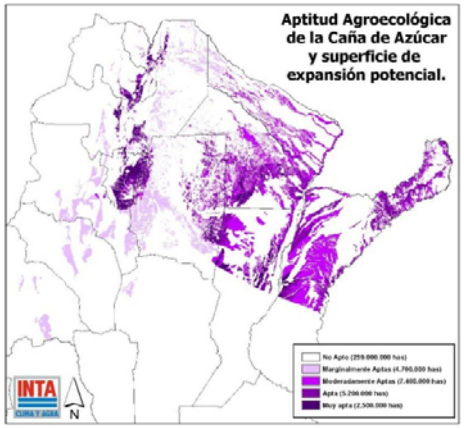




Fig13. Areas expansión potencial SOJA Fig14. Areas expansión potencial SORGO AZUCARERO



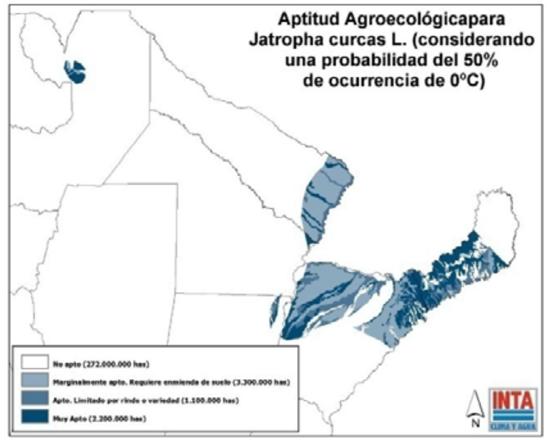




Fig15. Areas expansión potencial CAÑA   Fig16. Areas expansión potencial JATROPHA

Es importante considerar que en las áreas indicadas como agroecológica y ambientalmente aptas, para los diferentes cultivos, existen situaciones de solapamiento de superficie que deberán ser resueltos considerando información de orden económico que exige el análisis detallado en cada zona de costo de insumos, costo de labores, rendimientos, logística de comercialización, precio internacional, etc para definir la rentabilidad neta ,que en definitiva inclinará la preferencia por uno u otro cultivo en las diferentes zonas.

También deberán tenerse en cuenta razones sociales para favorecer con medidas de incentivo fiscal o crediticio la preferencia por determinados cultivos que sean demandantes de mayor mano de obra tanto en el proceso productivo como en el de transformación para cumplir con el criterio de sustentabilidad social que debe primar en los proyectos de desarrollo.

La oferta y demanda de recursos biomásicos (bosque y monte nativos, cultivos, plantaciones y residuos agro y foresto industriales) para generación de energía fueron siendo evaluados a través de la aplicación de la metodología WISDOM de FAO y volcados a Sistema de Información Geográfico para que pueda ser utilizado por los planificadores de políticas energéticas a nivel nacional y por inversores ateniéndose a los beneficios de la ley de fomento Nº 26190..

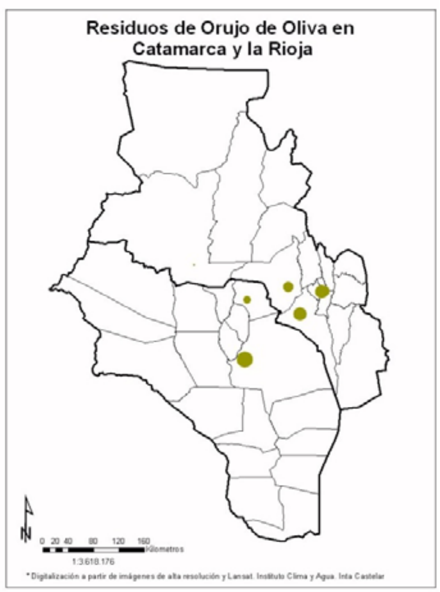
La bajada de la información a nivel provincial resultó imperativa ya que los recursos naturales en Argentina son propiedad de cada provincia y existe legislación específica para su manejo y protección.

La explotación de los recursos biomásicos (permisos de deforestación), las promociones a determinados cultivos o actividades agrícolas o forestales mediante políticas impositivas o crediticias específicas, junto a las condiciones socioeconómicas presentes en cada provincia crean un marco único para las inversiones que obliga al análisis sitio-específico.

Como ejemplo de la tarea realizada a nivel provincial se muestra el estudio realizado con las cadenas agroalimentarias regionales del olivo y vid en las provincias de Catamarca y La Rioja , desde la perspectiva de la probable utilización de los residuos en la generación de energía eléctrica.

Para abordar el estudio se incorporó al SIG nacional la información espacializada que permitiera evaluar el potencial del recurso. La información generada permitió proyectar la localización estratégica y dimensiones de las probables plantas de producción de energía eléctrica.

El mapa de la figura 17 muestra la localización de plantas de producción de aceite de oliva con la evaluación del volumen de residuos remanentes.




.

Fig17. Localización de plantas y evaluación de residuos de orujo de oliva.

La tabla 5 muestra la cantidad de residuos de orujo de oliva, su localización y la conversión energética que podría generarse en ambas provincias.

| Provincia | Localidad | Departamento | Kg de orujo | Tn de orujo | Total kj |
|---|---|---|---|---|---|
| CATAMARCA | CAPAYAN | CAPAYAN | 7.820.000 | 7820 | 123.556.000.000 |
| CATAMARCA | POMAN | POMAN | 4.692.000 | 4692 | 74.133.600.000 |
| CATAMARCA | SAN FERNANDO DEL VALLE DE CATAMARCA | CAPITAL | 9.384.000 | 9384 | 148.267.200.000 |
| CATAMARCA | TINOGASTA | TINOGASTA | 1.564.000 | 1564 | 24.711.200.000 |
| CATAMARCA | VILLA DOLORES | VALLE VIEJO | 3.128.000 | 3128 | 49.422.400.000 |
| LA RIOJA | AIMOGASTA | ARAUCO | 2.252.000 | 2252 | 35.581.600.000 |
| LA RIOJA | LA RIOJA | CAPITAL | 45.941.000 | 45.941 | 725.867.800.000 |

Tabla 5. Residuos de orujo y conversión energética.

Idéntico trabajo se realizó con la cadena de frutales de ambas provincias y finalmente se analizó la probable instalación de plantas de generación eléctrica, optimizando su localización y dimensionamiento.

A modo de ejemplo se muestra en el mapa de la figura 18.la probable localización de una planta en Valle Viejo utilizando residuos del área adyacente estimados en 78.000Tn lo que permitiría la instalación de una planta de 10MW de potencia.

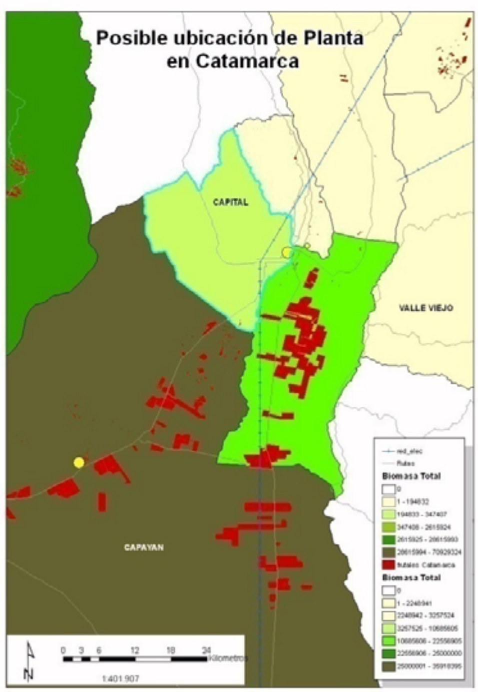


Fig18. Optimización de localización de plantas de generación de energía eléctrica.

4. - Conclusiones

La alteración del medioambiente es inevitable cuando los recursos son explotados pero debe existir un límite de uso o una forma racional de utilización del mismo para evitar la destrucción del patrimonio ecológico, facilitando su manejo racional con ventajas para los inversores y también para las poblaciones que se nutren de ese patrimonio natural.

El avance de la frontera agrícola sobre áreas marginales obliga a un conocimiento profundo del comportamiento de los sistemas agrícolas en condiciones próximas al límite de tolerancia ecológica.

El avance de la tecnología y la facilidad de manejo de grandes cantidades de información geoespacializada permite hoy efectuar un desarrollo racional atendiendo principalmente cuestiones ligadas al desarrollo territorial, el equilibrio ambiental y la rentabilidad de la producción para que la misma sea sustentable en el tiempo. El SIG desarrollado se ha pensado como soporte técnico a las decisiones gubernamentales y empresariales en bioenergía.

Constituye una herramienta de gran utilidad a la hora de considerar y evaluar proyectos de inversión destinados a la implantación de cultivos orientados a la generación de biocombustibles, especialmente aquellos que se proyecten sobre zonas marginales o de alta biodiversidad.

Por otra parte, la evaluación del potencial de residuos biomásicos derivados de las diferentes cadenas agroindustriales regionales para la generación de energía eléctrica contribuye a la posible captación de inversiones que permitirían dinamizar las economías regionales facilitando la optimización de la localización y dimensionamiento de las plantas de generación eléctrica a partir de recursos renovables. De concretarse estos proyectos producirían un impacto positivo sobre el medio ambiente, al prescindir de la energía fósil y evitar emisiones de $CO_2$ por quema de residuos o contaminación de suelos y agua por deposición de los mismos.

Este trabajo pretende aportar una visión amplia , a nivel nacional, de las potencialidades agroecológicas de las diferentes zonas del país para la difusión de cultivos que podrían ser derivados a bioenergía , teniendo en cuenta criterios de sustentabilidad ambiental, económico y social.

5.- Referencias

Carballo, S., Anschau, A., Flores M., N. y Hilbert, J. “Evaluación de las vulnerabilidades y potencial de expansión del cultivo de Piñón Manso (Jatropha curcas L.) en Argentina.”, Revista IDIA XXI.

CEADS-CAI, 2008. Consejo Empresario Argentino para el Desarrollo Sostenible, Centro Argentino de Ingenieros. “Perspectivas de los Biocombustibles en Argentina.”

INTA. 1996. “Atlas digital de suelos de la República Argentina.”

SAyDS. 2007. “Primer Inventario Nacional de Bosques Nativos. Proyecto de Bosques Nativos y Áreas Protegidas.” BIRF 4085-AR. 1198-2005.

SAGPyA, 2001. PROYECTO FORESTAL DE DESARROLLO. “Argentina: Inventario Forestal de Plantaciones Forestales.” Buenos Aires.

## 55. Bioactivated Process: Energy saving in the elimination

**Mallia M. Auxilia, Dautant S. Rafael, Fernández Celeste, Llobregat María José**

## of high organic loads in wastewater

Mallia M. Auxilia, Address: Flor Amarillo, Calle El Rosario, No. 37, Valencia, Estado Carabobo, Venezuela. University of Carabobo.Telephone: 58 241 878-3749. E-mail: amallia@uc.edu.ve, admallia@yahoo.es, admallia@gmail.com

Key words: Bioactivated , Biofilm , Suspended Biomass.

Abstract

Water is one of the fundamental natural resources that together with air, soil and energy constitute the four basic resources for the development of life, thus the importance of the quality of water. However, the treatment of water after being used for domestic, commercial and industrial purposes has been slow to develop. It is interesting to point out that it was not until the end of the XIX century that water was recognized as the source of numerous infectious illnesses due to the elimination of sewage water. Nowadays, both the quantity as well as the quality of water are necessary to satisfy the health and wellbeing of all forms of life on the planet.

It should be noted that nowadays, the sustainable development of life is based on water, that is, this resource is used worldwide for all daily activities. From feeding to recreational activities in some of its phases, all require the use of this natural

resource. Due to the very diverse activities carried out by mankind, it uses but does not renew or recycle wastewater. Therefore, if any natural resource is used in great amounts and is not preserved adequately, it can reach a level where this natural, life-sustaining element is depleted. The reasons previously stated motivate every country to make water a completely renewable resource through the implementation of new technologies in the treatment of wastewater.

Nature has an amazing ability to “clean” small quantities of wastewater and contamination. If it were to take charge of the thousands of millions of gallons of water and drainage that man produces daily, it would not have enough capacity to do so. That is the reason why liquid waste treatment installations are so important and justified, being that they reduce the contamination in wastewater to a level that nature can handle.

On the other hand, society demands more potable water every day, consequently creating a great amount of liquid waste. This waste must be treated adequately to avoid harming public health and the environment. Given that the Wastewater Treatment Systems include the development, design and manufacturing of innovative systems, this is the point where it is necessary to introduce Innovative Technologies in the Treatment of Wastewater, to generate new options which are both more effective and economical.

Due to these social, environmental and sanitary reasons, an innovative technology in the combination of two biological processes constituted by a Suspended Biomass Reactor and a Mobile Biofilm Reactor is outlined in a wastewater treatment system called Bio-Activated. The objective is to detect if the combined processes provide a better efficiency and profitability in the removal of contaminants present in domestic wastewater.

A Suspended Biomass Reactor is also introduced as a first stage treatment due to consultation with experts and experiences that agree that this process is one of the most efficient to reduce organic loads present in residual liquids. A Mobile Biofilm Reactor will be used as a second stage, due to its simplicity of use and energy saving.

Proceso Bioactivado: Ahorro energético en la eliminación de altas cargas orgánicas de aguas residuales

Mallia M. Auxilia D. *

Universidad de Carabobo

Dautant S. Rafael *

Universidad de Carabobo

Ingeniero Químico y M.Sc. en Ingeniería Ambiental Universidad de Carabobo (UC), Estudios de Doctorado en Ingeniería Ambiental UC y UCV. Docente e Investigador UC. Línea de investigación: Biotratamientos. Profesora de las cátedras de fisicoquímica y conservación ambiental Facultad de ingeniería, UC. Miembro del Programa de Promoción al Investigador (PPI) en la categoría de Candidato.

Ingeniero Civil, Magister en Ingeniería Civil. ITESM. Monterrey. México. Docente: Universidad de Carabobo. Línea de investigación Biotratamientos. Estudios de Doctorado en Ingeniería Ambiental UC y UCV. Docente e Investigador UC. Profesora de las cátedras de fisicoquímica y conservación ambiental Facultad de ingeniería, UC.

Celeste Fernández.

Universidad de Carabobo

María José Llobregat P.

Universidad de Carabobo

Dirección: Flor Amarillo, calle El Rosario Nº 37, Valencia, Estado Carabobo, Venezuela. Teléfono: 0058 241 8783749, e-mail: amallia@uc.edu.ve, admallia@yahoo.es, admallia@gmail.com

Dirección: Urb. Trigal Norte, Valencia, Estado Carabobo, Venezuela. Teléfono: 0058 241 8431904, e-mail: rafael_dautant@hotmail.com, faraledautant@ig.com.br

Resumen

El agua es uno de los recursos naturales fundamentales que junto con el aire, la tierra y la energía, constituyen los cuatro recursos básicos para el desarrollo de la vida. De allí la importancia de la calidad del agua, sin embargo ha tenido un lento desarrollo en cuanto al tratamiento de la misma luego de ser utilizada de forma domestica, comercial e industrial. Cabe señalar que hasta finales del siglo XIX no se reconoció el agua como origen de numerosas enfermedades infecciosas debido a la disposición de las aguas residuales. Hoy en día, tanto la cantidad como la calidad del agua son necesarias al momento de saciar las necesidades de salud y bienestar de todas las formas de vida existentes en el planeta.

Cabe destacar que, en la actualidad el desarrollo sostenible de la vida se basa en el agua, es decir, en todo el mundo se utiliza este recurso para todas las actividades cotidianas, desde la alimentación hasta las actividades recreativas en algunas de sus fases requieren del uso de este recurso natural, debido a las actividades tan diversas que realiza el hombre, lo llevan a la utilización más no a la renovación y reutilización del agua residual, por lo tanto si cualquier recurso es usado en gran masa y si no es preservado debidamente, puede llegar al nivel donde se agote este elemento natural que sustenta la vida. Razones como estas motivan a cada país hacer del agua un recurso totalmente renovable mediante la implementación de nuevas tecnologías en el tratamiento de aguas residuales..

La naturaleza tiene una habilidad asombrosa para "limpiar" pequeñas cantidades de agua de desecho y contaminación; sí esta se hiciera cargo de los miles de millones de galones de agua y drenaje que el hombre origina diariamente, no tendría la capacidad suficiente para hacerlo, es por ello la importancia y justificación de las instalaciones de tratamiento de desechos líquidos ya que reducen la contaminación en las aguas de desecho a un nivel que la naturaleza puede manejar.

Por otra parte, la sociedad demanda cada día más cantidades de agua potable dando como consecuencia una gran masa de desechos líquidos, estos desechos deben ser tratados adecuadamente para no afectar la salud pública y ambiental. Dado a que los sistemas de Tratamiento de Aguas Residuales incluyen el desarrollo, diseño y fabricación de novedosos sistemas, es aquí donde interviene la necesidad de Innovación Tecnológica en el Tratamiento de Aguas Residuales para generar nuevas opciones más efectivas y económicas a la vez.

Dado estas razones de índole social, ambiental y sanitaria se plantea una innovación tecnológica en la combinación de dos procesos biológicos conformados por un Reactor de Biomasa Suspendida y un Reactor de Biopelícula Móvil en un sistema de tratamiento de aguas residuales llamado Bio-Activado, y de esta manera detectar si se obtiene mayor eficiencia con los procesos combinados, y su rentabilidad en la remoción de contaminantes presentes en aguas servidas de uso domestico.

También se presenta como primera etapa de tratamiento un Reactor de Biomasa Suspendida debido a consultas realizadas y experiencias de profesionales, las cuales coinciden que este proceso es uno de los más efectivos al reducir cargas orgánicas presentes en líquidos residuales y como segunda etapa se empleará el Reactor de Biopelícula Móvil debido a su ventaja de simplicidad en el tratamiento y ahorro energético.

## 1.- INTRODUCCIÓN

En la actualidad los problemas relacionados con la disposición de las aguas residuales provenientes del uso comercial, doméstico e industrial han generado gran atención desde el punto de vista de la salud, ya que el agua es uno de los recursos naturales más fundamentales y básicos en que se apoya el desarrollo de la vida, debido a esto se busca con el tratamiento de los residuos líquidos resolver el problema que existe con el agua, dado que solo un pequeño porcentaje de esta a nivel mundial es la que se puede utilizar , únicamente el 3% es agua dulce, pero de este porcentaje, la mayoría (el 79%) está en forma de hielo (por lo que "a priori" no está disponible para su uso) y el resto se encuentra como agua "líquida": en forma de aguas subterráneas (el 20%) y, únicamente el 1% restante, como aguas superficiales.

La generación de aguas residuales ya sea de origen sanitario o sea proveniente de las actividades cotidianas de los humanos, de las actividades industriales, agrícolas y comerciales, son producidas casi de inmediato al consumo de agua potable o de otra índole, por lo tanto es un problema del día a día que si no es bien atendido acabara por convertir las fuentes de agua para el abastecimiento en cuerpos receptores de aguas sucias sin ningún valor para el ser humano, solo para tener una idea, por cada 100 litros de agua potable consumida se generan entre 80 y 90 litros de agua residual que van a para a cursos de agua sin ningún control a menos que las autoridades gubernamentales dicten normas y pautas para frenar este atropello ambiental y la única forma de controlar la situación es el empleo de tecnologías derivadas de la investigación para lograr transformar los contaminantes en productos cuya capacidad de alterar el medio ambiente sea mínima. Es por ello que, el tratamiento biológico del agua residual es una opción excelente ya que este se basa en un proceso en el que una población mixta de microorganismo utiliza como nutrientes la materia orgánica presente en sustancias contaminantes, en esto se basa el mecanismo en el cual las corrientes de aguas naturales se autopurifican, con el transcurrir del tiempo el uso de técnicas de ingeniería se ha intensificado y acelerado en los desarrollos tecnológicos y de investigación para disponer de un rango de sistemas biológicos de tratamientos de uso común en la purificación a gran escala de las aguas residuales, domesticas e industriales.

Por otra parte, existe un aspecto de fundamental importancia a tomar en cuenta para el desarrollo de esta novedosa tecnología como lo es el alto consumo de energía en las plantas de tratamiento de aguas residuales bien sea de origen doméstico o industrial, lo que trae como consecuencia directa una disminución considerablemente el impacto energético, ambiental y económico que involucra la construcción y operación de un sistema de tratamientos de aguas residuales convencional, dado que además de los elementos antes mencionados la utilización del especio físico es mucho menor.

Frente a esta realidad, surge la necesidad de realizar esta investigación, la cual tiene como objetivo el desarrollar una novedosa tecnología denominada Reactor Biológico del tipo Bioactivado a nivel de laboratorio, que provea una disminución notable de los contaminantes presentes en los residuos líquidos a tratar, que es combinación de un Reactor de Biomasa Suspendida con un Reactor de Biopelícula Móvil sin sedimentación intermedia reduciendo drásticamente los costos de construcción, de operación, energéticos y la carga orgánica contaminante de las aguas residuales tratadas.

Durante varios año en plantas de tratamiento utilizando los procesos anteriores sobre todo del ramo avícola específicamente plantas beneficiadora de aves así como de industrias del papel arrojaron resultados muy alentadores obteniéndose remociones en todo momento por encima del 98% en términos de contaminantes orgánicos, en el año 2005 se inicio a nivel meramente de consulta e intercambio profesional con profesores de otras universidades tanto de Venezuela como del exterior sobre la profundización de dos aspectos que a nivel del mundo microscópico funcionan excelentemente bien que son el respeto que generan los microorganismos cuando se trata de cuidar su comida (sustrato) y su espacio territorial ello genero inquietudes y despertó con una hipótesis en donde si se lograra congeniar en un proceso integrado empleando un reactor de biomasa suspendida como lo es el de los Lodos Activados (LA) seguido de un reactor de biopelicula móvil como lo es el de Biodiscos sin colocar la unidad de sedimentación secundaria entre ambos y solamente colocar una sola unidad de sedimentación después de la biopelícula móvil (definido como proceso

Bioactivado RDS), se estarían obteniendo tres zonas de trabajo desde el punto de vista microbiológico: la primera de ellas en el reactor de biomasa suspendida basándose en los postulados desarrollados por Jack Monod (Metcalf, 1995) en donde la producción de lodos o microorganismos es enviada directamente al reactor de biopelículas móviles en donde ya actúan y trabajan microorganismos bajo la figura de biomasa adherida (Crites, 2000). que intentaran repeler a los nuevos microorganismos invadir su territorio y comer su sustrato, obligándolos a obtener el sustrato de la fracción suspendida del reactor de biopelícula móvil que pasara a ser la tercera zona de trabajo es por ello que estimaba que la remociones fueran elevadas.

Descripción del proceso Bioactivado RDS

Es un sistema biológico de tratamiento de aguas residuales del tipo DUAL que combina reactores de biomasa suspendida con biopeliculas móviles, trabajando en serie sin sedimentación intermedia.

El proceso se fundamenta en tres pilares básicos, el primero conocido como el principio de la infalibiliad biológica que dice que todo desecho que tenga un origen orgánico podrá ser tratado microbiológicamente, en segundo termino en la capacidad de biodegradación, biotransformación y bioacumulación que ofrecen los procesos biológicos y en ultimo termino, en la creatividad microbiana para hacer respetar el espacio territorial y sustrato (comida o contaminante) a ser consumido.

En términos generales, los procesos biológicos para el tratamiento de las aguas residuales se fundamentan en la biotransformación y biodegradación de los compuestos orgánicos para ser llevados a compuestos simples como el dióxido de carbono, agua, otros gases y minerales, de tal manera que no ocasiones daños al medio ambiente y este los pueda absorber sin problema alguno a la naturaleza.

## 2.- METODOLOGÍA

Descripción del sistema Bioactivado RDS

Sistema de Llenado: Para este sistema se utilizó un tanque de almacenamiento, que consistió en un tambor de plástico, con una capacidad de 190 litros, sin tapa, para simular una entrada totalmente anaerobia de agua residual doméstica, la cual se asemeja a la situación de una planta de tratamiento de aguas residuales a escala real, donde el afluente llega a una zona de quietud, para ser preparada para una fase de pre-tratamiento. Adicionalmente se cuenta con un sistema de bombeo, para elevar el agua residual cruda desde el tanque de almacenamiento hasta el primer tanque aerobio del tipo Lodos Activados, por medio de una bomba dosificadora fija solenoide, modelo A 48-A, marca ADVENCE, de caudal máximo de 200 l/día y potencia de 0,004 hp.

Reactor de Biomasa Suspendida: El tanque fue construido con láminas de Acrílico, un plástico muy resistente al impacto, corrosión, facilidad de limpieza y debido a su transparencia permite observar el estado de los flujos durante el proceso, y hacer un rápido chequeo visual (color, aireación, recirculación, adición). El volumen real del reactor es de 100 litros con un volumen útil de 105 litros.

En el interior posee un sistema de aireación, el cual consta de mangueras plásticas colocadas en forma lineal para recrear a escala un sistema de Aireación Convencional, las cuales suministran el Oxigeno adecuado para la supervivencia de los microorganismos y bacterias ideales para la remoción de DBO y DQO. Las bombas utilizadas son de marca $\text{POWER}_{\text{TM}}$ y modelo 800 y 600.

Reactor de Biopelícula Móvil: Este tanque se construyó con láminas de acrílico de cinco milímetros (5 mm) de espesor, En su interior este presenta discos de Polietileno corrugado dispuestos en serie situados sobre un eje y a corta distancia. El Eje Central de Torque o Rotor utilizado es de acero macizo, resiste las cargas que resultan de los soportes de las placas de polietileno y de la biomasa. Este centro rotor es cuadrado de tres centímetros lado (3 cm.) para que los discos queden fijos, este mismo es redondeado en ambos extremos, los cuales están soportados por chumaceras, las que son deslizables y autoalineables en los extremos. El Sistema Motriz consta de un motoreductor de 0,2 HP, que se coloca en la parte de afuera del extremos del eje con piñones y cadenas que permiten obtener la velocidad deseada, en este caso de 15 r.p.m. se redujo a 3 r.p.m. La unidad de biodisco cuenta con una altura de 61 cm, ancho 100 cm y largo 120 cm, además pposeen un diámetro de 90 cm, son 20 discos en total, colocados en grupos de 4, con eje rotor de área 9 $cm^2$.

Sedimentador: Este tanque de disposición fue realizado con el mismo material acrílico con el cual también se construyó el Reactor de lodos Activados y el Reactor de Biopelícula Móvil, por las razones ya antes mencionadas de visibilidad, facilidad de trabajo y limpieza, resistencia al impacto y a la corrosión, además en este tanque se hace necesaria la transparencia del material, debido a que el

Sedimentador debe estar en observación continua para el seguimiento, mantenimiento y disposición de lodos

Tuberías y Válvulas: El Sedimentador requiere un juego de tuberías y válvulas de diferentes diámetros, el primer juego de tubos de PVC es de tres cuartos de pulgada (3/4”) con una válvula de globo del mismo material y diámetro destinado al sistema de purga de este tanque. Existe un segundo juego de tuberías y válvulas fue construido para sistema de descarga de agua tratada por el Reactor Bio-Activado, este sistema es de media pulgada de espesor (1/2”) y además posee conectado después de la válvula de globo una manguera de plástico de 1/2”, que dispone el agua tratada de dos formas, la primera para ser descartada del sistema y la segunda para realizar los análisis correspondientes a la remoción total del sistema Bio-Activado.

Air-Lift: La función básica de estos dispositivos es de recirculación, esto se logro inyectando aire en la base del dispositivo, luego por medio de mangueras se hace un equilibrio hidráulico al entorno del mismo logrando elevar el lodo resultante por la decantación junto con el aire previamente inyectado. Este lodo es retornado al primer reactor aerobio.

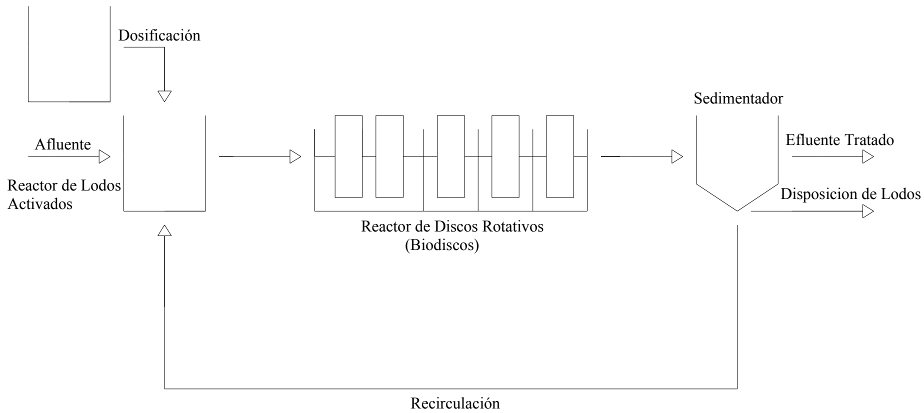
Sistema de Bombeo: En este diseño se utilizaron bombas de marca POWERTM modelo 600. Estas bombas son reguladas mediante una perilla para suministrar el caudal de retorno calculado en el reglón del Reactor de Lodos.

Agua residual sintética (A.R.S)

En las experimentaciones el sistema se alimentó con agua residual sintética, para lograr la mayor uniformidad (concentración y composición), permitiendo realizar los ensayos con carga orgánica alimentada constante (Figura 1).

El agua residual sintética se preparó con los siguientes compuestos: azúcar comercial, Fosfato Monohidratado de Sodio y Urea.

Figura 1 Esquema del Sistema Bio-Activado RDS.




Determinaciones Analíticas

Para cada una de las corrientes de entrada y salida del reactor se determinó el valor de los parámetros físicos-químicos ( OD, DBO, DQO, Sólidos Suspendidos, Nitrógeno y  Fósforo total, SST y DQO), de acuerdo a las técnicas del Standard Methods de la A.W.W.A.

Recolección de Muestras

El tipo de muestra es: Muestra Dirigida de Laboratorio, para diseños experimentales y situaciones de laboratorio. La forma del muestreo es llamado compuesto, ya que se toman muestra en un mismo punto en diferentes momentos, este tipo de muestras se realizan con el fin de tener concentraciones promedio del sustrato y calcular las respectivas cargas orgánicas para determinar la eficiencia de la planta de tratamiento a escala para alta rata. La recolección y análisis de muestras se llevó a cabo en un lapso de siete (7) semanas después de haberse cumplido el periodo de adaptación y aclimatación del sistema Bioactivado.

Las muestras se recolectan en tres puntos del reactor Bioactivado. El primer punto de muestreo es la entrada del reactor de lodos, es decir, el afluente crudo que entra al mismo. El segundo es la salida del tanque de Lodos Activados y el tercer punto de muestreo, es el Sedimentador, se tomaron estos tres puntos ya que son los puntos más representativos del sistema.

Condiciones de Operación del Sistema

Se evaluaron cuatro caudales distintos (50,4; 100,8; 151,2 y 180,0) l/d para la obtención de la carga volumétrica real del proceso bioactivado. Cuyo diseño se hizo en función de un proceso de lodos activados de alta rata. Una vez comprobado el caudal que arrojaba como resultado la carga volumétrica comprendida en el rango del sistema de alta rata se procedió a fijar el caudal de operación en el cual se hicieron las mediciones de los diferentes parámetros (DBO, DQO, Pt, Nt, pH y sólidos en todas sus formas). Las determinaciones de los parámetros se hizo en base a la metodología establecida en el Standart Methode.

Determinación del Consumo Energético

Para llevar a cabo la evaluación comparativa del consumo energético entre el sistema desarrollado (Proceso Bioactivado RDS) un sistema de tratamiento convencional ( lodos activados en su modalidad de aireación extendida) se determinó el consumo de energía para distintas cargas orgánicas y se llevo a término de población equivalente para tener una idea más clara de lo que representa el ahorro sustancial en el consumo de energía empleando el proceso Bioactivado RDS para eliminar materia orgánica contaminante partiendo de la misma base de cálculo, es decir, de las mismas condiciones de alimentación para los dos procesos

## 3.- RESULTADOS

Los estudios hechos a nivel de laboratorio, en desechos líquidos con características similares a los descargados por una planta de alcohol y azúcar, han demostrado la total viabilidad para procesar estos desechos, obteniendo una calidad de agua después de tratamiento con características listas para ser reusadas en diferentes procesos dentro de la planta, por supuesto dándole un tratamiento adicional para situaciones especificas como la de generación de vapor. El tener disponible esta herramienta se traduciría en una economía de agua en el orden del 60 al 80%, lo que se traduciría en economía de costos de facturación de agua para consumo proveniente de los cuerpos de agua así como el un ahorro sustancial de casi un 50 % en el consumo de energía.

### 3.1.- Los objetivos del proceso Biaoactivado RDS son los siguientes

Alcanzar eficiencias elevadas en la eliminación de los compuestos orgánicos a través de la combinación de procesos de flujo continuo mezcla completa y pistón así como reactores de biomasa suspendida con biopeliculas en medio aerobio, minimizando el riesgo de perdida de biomasa.

Economía importante en la inversión inicial y en el consumo de energía del sistema de tratamiento.

Se utiliza en la remoción de cargas orgánicas medias y elevadas así como en la remoción conjunta de carga orgánica y nitrificación. Con eficiencias superiores al 98% en términos de DBO, y sobre el 95% en nitrificación.

Promociona el reuso del agua dada la calidad obtenida en el efluente tratado.

### 3.2.- Las consideraciones para el diseño que deben tomarse en cuenta son las siguientes:

Se tiene actividad microbiología en el tanque de aireación (biomasa suspendida), en la biopelicula móvil y en la fracción suspendida del reactor de biopeliculas.

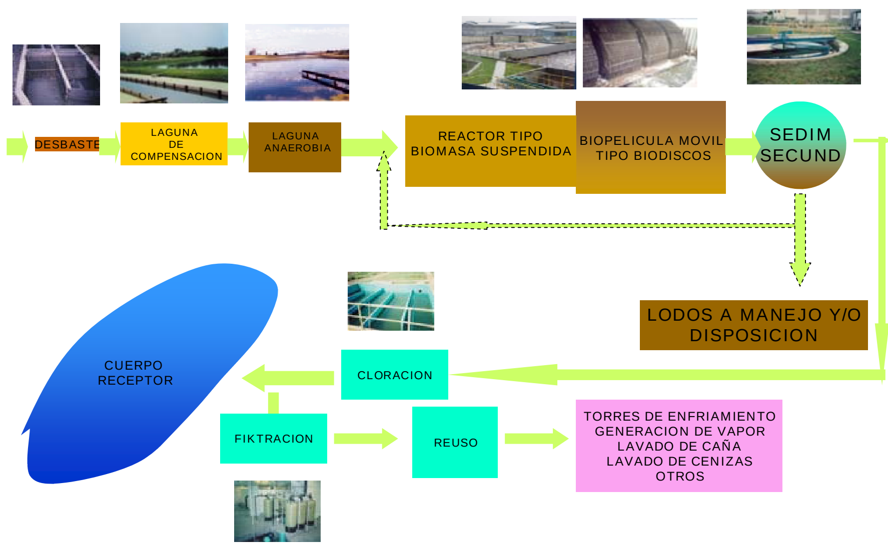
Se desarrolla un *pool* de microorganismos derivados de la intensa actividad enzimática.

Se promueve la *desnitrificación aerobia*.

El sedimentador secundario utilizado después del proceso de biopeliculas, debe calcularse con un tiempo de retención mayor a dos horas y media pues recibirá la carga de sólidos suspendidos generada en ambos etapas biológicas.

La concentración de sólidos en el fondo del sedimentador secundario, se encuentra en el orden del 1 al 1.5%. Lo que ocasiona que la recirculación de lodos se pueda hacer en forma intermitente.

Figura 2 Diagrama de flujo tipo recomendado para el tratamiento




En cuanto a la Carga Orgánica Volumétrica real (tabla 1), el valor obtenido fue el esperado para un sistema de Alta Tasa el cual está comprendido entre 1,0-2,4 KgDBO/m$^3$*día y cumplió con los parámetros de diseño para el proceso de Lodos Activados de Alta Rata (Ver tabla 1), el cual estuvo próximo al valor de 1,6 KgDBO/m$^3$*día (Henze, 1987). Este cálculo se realizo para comprobar que el sistema Bio-Activado estuvo trabajando a Alta Tasa.

Tabla 1: Carga Orgánica Volumétrica Real

| Composición: 432 azúcar + 32,4 fosfato + 25,2 urea | | | |
|---|---|---|---|
| Volumen del LA= 105,0 L = 0,105 m3 | | | |
| Caudal (l/d) | DBO Entrada (mg DBO/l) | DBO Salida (mg DBO/l) | Vs(KgDBO/m3 *día) |
| 50,4 | 1358 | 22 | 0,641 |
| 100,8 | 1673 | 48 | 1,560 |
| 151,2 | 1143 | 179 | 1,388 |

| | | | |
|---|---|---|---|
| 180,0 | 1208 | 142 | 1,827 |

3.3.- Eliminación de Materia Orgánica

La DBO de entrada en el sistema Bioactivado, no dependió del caudal, se mantuvo en un rango de 1100 a 1900 mgDBO/l a lo largo del tiempo en estudio, cabe destacar que los valores más bajos se presentaron en los caudales 151,2 l/día y 180,0 l/día, esto se debió a la capacidad del tanque de almacenamiento que es de 190 l/día, en donde los nutrientes encargados de recrear DBO tuvieron muy poco tiempo para descomponerse y arrojaron resultados de DBO de entrada menores al DBO supuesto para el diseño, el cual fue de 2000 mgDBO/l. De esta manera, también se observó que el caudal de 100,8 l/día fue el que se consideró como caudal optimo de operación, puesto que para éste valor dse reproduce la carga orgánica volumétrica de diseño, siendo su DBO de entrada promedio igual a 1796 mg DBO/l, siendo este el valor mas alto con respecto a los promedio de los caudales restantes (50,4 l/día, 151,2 l/día, 180l/día). Los resultados obtenidos para la DBO a la salida del sistema Bioactivado para cada caudal, fueron satisfactorios, ya que al compararlos con la entrada, son valores mucho menores y estuvieron por debajo de la concentración máxima permisible según Gaceta Oficial Extraordinaria Nº 5305 Decreto 3219 de las Descargas a Cuerpos de agua.

Tabla 2 Variación de la $DBO_{5,20}$ en el Sistema para Diferentes Caudales.

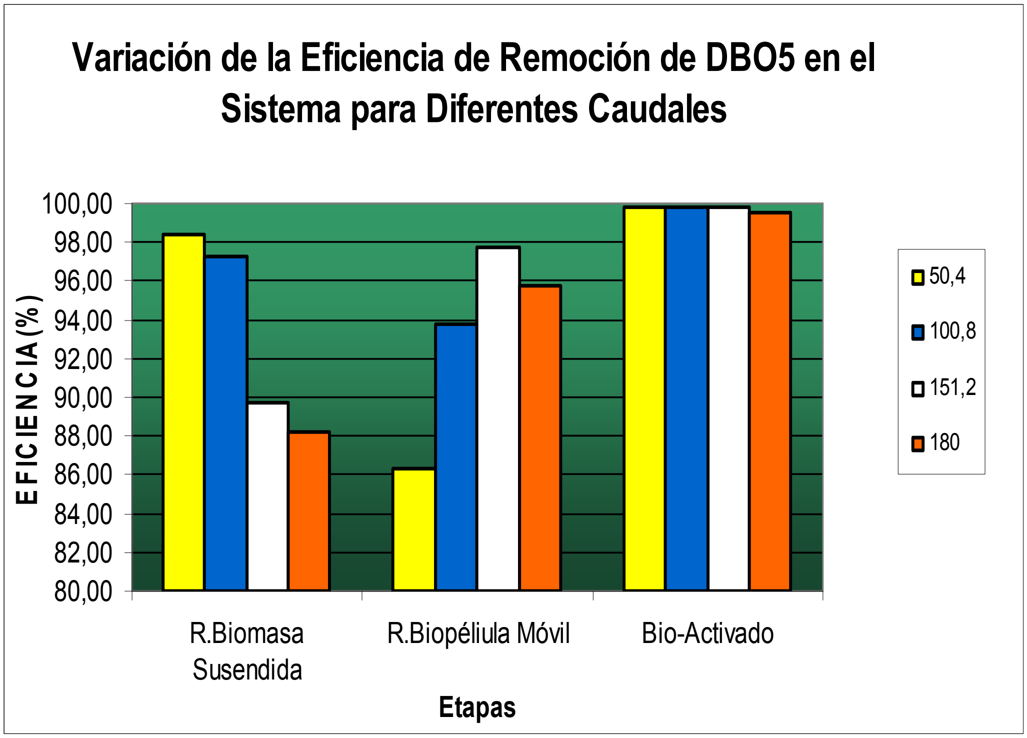
| Caudal (l/d) | Efluente crudo | Reactor Biomasa suspendida | Reactor biopelicula móvil |
|---|---|---|---|
| 50 | 1358 | 22 | 3 |
| 100 | 1673 | 48 | 3 |
| 150 | 1733 | 179 | 4 |

| | | | |
|---|---|---|---|
| 180 | 1208 | 142 | 6 |

Tabla 3 Variación de la Eficiencia de Remoción de $DBO_{5,20}$ en el Sistema para Diferentes Caudales

| Caudal (l/d) | Reactor Biomasa suspendida | Reactor biopelicula móvil | Proceso Bioactivado RDS |
|---|---|---|---|
| 50 | 98,38 | 86,36 | 99,78 |
| 100 | 97,30 | 93,75 | 99,83 |
| 150 | 89,67 | 97,77 | 99,77 |
| 180 | 88,25 | 95,77 | 99,50 |

Figura 3 Variación de la Eficiencia de Remoción de $DBO_{5,20}$ en el Sistema para Diferentes Caudales




Por otra parte, se observa que la DQO presentó valores que duplicaban la DBO, esto se cumplió a lo largo del tiempo de estudio, los resultados en la salida del proceso Bio-Activado fueron muy satisfactorios para cada caudal, ya que son valores mucho menores comparados con la entrada y estuvieron por debajo de la concentración máxima permisible según Gaceta Oficial Extraordinaria Nº 5305 Decreto 3219 de las Descargas a Cuerpos de agua. Se presento una gran remoción de DQO en el Sistema Bioacivado, con una eficiencia muy cercana al 100%.

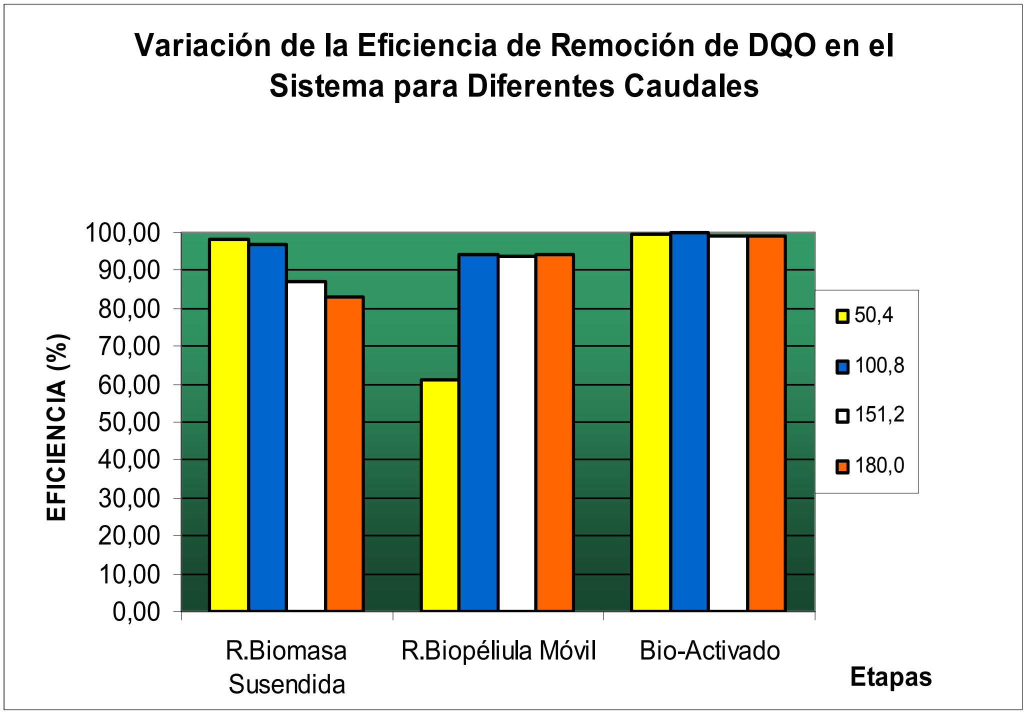
Tabla 4 Variación de DQO en el Sistema para Diferentes Caudales.

| Caudal (l/d) | Efluente crudo | Reactor Biomasa suspendida | Reactor biopelicula móvil |
|---|---|---|---|
| 50 | 1922 | 31 | 12 |
| 100 | 3688 | 119 | 7 |
| 150 | 3530 | 458 | 28 |
| 180 | 1850 | 315 | 18 |

Tabla 5 Variación de la Eficiencia de Remoción de DQO en el Sistema para Diferentes Caudales.

| Caudal (l/d) | Reactor Biomasa suspendida | Reactor biopelicula movil | Bioactivado RDS |
|---|---|---|---|
| 50 | 98,39 | 61,29 | 99,38 |
| 100 | 96,77 | 94,12 | 99,81 |
| 150 | 87,03 | 93,89 | 99,21 |
| 180 | 82,97 | 94,29 | 99,03 |

Figura 4 Variación de la Eficiencia de Remoción de DQO en el Sistema para Diferentes Caudales.




Las formas de sólidos estudiadas fueron: Sólidos Suspendidos Totales (SST), Sólidos Suspendidos Volátiles (SSV) y Sólidos Suspendidos Fijos (SSF), la reducción de estos es considerable, siendo el caudal de 151,2 l/día el que presentó mayor remoción de sólidos y estuvo por debajo de la concentración máxima permisible según Gaceta Oficial Extraordinaria Nº 5305 Decreto 3219 de las Descargas a Cuerpos de agua. El caudal de 180,0 l/día no remueve sólidos (Ver tabla 6), esto se debió a su alto caudal, ya que el Sedimentador no se da abasto para la gran producción de lodos que se genera. Los Sólidos Suspendidos Volátiles predominan en el sistema sobre los Sólidos Suspendidos Fijos.

Tabla 6 Porcentaje de Remoción de Sólidos en todas sus Formas a través del Sistema Bioactivado RDS para distinto  Caudales de Operación

| Caudal (l/d) | BIO-ACTIVADO | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | SST (mg/l) | | | SSV (mg/l) | | | SSF (mg/l) | | |
| | Entrada | Salida | %Remoción | Entrada | Salida | %Remoción | Entrada | Salida | %Remoción |
| 100,80 | 160 | 4 | 97,50 | 155 | 3 | 98,06 | 5 | 1 | 80,00 |
| | 160 | 3 | 98,13 | 155 | 3 | 98,06 | 5 | 2 | 60,00 |
| 151,20 | 273 | 3 | 98,90 | 267 | 2 | 99,25 | 7 | 1 | 85,71 |
| | 283 | 26 | 90,81 | 263 | 20 | 92,40 | 20 | 6 | 70,00 |
| | 132 | 3 | 97,73 | 124 | 2 | 98,39 | 8 | 1 | 87,50 |
| 180,00 | 101 | 2107 | --- | 97 | 1847 | --- | 4 | 260 | --- |
| | 190 | 2107 | --- | 175 | 1847 | --- | 15 | 260 | --- |
| | 278 | 2107 | --- | 258 | 1847 | --- | 20 | 260 | --- |

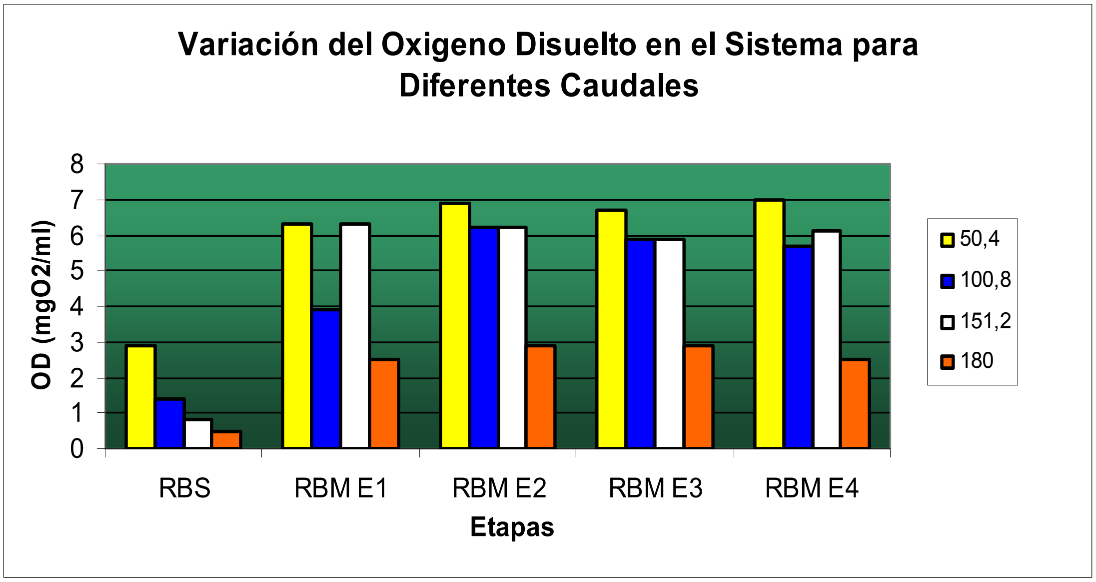
El Oxigeno Disuelto se mantuvo dentro del rango para mantener la vida microscópica, el resultado más bajo fue 0,5 $mgO_2/l$ en el caudal de 180,0 l/día, estando en el límite requerido para la supervivencia (Rivas, 1978) tal como se puede observar en la tabla 7.

Tabla 7 Variación del Oxigeno Disuelto en el Sistema para Diferentes Caudales de Operación

| Caudal (l/d) | Reactor Biomasa | Reactor biopelicula | Reactor biopelicula | Reactor biopelicula | Reactor biopelicula |
|---|---|---|---|---|---|

| | suspendida | Movil Etapa 1 | Movil Etapa 2 | Movil Etapa 3 | Movil Etapa 4 |
|---|---|---|---|---|---|
| 50 | 2,9 | 6,3 | 6,9 | 6,7 | 7 |
| 100 | 1,4 | 3,9 | 6,2 | 5,9 | 5,7 |
| 150 | 0,8 | 6,3 | 6,2 | 5,9 | 6,1 |
| 180 | 0,5 | 2,5 | 2,9 | 2,9 | 2,5 |

Figura 5 Variación del Oxigeno Disuelto en el Sistema para Diferentes Caudales de operación.




3.4.- Eliminación de Materia Orgánica

Con respecto a la variación que presentó el Fósforo Total (ver tabla 8), se tiene que los componentes que conforman el sistema Bioactivado no son eficaces en la eliminación del Fósforo, y la aparente disminución del contenido del mismos se debe a procesos estrictamente metabólicos de los microorganismos presentes en el sistemas responsables de la biodegradación de la materia orgánica contenida en el agua residual tratada alcanzado en promedio un 32% por efectos de asimilación.

La variación del Nitrógeno Total desde el punto de entrada hasta el de salida del sistema fue notable, para los diferentes caudales ocurrió una remoción muy alta, donde muchas veces se observó hasta más del 95% (Ver tabla 8), en cuanto a los resultados obtenidos en la salida del proceso Bioactivado estuvieron por debajo de las concentraciones máxima permisible establecidas según Gaceta Oficial Extraordinaria Nº 5305 Decreto 3219 de las Descargas a Cuerpos de agua cuyo valor es de 10 ml/l. La remoción de nitrógeno se debe principalmente a que los niveles de oxígeno disueltos son bastante altos de hasta 7 mg/l, lo que trae como consecuencia que ocurra el proceso de desnitrificación aerobia que normalmente se da en condiciones anóxicas, es decir, en ausencia de oxígeno molecular.

Tabla 8 Porcentaje de Remoción de Nitrógeno y Fósforo a través del Sistema Bioactivado RDS para distinto Caudales de Operación

| Caudal (l/d) | BIOACTIVADO | | | | | |
|---|---|---|---|---|---|---|
| | N (mg/l) | | | P (mg/l) | | |
| | Entrada | Salida | %Remoción | Entrada | Salida | %Remoción |
| 100,80 | 247,5 | 9,63 | 96,11 | 29,2 | 22,11 | 24,28 |
| | 201,67 | 5,5 | 97,27 | 31,96 | 17,05 | 46,65 |
| | 183,33 | 9,63 | 94,75 | 32,72 | 22,11 | 32,43 |
| 151,20 | 174,17 | 5,5 | 96,84 | 20,79 | 7,99 | 61,57 |
| | 174,17 | 5,5 | 96,84 | 18,6 | 7,99 | 57,04 |
| | 174,17 | 5,5 | 96,84 | 18,39 | 7,99 | 56,55 |
| 180,00 | 155,83 | 12,65 | 91,88 | 31,63 | 9,74 | 69,21 |
| | 128,33 | 5,5 | 95,71 | 35,57 | 4,16 | 88,30 |
| | 134,75 | 12,65 | 90,61 | 30,1 | 9,74 | 67,64 |

3.5.- Determinación del Consumo Energético

El proceso Bioactivado RDS es un sistema de eliminación de carga orgánica contaminante de las aguas residuales de origen doméstico o industrial con altas eficiencias de remoción a expensas de un considerable ahorro energético, como es bien sabido las fuentes de generación de la energía eléctrica empleando combustibles fósiles son altamente contaminantes, ya que implican la combustión de hidrocarburos derivados del petróleo para la producción de energía. Es por ello que es importante disminuir el consumo de energía eléctrica y una clara idea de ello lo constituye el proceso Bioactivado RDS ya que es un sistema que no solo descontamina el agua residual, si no que contribuye al ahorro considerable de energía y en consecuencia a la disminución de las emisiones de $CO_2$ a la atmosfera.

Es por ello que, se realizo la evaluación comparativa entre el consumo de energía del proceso Bioactivado RDS y un Sistema Convencional, en este caso, aireación extendida, obteniéndose resultados muy satisfactorios en materia de ahorro energético.

Se puede apreciar en la tabla 9 el consumo de energía en Kw-h y Kw-hora/año, para tres valores de cargas orgánicas distintas, donde se observa que el consumo está entre el 35 y 40 % menos empleando el proceso Bioactivado RDS para tratar el mismo tipo de agua residual en comparación con el sistema de aireación extendida.

Por otra parte se presenta la población equivalente (PE) este es un índice que relaciona carga orgánica y personas, es decir, este parámetro da una idea de la contaminación que generaría una población de determinado número de personas en base al valor de la carga orgánica a procesar en una planta de tratamiento. Ejemplo una población de 18520 habitantes genera una carga orgánica de 1000 KgDBO/d para tratar este afluente residual se consumirían 1271 Kw-h si se utiliza el proceso Bioactivado RDS con un costo de 407 $ en cambio que si se usa un sistema convencional, como es el caso del de aireación extendida se tendría un gasto energético de 2059 Kw-h a un costo de 659 $, entonces se hablamos de un ahorro de energía y de costos de un 38%. Para el caso de 5000 Kg DBO/d y de 10000Kg DBO/d se obtienen ahorros de 40 % tanto en energía como en costos.

Todo esto lleva reflexionar sobre la disminución del consumo energético a través del desarrollo de tecnologías novedosas que aprovechan la eficiencia de los sistemas duales, así como las interacciones microbiológicas que se dan en este nuevo proceso donde se ponen en contacto microorganismos que en los sistemas convencionales no trabajan conjuntamente, y el aumento en la eficiencia y disminución en los costos y en el consumo energético muy probablemente estén estrechamente relacionados con la generación de una zona de trabajo única en su estilo como lo es la zona dinámica funcional microbiológica ADM (ZDFM-ADM) que es la zona de trabajo donde confluyen los microorganismos generados en el reactor de biomasa suspendida, reactor de biopelicula móvil y biomasa adherida desprendida, que trae consigo el hecho de eliminar la sedimentación intermedia, pues se está creando una tercera zona de trabajo donde convergen los microorganismos suspendidos y los adheridos, cambiando totalmente la dinámica del sistema desde el punto de vista microbiológico y haciéndolo más eficiente.

Tabla 9 Comparación del Consumo Energético en Función de la Carga Orgánica entre el Proceso Bioactivado RDS y el Sistema Convencional (Aireación extendida)

| Sistema | CO (Kg DBO/D) | Kw-h | Kw-año | *$/año | PE (personas) |
|---|---|---|---|---|---|
| Bioactivado RDS | 1000 | 1271 | 463915 | 148453 | 18520 |
| | 5000 | 6193 | 2260445 | 723343 | 92593 |
| | 10000 | 12331 | 4500815 | 1440261 | 185186 |
| Aireación Extendida (Convencional) | 1000 | 2059 | 751353 | 240492 | 18520 |
| | 5000 | 10255 | 3743075 | 1197784 | 92593 |
| | 10000 | 20492 | 7479580 | 2393466 | 185186 |

CO: Carga Orgánica

*Para este cálculo se tomó como costo del Kw-h el de Brasil que tiene un valor de 0, 32 $.

Tabla 10 Comparación del Ahorro Energético del Proceso Bioactivado RDS con respecto al Sistema Convencional (Aireación extendida) para distintas Cargas Orgánicas

| CO (Kg | Ahorro Kw-año | Ahorro $/año | % Ahorro |
|---|---|---|---|

| | | | |
|---|---|---|---|
| DBO/D) | | | |
| 1000 | 287438 | 92039 | 38 |
| 5000 | 1482630 | 474441 | 40 |
| 10000 | 2978765 | 953205 | 40 |

## 4.- CONCLUSIONES

El Reactor Biológico del tipo Bioactivado funciona principalmente para la remoción de DBO, DQO, Nitrógeno y Sólidos, también cumple una función en la remoción de Fósforo en menor proporción.

El sistema Bioactivado funciona eficientemente como un todo, ya que por primera vez se emplean el Reactor de Biomasa Suspendida y Reactor de Biopelícula Móvil con Sedimentador, así que cuando se comente sobre el sistema Bioactivado se referirá a que es uno solo y no el reactor de lodos, biodisco y sedimentador.

Al trabajar bajo cargas orgánicas expresadas en términos de DBO aproximadamente iguales a 1800 mg/l estas fueron llevadas a 3 mg/l con una eficiencia de remoción que supera el 99 %, independientemente del caudal de operación. Igualmente la DQO presentó porcentajes de remoción considerablemente elevados hasta un 99%. Lo que literalmente hablando representa una excelente eliminación de la carga orgánica contaminante.

Se confirmó que la eliminación del sedimentador secundario del reactor de biomasa suspendida del tipo de LA indujo a que se generaran las zonas de trabajo en la biomasa adherida y en la biomasa suspendida del reactor de biopelicula móvil lo que garantiza por otro lado una reducción importante en los costos de implementación y los de operación dado que se prescinde de la unidad de retorno de lodos de esa parte del proceso.

Efectuando una comparación del consumo energético para tratar un agua residual con cargar orgánicas similares empleando dos sistemas de tratamiento distintos como lo son el de aireación extendida y el proceso Bioactivado RDS se comprobó que al utilizar este último se obtienen ahorros sustanciales que van desde un 35 hasta un 55% en energía y en dinero.

La población equivalente es un índice práctico que permite hacer comparaciones entre la carga orgánica y los habitantes de una población.

Se establece una relación probable entre el aumento de la eficiencia y disminución del consumo energético con la aparición o generación de una nueva zona de trabajo denominada zona dinámica funcional microbiológica ADM (ZDFM-ADM)

El reactor biológico del tipo Bio-Activado no presentó olores desagradables.

## 5.- RECOMENDACIONES

Debido a la eficiencia en la remoción del nitrógeno total se sugiere un estudio minucioso de las diferentes fases del nitrógeno, como lo es: la reducción a través del sistema del nitrógeno orgánico y amoniacal, al mismo tiempo conocer la reducción y comportamiento de los nitritos y nitratos. Para así también realizar un estudio de la desnitrificación presente en la unidad de tratamiento.

Por no presentar olores desagradables este sistema se recomienda como una solución para plantas de tratamientos ubicadas en zonas residenciales.

Dada la alta eficiencia del sistema se sugiere adicionar las unidades requeridas para la eliminación de nutrientes y evaluar la eficiencia de remoción de los mismos.

## 6.- REFERENCIAS BIBLIOGRÁFICAS

*Crites, R. y Tchobanoglous, G. (2000). Tratamiento de Aguas Residuales en pequeñas

poblaciones. Santa fe de Bogota, Colombia: Mc. Graw Hill Interamericana S.A.

*Greenberg, Arnold, et al. (2005) Standard Methods for the Examination of Water and

Wastewater, 21st Edition American Water Works Association

*Henze M., Grady Jr. C.P.L., Gujer W., Marais G. v R. and Matsuo T. (1987). Activated Sludge Model nº1.

*Metcalf & Eddy (1995). Ingeniería de Aguas Residuales; Tratamiento, Vertido y reutilización. Santa fe de Bogotá, Colombia: Mc. Graw Hill Interamericana S.A.

*Normas sobre la Clasificación y Control de la Calidad de las Aguas. Cuenca del Lago de Valencia (Decreto Nº. 3219). Gaceta Oficial de las Descargas a Cuerpos de Agua, 5305 (Extraordinaria).

*Rivas Mijares, G. (1978). Tratamiento de Aguas Residuales (2a. ed.). Madrid, España: Edición.

*Standard Methods for the Examination of Water and Wasterwater, 17 th ed, APHA, AWWA, WPCF, 1989.

*Technical Report by IAWPRC Task Group on Mathematical Modelling for Design and Operation of Biological Wastewater Treatment.

56. # Barriers to the Implementation of Solar Heaters in Mexico

## Tanya Moreno- Augusto Sanchez, Juan C. Ovando, Miguel Martínez

Tanya Moreno[1], Augusto Sanchez[1], Juan C. Ovando[2], Miguel Martínez[2]
1 Facultad de Ingeniería, UNAM, México., Posgrado de Ingeniería

tel (52.55) 56.22.31.38. email augsan@ unam.mx

2 Facultad de Ingeniería, UAC, México

Key words: Solar energy, water heaters, solar heater market.

Abstract: For its geographical location, Mexico has excellent resources on solar energy, with an average radiation level of about 5 kWh/$m^2$ daily, which means that with one solar device with a one $m^2$ of area and efficiency of 50% , equivalent to the energy contained in one cubic meter of natural gas may be obtained daily, or 1.3 liters of gas LP.

Annual consumption to heat water in Mexico as is estimated about of 230 PJoules. Its will be provided with solar equipment, the area that would be installed is close to 70 million square meters, which would represent an approximate savings of nearly 5 million tons of liquefied gas and 640,200 cubic meters of natural gas, equivalent to just over 49 billion pesos in resources saved, plus a decline of about 4 million tons in emissions of $CO_2$ equivalent per year.

Studies in recent years indicate that the main problems for the massive use of solar heaters in Mexico are: the high cost of initial investment, which translates into the need for appropriate marketing schemes and funding, lack of standards and procedures to ensure quality in its installation and operation, as well as the absence of strategies for diffusion, promotion and dissemination of technology.

In this paper identifies the various options offered by the market for solar water heaters for low temperature for the residential sector in Mexico, with the aim of obtaining information to determine prices and yields of the various options for solar heaters.

# BARRERAS PARA LA IMPLEMENTACION MASIVA DE CALENTADORES SOLARES EN MEXICO

Tanya Moreno[1], Augusto Sanchez[1], Juan C. Ovando[2], Miguel Martínez[2]

1 Facultad de Ingeniería, UNAM, México., Posgrado de Ingeniería

tel (52.55) 56.22.31.38. email augsan@ unam.mx

2 Facultad de Ingeniería, UAC, México

Palabras Claves : Energía solar, calentadores de agua, mercado de calentadores de agua

Por su ubicación geográfica, México cuenta con excelentes recursos de energía solar, con un promedio de radiación de alrededor de 5 $kWh/m^2$ por día, lo que significa a que en un $m^2$ y con un equipo solar de eficiencia de 50% se reciba diariamente el equivalente a la energía contenida en un metro cúbico de gas natural, o bien, la de 1.3 litros de gas licuado de petróleo.

Suponiendo que los 230 PJoules que se estiman arriba como consumo anual para calentar agua en México, se proveyera con equipos solares, el área que se tendría instalada sería cercana a los 70 millones de metros cuadrados,10 lo que representaría un ahorro aproximado de casi 5 millones de toneladas de gas licuado y 640,200 metros cúbicos de gas natural, equivalentes a poco más de 49 mil millones de pesos en recursos ahorrados, además de una disminución de alrededor de 4 millones de toneladas en emisiones de CO2 equivalentes al año.

Estudios realizados en los últimos años indican que los principales problemas para el uso masivo de Calentadores Solares en México son: el alto costo de la inversión inicial, lo cual se traduce en la necesidad de esquemas adecuados de comercialización y financiamiento; la falta de normas y procedimientos para garantizar la calidad en su instalación y funcionamiento; así como la ausencia de estrategias de difusión, promoción y divulgación de la tecnología.

En el presente trabajo se identifican las distintas opciones que ofrece el mercado de calentadores solares de baja temperatura destinado al sector residencial en México, con el objetivo de obtener información para evaluar precios y rendimientos de las distintas opciones de calentadores solares.

# 57. Índices Energéticos en la Universidad Simón Bolívar, Venezuela

**Aminta Villegas de Olivera**

Departamento de Conversión y Transporte de Energía

Universidad Simón Bolívar

Apartado Postal 89000, Caracas 1080, Venezuela

Tel: +58-212-9063728, Fax: +58-212-9063720, E-mail: avillega@usb.ve

Keywords: Ahorro energético, consumo eléctrico, índices

Resumen: El Programa de Ahorro Energético (PAE) de la Universidad Simón Bolívar se inició en 1997, luego de un estudio piloto que mostró que el sistema de iluminación constituía la principal carga energética (75 % de la factura eléctrica en ese entonces) en un edificio de aulas de clases, y que se podía lograr reducciones sustanciales del gasto rediseñando los sistemas eléctricos y sustituyendo las luminarias por otras de tecnología más avanzada. Desde esos comienzos, muchas de las propuestas del PAE han sido implantadas en el campus universitario, incluyendo: promoción de conciencia en la comunidad de la estructura de costos de la facturación eléctrica, y la necesidad de uso racional de la energía; reemplazo gradual de los equipos energéticamente ineficientes (e. g. sustitución de luminarias de 4 x 40 W con balastos electromagnéticos por luminarias de 3 x 32 W con balastos electrónicos); rediseño de circuitos para permitir el encendido y apagado individual de luces en aulas de clases y oficinas; instalación de sensores de presencia en aulas, y fotocélulas en pasillos y escaleras para apagado automático de las luces; seguimiento permanente de la facturación eléctrica mensual para detectar errores de medición o de cobre por la compañía eléctrica. El apoyo entusiasta y la participación activa de la comunidad estudiantil ha sido especialmente notable, tanto en actividades masivas de

equipos para instalación de nuevas lámparas y sensores, como en el trabajo individual en tesis, pasantías y tópicos dirigidos que han contribuido a diseñar sistemas para auditoría, registro, almacenamiento digital y evaluación de llas condiciones operativas de los equipos e instalaciones eléctricas de la Universidad. En los últimos años, se han calculado índices de consumo de energético en kWh por metro cuadrado de área de construcción, y también en kWh por estudiante, a fines de efectuar comparaciones con estadísticas similares disponibles para instituciones académicas internacionales. El propósito del presente trabajo es exponer las actividades y logros del PAE hasta la fecha, y discutir las posibilidades para futuros desarrollos que puedan continuar contribuyendo a mejorar los índices energéticos de la Universidad.

## 1.- Introducción: Inicios del PAE

Cuando, en el año 1997, la Dirección de Servicios de la Universidad Simón Bolívar (USB) solicitó al Departamento de Conversión y Transporte de Energía un análisis de la facturación eléctrica en la Universidad, el objetivo único era estudiar las posibilidades de bajar el costo del servicio eléctrico. Se realizó entonces un primer proyecto que contempló los siguientes objetivos:

Estudio del sistema de iluminación del edificio de Energética (ENE), como caso piloto.

Análisis del esquema tarifario aplicado en la USB.

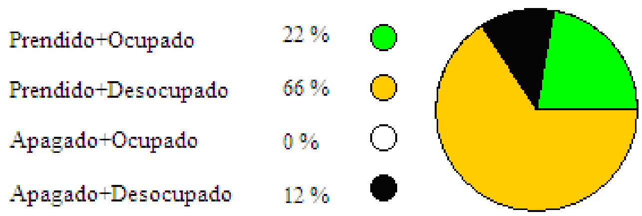
Las conclusiones más importantes obtenidas de este primer estudio destacaron los siguientes aspectos:

El 75 % de la demanda y el consumo en el edificio de ENE lo constituía el sistema de iluminación.

Existía un consumo por iluminación en horas no laborables, que podía ser disminuido. En la Figura 1 se muestra la medición de la ocupación vs iluminación realizada en una de las áreas comunes del edificio piloto.

Figura 23

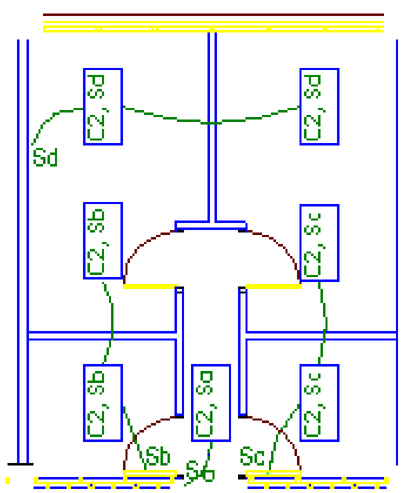
Ocupación v. iluminación




Era imprescindible realizar un recableado en algunas áreas, con el objeto de permitir al usuario local el control del encendido y apagado de su área de trabajo. Tal era el caso, por ejemplo, de los cubículos de profesores del Departamento de Conversión y Transporte de Energía, cuyo esquema se muestra en la Figura 2.

Figura 24

Conexiones eléctricas pre-existentes en cubículos de profesores




Existían áreas donde no era suficiente un control manual para el apagado de las luces, porque no era posible designar un responsable único de esta tarea. En estos casos por consiguiente era conveniente usar un control automático; el principal ejemplo era el de áreas de uso común, como salones de clase y de conferencia, baños, pasillos y algunas áreas administrativas.

La sustitución de las luminarias convencionales de 4 x 40 W y balasto electromagnético constituía la mejor alternativa para lograr la disminución simultánea de la demanda y del consumo eléctrico, sin menoscabo de los niveles de iluminación existentes para ese momento.

La Universidad Simón Bolívar compraba la energía eléctrica en baja tensión, existiendo para el año 1997 un total de 36 medidores con 2 tipos de tarifas aplicables, de acuerdo al valor de la Demanda Asignada Contratada. Existía sin embargo la posibilidad de negociar una tarifa más atractiva a los intereses de la USB, a través de la compra en alta tensión. Esta alternativa, aunque suponía una elevada inversión y una operación y mantenimiento que pasarían a ser de responsabilidad de la Universidad como cliente, presentaba una rentabilidad cercana al 20 %.

De acuerdo con las recomendaciones de este estudio, en el año 2000 se comenzaron a implementar medidas dirigidas a controlar el consumo eléctrico. Las acciones emprendidas fueron:

Remodelación de los circuitos de iluminación en espacios del edificio que no disponían de interruptores para el control independiente del alumbrado.

Adecuación de los circuitos de iluminación de los salones grandes con el fin de sectorizar la operación de encendido automático. Esto se hizo con el fin de permitir que en salones grandes con 24 luminarias, se encendiera sólo la mitad cuando el número de alumnos ocupara sólo la parte delantera del salón.

Instalación de 84 controles automáticos, mediante el uso de sensores de presencia, para el encendido y apagado de la iluminación en espacios de uso común: salones de clase, auditorio, salas de conferencia y de lectura, baños y pasillos, etc.

Instalación de un reloj para el control de las luminarias de las escaleras y áreas centrales del edificio de manera que solo encendieran en horario nocturno, aprovechando en todos los demás horarios la buena iluminación natural.

Campaña de concientización en los diferentes niveles de la universidad a favor de un uso racional de la electricidad.

Los trabajos relacionados con la adecuación de las instalaciones y colocación de los sensores se concluyeron en abril del año 2000, con un costo de Bs. 11.500.000. El seguimiento del comportamiento del consumo en el edificio de ENE se hizo en mayo, obteniéndose como resultado un 24 % de disminución en el consumo de todo el edificio, lo cual representaba un monto de Bs. 438.000 mensuales en base a la tarifa del momento. Los sensores tienen una vida útil de 10 años y una garantía de 5. Es de hacer notar que esta reducción se logró a pesar de dos circunstancias que se presentaron a partir de ese mismo mes, y que afectaron las perspectivas de racionalización del consumo energético: el traslado de actividades del Núcleo del Litoral de la Universidad al campus de Sartenejas, lo que incrementó el uso de salones en un 8 %, aproximadamente, y el funcionamiento descontrolado del sistema de aire acondicionado en el Auditorio de ENE, que significó un incremento del consumo en el orden del 10 %.

## 2.- Consolidación del PAE: Actividades en Planta Física

El PAE se consolidó como una iniciativa permanente de la Universidad, adscrita al Vicerrectorado Administrativo, a partir del año 2002. En ese año, el nuevo Vicerrector autorizó el apagado de la iluminación en el edificio de Biblioteca Central en horario no laboral, es decir los días de semana desde las 7 de la noche hasta las 7 de la mañana; y los fines de semana a partir de la 1 de la tarde del sábado. Casi simultáneamente, se llevó a cabo una gran jornada de sustitución de luminarias de 4 x 40 SW y balasto electromagnético por equipos de 3 x 32 W y balasto electrónico, con la participación masiva de estudiantes, profesores, empleados y egresados. Lo resaltante de estas jornadas es que plantean un gran aporte al programa pues significan mano de obra gratuita.

En el año 2003, y nuevamente con la participación de estudiantes y profesores, se realizó el acondicionamiento de los circuitos ramales y la subsiguiente instalación de sensores de presencia en el edificio de Mecánica y Urbanismo (MEU). En la Figura 3 se presenta la evolución histórica de la facturación del medidor que sirve a cuatro edificios de la Universidad, incluyendo los de ENE y MEU que representan alrededor del 50 % de la carga conjunta. Al respecto es preciso aclarar que en los otros dos edificios (Mecánica y Materiales, MEM, y Estudios Generales, EGE) no se han realizado acciones por parte del PAE hasta la actualidad. La curva suavizada en la Figura 3 corresponde a una correlación desarrollada excluyendo los datos del consumo registrado en los años 2002 y 2003, por cuanto éstos fueron inusualmente bajos debido a eventos nacionales que produjeron una caída general del consumo no imputable al PAE.

Figura 25

Evolución del consumo de los edificios MEM, MEU, EGE y ENE

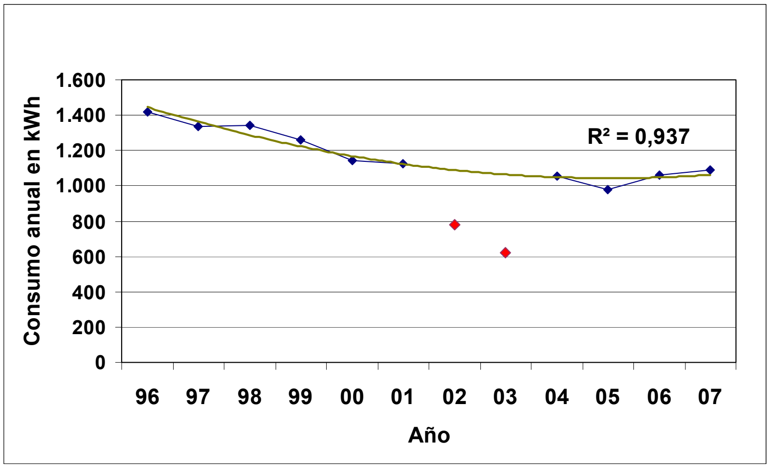
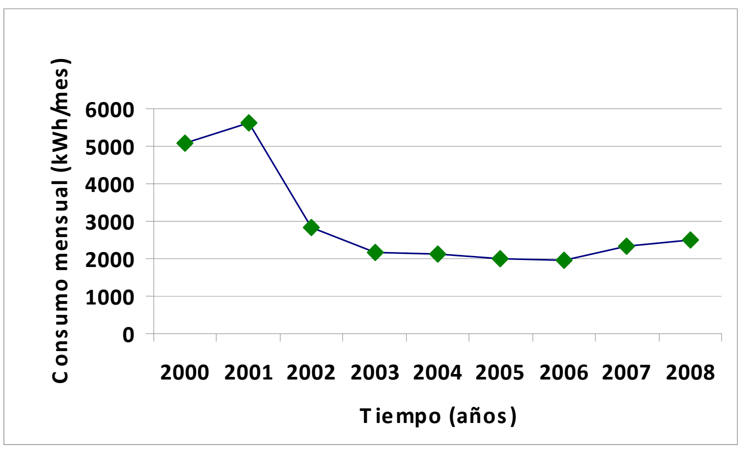



Figura 26

Evolución del consumo en el edificio de Biblioteca Central




En mayo de 2004, noviembre de 2005 y luego en febrero de 2008, se continuó con las jornadas especiales de cambio de luminarias en el 1er piso de Biblioteca, Casa del Rectorado, y 3er piso de la Biblioteca respectivamente. Todos estos eventos se realizaron con la participación entusiasta de estudiantes, acompañados por profesores, egresados y técnicos. En la Figura 4 se presenta la evolución del consumo eléctrico en el área de iluminación y tomacorrientes del edificio de Biblioteca Central.

A medida que se fue implementando el Programa de Ahorro Energético, se observó la carencia de planos e información general de los sistemas de distribución en media, baja tensión y de las instalaciones interiores de los edificios. Esto dio pie a la realización de diversos estudios complementarios, los que se han venido llevando a cabo a través de tesis, pasantías largas y cortas, tópicos especiales y laboratorios ofrecidos a los estudiantes de la Universidad. Se mencionan brevemente a continuación algunos de los proyectos más relevantes vinculados al PAE.

Registro y digitalización del sistema eléctrico de varios edificios:

Este trabajo consistió en la auditoría y realización de planos en autoCAD que registren las instalaciones actuales y que permitan la actualización constante de las mismas. Este trabajo es muy lento por cuanto no debe interferir con el normal desempeño de las actividades docentes y administrativas de la universidad.

Estudio de factibilidad para la producción independiente de energía en la USB:

En este estudio se analizó el uso de motores diesel y a gas y turbinas a gas para generación de electricidad, y se consideraron los aspectos ambientales, técnicos y económicos que presenta cada alternativa propuesta (Aguilar, 2001).

Levantamiento y análisis de la red de media tensión:

Este trabajo surgió como una necesidad derivada de la propuesta de comprar la electricidad en alta tensión. Ahora la Universidad dispone de un plano digitalizado de su red de media tensión, con indicación de la ruta y calibre de conductores, ubicación de sótanos y equipos de transformación, protección y maniobra (Pulido, 2002).

Evaluación de la compra en alta tensión y racionalización de la red de media tensión de la USB :

Este trabajo se planteó dos objetivos principales, el primero de ellos consistente en una auditoría y evaluación económica de las instalaciones de media tensión existentes en el campus, y el segundo, en un estudio técnico que tenía como propósito la racionalización de esas instalaciones (Carrillo y Mariosa, 2003).

Adecuación de la red de media tensión para compra en alta tensión:

Actualmente, los alimentadores del Instituto de Estudios Avanzados (IDEA), institución que colinda con el campus universitario, se derivan de los dos circuitos que alimentan la USB. En el caso de una compra en alta tensión, se requiere independizar ambas alimentaciones de manera que la medición en alta tensión de la USB sólo contemple las cargas propias de ella. Esto requiere un estudio de la probable ruta que signifique los menores costos (Urdaneta, 2004).

Selección óptima de una propuesta de autogeneración para la Universidad Simón Bolívar:

Se presentó un modelo matemático que permite seleccionar un sistema óptimo independiente para generación de energía eléctrica en la USB, minimizando los costos de inversión del proyecto basados en el valor de las unidades de generación a gas actualmente existentes en el mercado. Se consideran además los costos asociados de operación, mantenimiento y confiabilidad de las unidades a utilizar. Como restricciones a la función objetivo se consideran variables ambientales y técnicas (Khodr, 2004).

Análisis para la unificación de esquemas de baja tensión en la USB:

En la USB existen varios esquemas de medición en baja tensión: 480, 416 y 208 voltios. El objeto de este trabajo fue ver la conveniencia, desde los puntos de vista técnico y económico, de unificar los diferentes esquemas.

Levantamiento de información del alumbrado público y anteproyecto para mejorar áreas:

La iluminación vial y de los espacios de tránsito entre edificios del campus ha sido tradicionalmente deficiente, por lo cual se realizó este estudio para plantear propuestas de solución en las áreas más críticas (Ravard 2005).

Propuestas para mantenimiento:

Este trabajo tuvo como finalidad el diseño de un programa de mantenimiento para las instalaciones eléctricas de la Universidad. Para lograr el objetivo se realizó un registro de los equipos más expuestos a fallas y se calcularon las cantidades necesarias para tener un stock confiable. Finalmente se creó una herramienta computacional para el proceso de solicitud de materiales en el almacén con el propósito de ir generando una base de datos histórica real.

Desarrollo de una base de datos espacial para la supervisión y control del PAE:

Esta tesis tuvo tres objetivos fundamentales: Supervisar y controlar los datos del consumo y la demanda de energía eléctrica en la USB, generar los reportes prioritarios del PAE en lo relativo al consumo y la demanda de electricidad de la USB de forma rápida y sencilla, y servir de fuente de información para los distintos usuarios potenciales, ofreciendo vistas personalizadas.

Diseño de un sistema de control computarizado para el manejo de sensores:

Se diseñó un controlador inteligente en Matlab® que interpretara un horario de asistencia y comparara en cada bloque de horas sin presencia dos escenarios de operación: la reducción de la vida útil de los tubos por el incremento de la frecuencia de encendido, y el incremento en el gasto de electricidad evitando apagar la iluminación, con la finalidad de optimizar el horario inicial y reducir el gasto total (por concepto de electricidad y reemplazo de tubos fluorescentes) (Olivera, 2004).

Uso de un PLC para control de aire acondicionado en el Auditorio de ENE:

Aprovechando las características de los sensores de movimiento y la disponibilidad de un PLC donado al Programa, se realizó una propuesta para el control del aire acondicionado en el auditorio de Energética.

Análisis de la calidad del servicio en la USB:

Esta tesis consistió en el análisis de distintos parámetros eléctricos que definen la calidad del servicio dentro de la Universidad Simón Bolívar. Se realizaron mediciones de parámetros generales, de arranques y perturbaciones (Berrocal, 2005).

Alternativas de alimentación del Portal de Entrada al campus de Sartenejas:

El tópico tuvo por objetivo sustituir el esquema actual de alimentación de la puerta de entrada de la sede de Sartenejas de la Universidad por un sistema que utilice alternativas no convencionales de generación, específicamente energía solar.

Levantamiento y análisis de la red de baja tensión en la USB:

Con este trabajo se persiguió la documentación y digitalización del sistema de baja tensión. Así mismo se hizo un análisis, utilizando técnicas de optimización de la alimentación del sector de pabellones, tomando en consideración el plan de remodelación de esta área actualmente en discusión (Zambrano, 2008).

Análisis del impacto del apagado y cambio de luminarias en la humedad de la Biblioteca:

Para verificar el impacto real sobre las condiciones ambientales del edificio de Biblioteca Central, se llevó a cabo este trabajo experimental de medición y registro de temperatura y humedades. Los resultados obtenidos demuestran que el apagado de luces y uso de equipos energéticamente más eficientes produce efectivamente temperaturas menores y humedades mayores. Sin embargo el costo de control de las condiciones ambientales mediante la iluminación no se justifica económicamente, resultando preferible atacar el problema a través de la optimización del funcionamiento de los equipos del aire acondicionado (Olivera y Villegas, 2009).

## 4.- Indíces Energéticos

En adición a los trabajos mencionados más arriba, se realizó un proyecto dedicado al cálculo y evaluación de índices energéticos de la USB. Los índices energéticos, expresados en kWh/(día.$m^2$), de 51 áreas del campus, se estimaron con base en lineamientos expuestos en la guía operacional de ahorro energético en edificaciones públicas elaborada por el Ministerio de Energía y Petróleo, y en la información recopilada por el PAE. El análisis de estos índices permitió identificar las áreas con los índices más elevados, para las cuales se plantearon acciones tendientes a lograr importantes reducciones en el consumo sin afectar las condiciones mínimas de bienestar y comodidad para los usuarios. En el trabajo se presentaron propuestas de baja inversión para continuar disminuyendo el consumo eléctrico en la USB. Se investigó si existían índices similares publicados en Venezuela, pero lamentablemente no se encontraron; se localizó, en cambio, información de los 3 campus de la Universidad Carlos III de Madrid. En la Figura 5 se muestran los índices en kWh/(año.$m^2$) del campus de Sartenejas de la USB para los años 2003 y 2004. Para fines de comparación, se incluye información análoga de los tres campus (Leganés, Getafe y Colmenarejo) de la mencionada universidad española.

Un segundo tipo de índices se elaboró en términos del consumo energético por estudiante. Hasta el año 2006, el PAE hacía seguimiento del consumo y la demanda para tener una medida del impacto de las acciones del programa, y aunque se observaba una notoria disminución en el consumo, la información se consideraba incompleta, porque la población estudiantil de la USB ha ido aumentando (y con ella, también los números de personal académico y de apoyo). Es por ello que, con la nómina estudiantil por año desde 1996 hasta 2006, se calcularon índices energéticos de consumo anual, en kWh/estudiante, los cuales se muestran en la Figura 6. Se presentan además, en la Figura 7, índices de consumo anual por usuario, que incluye no sólo estudiantes, sino también profesores, empleados administrativos y obreros.

Figura 27

Índices energéticos en kWh/(año.m$^2$)

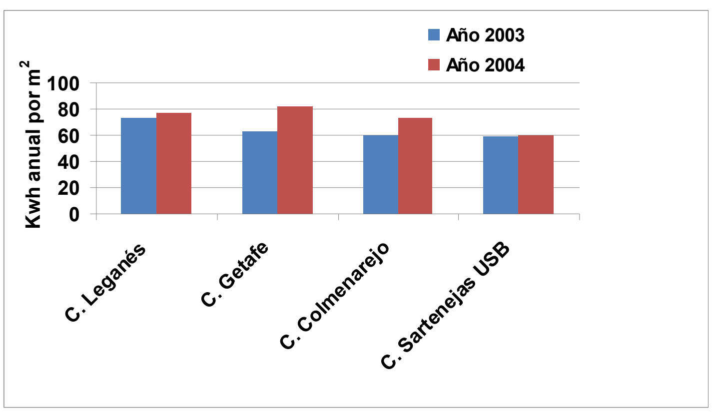



Figura 28

Índices energéticos en función de la nómina estudiantil

|

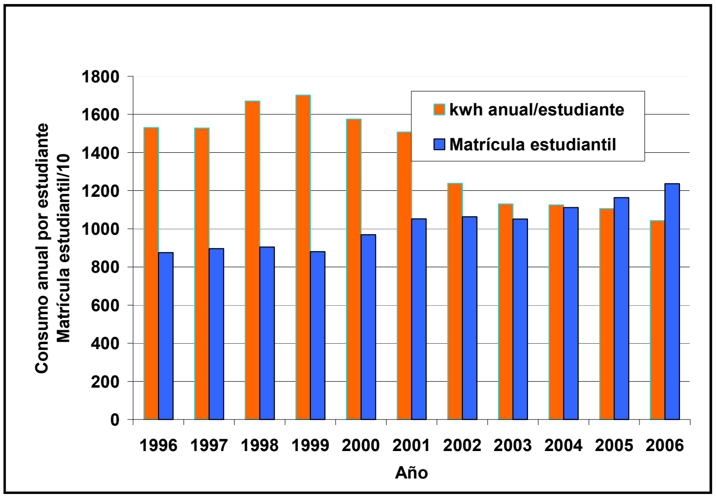
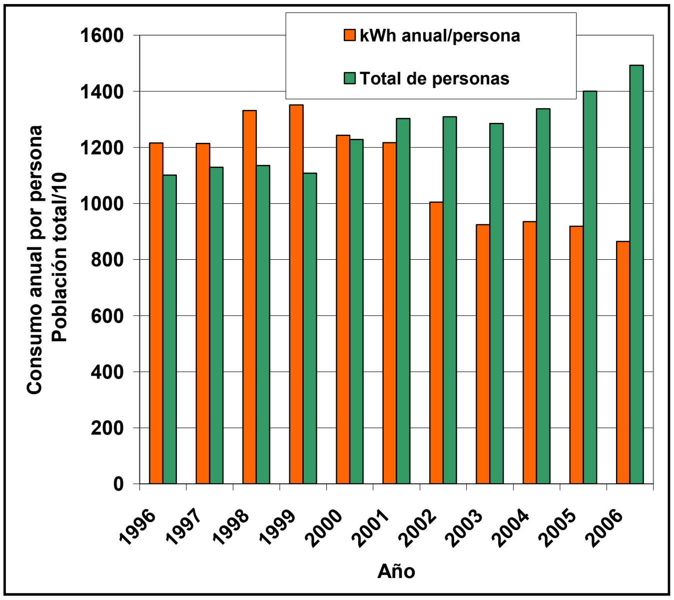



Figura 29

Índices energéticos en función de la población total




## 5.- Conclusiones

Desde su inicio, el Programa de Ahorro Energético de la Universidad Simón Bolívar ha contribuido a la racionalización del consumo, reducción del gasto, ordenamiento de la información e incremento del conocimiento en materias eléctricas en la Universidad. A través de estas acciones, el PAE se ha consolidado de tal manera que, en la actualidad, las unidades responsables de mantenimiento y ejecución de obras nuevas en la USB están tomando en cuenta los criterios de ahorro divulgados por el programa.

Como un aspecto importante, se ha logrado incentivar la participación estudiantil en trabajos prácticos y proyectos de investigación que han redundado en un beneficio directo para la institución. Las jornadas de reemplazo de luminarias e instalacieon de sensores han constituido eventos particularmente exitosos y de alto impacto en la comunidad.

Los principales problemas encontrados en el transcurso del programa han sido de índole financiera, derivados de las restricciones presupuestarias de la Universidad. Sin embargo, a medida que el PAE se ha ido consolidando, se han conseguido algunos recursos, incluyendo donaciones de entes externos, para seguir implementando la racionalización del consumo eléctrico. Una situación peculiar se generó en el año 2005, cuando la Oficina de Presupuesto del Sector Universitario (OPSU), ente gubernamental que controla las universidades públicas, decidió encargarse en forma centralizada del pago de los servicios (electricidad, agua, teléfonos, etc.) prestados a las universidades públicas. Esta decisión atentaba directamente contra la permanencia del PAE, por cuanto se perdía el seguimiento y control de la facturación, y desaparecía el estímulo para la racionalización energética impulsada por el PAE. Afortunadamente, la iniciativa de OPSU fue de corta duración, y en el año 2006, la cancelación de la facturas por servicios regresó a las universidades.

Los índices energéticos (Figuras 6 y 7) demuestran claramente que, a pesar del crecimiento sostenido de la población universitaria, el PAE ha tenido efectos positivos. A manera de ejemplo, el consumo anual por estudiante en el año 2006 muestra una reducción del 30 % con relación al del año 2000. Esta reducción relativa, aunque alentadora, no puede sin embargo considerarse como un logro final. Hace falta todavía disponer de índices energéticos referenciales, adecuados a las condiciones de Venezuela, que permitan a la institución conocer si, en términos absolutos, está usando eficientemente la energía eléctrica, o si existen aún metas por alcanzar para ponerse a la par de entes similares a nivel internacional.

## 6.- Referencias


Aguilar, H. (2001). “Estudio de factibilidad para la producción independiente de energía en la USB”, Proyecto de Grado, Universidad Simón Bolívar, Sartenejas.

Berrocal, S. (2005), Proyecto de Grado, Universidad Simón Bolívar, Sartenejas.

Carrillo, C. y Mariosa, A. (2003) “Evaluación de la compra en A.T. y racionalización de la red de media tensión de la U.S.B., Proyecto de Grado, Universidad Simón Bolívar, Sartenejas.

Khodr, H.M.; Bodu Gilberto; de Oliveira P.; Yusta J. M.; Villegas, A.; Paiva, P; Hussein H. (2004) "Selección Óptima de una Propuesta de Autogeneración para la Universidad Simón Bolívar". IV Congreso Venezolano de Ingeniería Eléctrica, CVIE´2004. Caracas, Venezuela.

Lugo, V. (2004), Desarrollo de una base de datos espacial para la supervisión y control del PAE, Proyecto de Grado, Universidad Simón Bolívar, Sartenejas.

Olivera Fuentes, C. y A.Villegas de Olivera (2009). “Energy Interaction between Lighting and Air Conditioning in a Library Building”, 2nd Latin American Meeting on Energy Economics (ELAEE 2009), Santiago, Chile.

Olivera Villegas, H. (2004) “Diseño de un sistema de control computarizado para el manejo de sensores”, Proyecto de Grado, Universidad Simón Bolívar, Sartenejas.

Pulido A., O. (2002). “Levantamiento y Estudio de la Red de Distribución de Energía Eléctrica de la U.S.B’, Proyecto de Grado, Universidad Simón Bolívar, Sartenejas.

Ravard Nieto, O. y Hidalgo Martínez, E. (2005) “Levantamiento de información del alumbrado público de la USB y anteproyecto para mejorar áreas”, Proyecto de Grado, Universidad Simón Bolívar, Sartenejas.

Urdaneta, M. (2004) “Adecuación de la red de media tensión para compra en AT, Proyecto de Grado, Universidad Simón Bolívar, Sartenejas.

Zambrano, E. (2008), “Levantamiento y análisis de la red de baja tensión en la USB”, Proyecto de Grado, Universidad Simón Bolívar, Sartenejas.

# 58. Impactos socioeconômicos e ambientais do programa brasileiro de avaliação de conformidade para etanol combustível

**José A. Scaramucci*, Isabel M. A. de Lemos Loureiro** e Wellington M. S. da Cruz*****

*** Instituto Nacional de Metrologia, Normalização e Qualidade Industrial (Inmetro) e Núcleo Interdisciplinar de Planejamento Energético (NIPE) – Universidade Estadual de Campinas (Unicamp); jascaramucci@inmetro.gov.br;**

**** Instituto Nacional de Metrologia, Normalização e Qualidade Industrial (Inmetro); imlemos@inmetro.gov.br;**

***** Instituto Nacional de Metrologia, Normalização e Qualidade Industrial (Inmetro); aluno do programa de pós-graduação em economia – Universidade Federal Fluminense (UFF); wmcruz@inmetro.gov.br.**

**Rua Santa Alexandrina, 416 – Anexo Sesao – Rio Comprido, 20261-232 Rio de Janeiro, RJ, Brasil. Tel.: + 55 21 2563-5570 Fax: + 55 21 2563-5579.**

**Palavras-chave: Análise de impacto, avaliação da conformidade, certificação, bioetanol.**

**Resumo:** O regulamento técnico de avaliação da conformidade para etanol combustível, desenvolvido pelo Instituto Nacional de Metrologia, Normalização e Qualidade Industrial (Inmetro), era previsto ser implementado até o final de 2008. A certificação voluntária do etanol produzido no Brasil visa superar barreiras técnicas (não-tarifárias) que podem ser impostas a ele por outros países. Os critérios de certificação atendem a diversas questões ambientais, sociais e econômicas que aparecem freqüentemente no debate sobre as fases agrícola e industrial da cadeia produtiva do etanol brasileiro. O Regulamento de Avaliação de Conformidade – RAC (como ele é chamado) proposto pelo Inmetro vai além das características intrínsecas do álcool carburante, envolvendo também aspectos importantes do processo de produção, como a redução de gases de efeito estufa e as chamadas boas práticas no cultivo da cana-de-açúcar, matéria-prima para a produção do etanol. Busca-se, em resumo, assegurar que o bioetanol brasileiro, ao cumprir requisitos preestabelecidos, seja, entre outras coisas, ambientalmente seguro e socialmente responsável. Este trabalho não pretende discutir a formulação do Regulamento de Avaliação da Conformidade para Etanol Combustível *per se* – isso seria função de instâncias organizacionais particulares do Inmetro. O objetivo principal aqui é descrever os principais mecanismos econômicos subjacentes à certificação voluntária do etanol e fazer uma avaliação *ex post* preliminar dos efeitos socioeconômicos esperados de sua introdução no Brasil.

**Key-words: Benefit–cost analysis, conformity assessment, certification, ethanol, biofuels**

**Abstract:** The Brazilian conformity assessment scheme for fuel ethanol, developed by the National Institute of Metrology, Standardization and Industrial Quality (Inmetro), was planned to be implemented by the end of 2008. The voluntary certification of the ethanol produced in Brazil aims at overcoming technical (non-tariff) barriers that can be imposed by other countries. The certification requirements comprise various environmental, social and economic issues which appear often in the debate about the agricultural and industrial stages of the Brazilian ethanol productive chain. Besides the intrinsic fuel ethanol characteristics, the conformity assessment scheme proposed by Inmetro involves also other important production aspects, such as mitigation of greenhouse gases and the so-called best practices for growing sugarcane, feedstock used in Brazil for producing ethanol. The objective is to ensure, among other things, that by meeting predetermined requirements the Brazilian ethanol is environmentally safe and socially responsible. This paper does not intend to discuss the formulation of the ethanol conformity assessment scheme *per se* – this task lies under the responsibility of other Inmetro sectors. The main goal here is to describe the economic mechanisms underlying the voluntary ethanol certification process and to conduct an *ex post* preliminary evaluation of the socioeconomic impacts of its implementation in Brazil.

## 1.- Introdução

Em 2007, o Brasil foi o maior produtor mundial de cana-de-açúcar – 420 milhões de toneladas forma processadas, para produzir cerca de 30 milhões de toneladas de açúcar e aproximadamente 17,5 bilhões de litros de etanol .[208]

Segundo estudos recentes (CGEE 2005 e CGEE 2007), o Brasil tem condições para produzir de forma sustentável etanol de cana-de-açúcar para substituir em 20 anos até 20% do consumo de gasolina no mundo. Contudo, persistem ainda diversas barreiras alfandegárias e não-tarifárias impostas por muitos países ao álcool brasileiro. Tal impedimento do livre exercício da atividade econômica é sempre motivo de discussão em fóruns multilaterais sobre comércio internacional, principalmente os que tratam de bens e serviços com preços determinados em mercados globais, as chamadas *commodities*.

O Brasil avançou muito na fronteira do conhecimento relacionada à produção dos biocombustíveis, em especial no caso do etanol, e pode usar tal experiência para influenciar a forma do desenvolvimento tecnológico e os padrões que poderão vir a existir no potencial mercado que se materializa. Tais questões podem ser conduzidas em várias frentes nacionalmente importantes, como a proteção ao meio ambiente (regulamentando todo o processo produtivo do setor sucroalcooleiro), à garantia de condições adequadas de trabalho (sobretudo no que se refere à inserção do trabalhador rural e fomento à agricultura familiar), e à promoção de um maior nível de desenvolvimento econômico e de diminuição das disparidades regionais.

O presente artigo faz uso deste contexto para discutir a ação de Estado que pode executar essa agenda política, bem como trata dos métodos existentes para avaliar essa ação, de forma que permita o adequado controle por parte da sociedade. Essas duas colocações estão em consonância com as atuais pressões sociais que entendem ser necessário justificar toda a intervenção governamental em mercados e ao mesmo tempo cobram políticas de desenvolvimento produtivo e socioeconômico.

As páginas que se seguem organizam a discussão da seguinte forma: a segunda seção chama a atenção para o argumento desenvolvido na literatura econômica a respeito da atividade regulatória por meio da padronização industrial no âmbito da infra-estrutura da qualidade; a terceira seção avalia a proposta de regulamentação do etanol biocombustível brasileiro tomando como referência o documento que o Inmetro planeja executar enquanto política para o setor; a quarta seção traz comentários a respeito de como essa ação poderia ser avaliada por meio de uma

[208] O conteúdo de energia primária (potencial) de uma tonelada de cana-de-açúcar é aproximadamente 1,2 barris equivalentes de petróleo (considerando o caldo, bagaço e a palha). Portanto, 420 milhões de toneladas de cana-de-açúcar correspondem a 1,15 milhões de barris de petróleo por dia – pouco mais da metade da produção atual de óleo cru do Brasil. Em 2007, os produtos da cana-de-açúcar (etanol do caldo e eletricidade de bagaço) representaram 18,1% da produção de energia primária no Brasil; para efeito de comparação, a participação do petróleo e da energia hidráulica na matriz energética brasileira em 2007 foram, respectivamente, 40,6% e 14,4% (MME, 2008).

metodologia de custo-benefício, chamando a atenção de que essa metodologia ainda precisa ser rigorosamente formulada para lidar com esta tarefa; e por fim, algumas considerações finais que buscam sumarizar e conectar as amplas linhas de discussão apontadas no texto.

## 2.- Avaliação da Conformidade: a questão econômica geral

O problema econômico tradicional envolvido na prática da regulação está nas muitas falhas de mercado contra as quais ela pretende ser efetiva, em especial a assimetria de informação entre os envolvidos e as externalidades positivas que não podem ser exploradas pela atividade econômica privada. Isso pode ser exemplificado de forma geral no âmbito do sistema de infra-estrutura da qualidade, que fornece bens e serviços públicos, i.e., produtos que a iniciativa privada não tem estímulos suficientes para prover – ou, se produz, o fará muitas vezes conforme uma lógica oportunista, procurando criar mecanismos favoráveis a si própria. Ademais, é interessante notar que se as atividades de governo, no que tange à regulação, fossem correlacionadas com o interesse da iniciativa privada no sentido amplo, elas seriam supérfluas, como revela a chamada teoria da captura:

> *The concept of 'regulatory capture' is the idea that some producers may lobby so skillfully that they persuade the regulator to define regulations in the interest of the producers rather than in the interest of the customer (as originally intended)* (Swann, 2000, p. 8).

Muito menos comum é definir esta hipótese quando a ação do governo é favorável ao consumidor, o que não significa que outras situações de conflito não possam surgir daí. Em um tipo de contexto como esse, a atuação das instituições responsáveis por esta área regulatória, agências e institutos de normalização e regulamentação, é colocada no centro da questão e estas organizações são convidadas a prestarem contas e justificarem à sociedade o volume de investimento que é necessário para a manutenção permanente e ampliação desta estrutura, em especial quando desfrutam de dinheiro público.

A literatura econômica, como apontado, também aborda o assunto pela perspectiva da informação assimétrica ao trabalhar a questão da padronização de produtos. Para tanto, apresenta uma categorização que indica algumas das externalidades positivas e negativas envolvidas com a padronização: a) compatibilidade/interface que cria uma rede de usuários, *network externalities*, que é de interesse coletivo, mas que pode criar um monopólio e ameaçar a segurança de certos setores estratégicos; b) qualidade e atributos mínimos que possibilitam uma discriminação a favor dos melhores produtos (eliminando o *lemon problem*, isto é, a informação assimétrica) e resultam na diminuição dos custos de transação, contudo, pode ser fonte para o problema da captura por ser decorrência de um trabalho de cunho cooperativo, onde os produtores (individualmente ou em grupo) pressionam o poder público ou o setor a adotarem atributos que beneficiem deliberadamente alguns poucos envolvidos; c) redução da variedade que propicia economias de escala e capacita os agentes a desenvolverem melhor certas linhas e processos, mas pode levar ao efeito adverso de estabelecer um *lock-in* ; d) informações técnicas de referência padrão que facilitam a troca, manutenção e uso, além de, em adição, reduzir os custos de transação, mas sofrem das mesmas limitações de qualidade mínima (b) (David, 1985; Swann, 2000; Haimowitz e Warren, 2007). Dentre os itens indicados acima, o ponto (c) é uma adição sugerida por Swann para discutir, entre outras coisas, questões de bem-estar macroeconômico, comércio internacional e o papel de governo. Primeiramente, com relação a este último aspecto, o problema colocado do *lock-in*, associado com o problema da captura, pode resultar de uma condução política inadequada que leve ao uso ineficiente dos recursos. David chama essa possibilidade indesejável de problema do "*blind giant*" quando se refere ao governo que se torna refém dos "*angry orphans*", isto é, os agentes produtivos dependentes de uma tecnologia "inferior" e que necessitam de ajuda oficial para sobreviver no mercado.

Haimowitz e Warren (2007, p. 8) discutem a segunda questão, do comércio internacional e sua relação com o crescimento econômico via fomento à atividade inovativa, chamando a atenção para o fato que:

> *Standards impact international trade in three ways. They act as a form of non-price competition; they help to improve trade performance because they provide information on quality, and internationalized standards can also increase the potential for international trade by improving compatibility, product information and measurement. (...) Recent studies done in Europe have concluded that standards have had a positive impact on the economy and have played an important role in improving labor productivity. (...) Standards have an important impact on innovation by providing information and reducing uncertainty thus mitigating the risk of R&D investment.*

Por fim, estes elementos em conjunto apóiam a caracterização de um ambiente macroeconômico funcional, capaz de produzir e difundir o bem-estar socioeconômico à população, ao passo que indica como a regulamentação eficiente na gestão de padrões e certificações (tarefa que é realizada, tecnicamente, por vários órgãos públicos e privados) pode aprimorar a inserção produtiva nacional no fluxo tecnológico e comercial entre países (inclusive, atraindo novos investimentos).

De forma a destacar a não-linearidade dos (ou melhor, a retroalimentação) entre os efeitos mencionados acima, Blind e Grupp, citados por Swann (2000, p. 18), apontam que a inovação, aliada a sua difusão e à padronização que facilita esse processo, tem forte capacidade de aumentar o ritmo de crescimento econômico e a participação dos países no comércio internacional. Inclusive comparam a contribuição do sistema de padronização com os demais insumos comumente listados na literatura. Desta forma argumentam que a infra-estrutura de qualidade e padronização é um dos componentes mais relevantes do Sistema Nacional de Inovação (NSI, sigla em inglês) por proporcionar um ambiente inovativo favorável, seja para a padronização formal ou para a padronização *de facto*, diminuindo a dificuldade em construir a capacidade de absorção do país, por codificar parte do conhecimento tácito existente (Swann, 2000). Outra característica econômica básica da padronização relacionada a essa retroalimentação, e que é responsável por boa parte das falhas de mercado notadas, é a dos retornos crescentes de escala nas atividades produtivas que fazem uso deste sistema (Swann, 2000).

## 3.- O Mecanismo da Avaliação da Conformidade

O programa brasileiro de avaliação de conformidade é fruto de uma ampla discussão com vários segmentos da comunidade nacional e internacional e busca atender demandas diferenciadas com relação aos produtos, serviços e processos produtivos no que tange a sua inserção na sociedade. Este programa é, sobretudo, um instrumento de política pública uma vez que lida com interesses variados, ligados à economia, à saúde e segurança, ao meio ambiente e ao bem-estar social em geral.

A grande heterogeneidade dos objetos postos à avaliação precisa e pode ser trabalhada por meio de um número também expressivo de mecanismos que compõem a agenda da conformidade (certificação, inspeção, declaração pelo fornecedor, etiquetagem, ensaio) e visam, principalmente, garantir a confiança nos bens adquiridos em mercados regulamentados.

O Inmetro é o órgão ligado ao governo federal brasileiro responsável pelo desenvolvimento e execução dos regulamentos específicos de avaliação da conformidade. Ele implementa, tendo por referência uma norma técnica ou um regulamento técnico, um esquema propositivo que define o que deve ser avaliado pelo programa e como essa avaliação deve ser conduzida para que o produto, serviço, ou processo, esteja de acordo com um grau mínimo estabelecido em termos de qualidade, representando o menor risco para os usuários em geral. Tais colocações práticas são respaldadas na literatura resenhada na seção anterior.

Este procedimento, do ponto de vista do setor produtivo, tem como resultados mais gerais, entre muitos, o de proteger o produtor nacional da concorrência desleal por parte de bens comercializáveis internacionalmente, bem como, por meio da melhoria dos padrões internos, o de permitir aos produtores agregarem valor aos produtos exportados e apropriarem um preço-prêmio que aumente a renda interna. Outro ponto digno de nota, relacionado ao governo, se refere à participação do país nos fóruns de discussão que buscam relações mais transparentes e igualitárias de comércio entre nações, que tem como implicação adicional a consolidação da credibilidade e reconhecimento das instituições brasileiras no que é denominado gestão da qualidade. Os consumidores também são beneficiários diretos desta atividade, pois tem seus direitos e segurança preservados nas relações estabelecidas através do mercado, bem como se tornam melhor informados sobre os impactos sócio-ambientais das atividades econômicas.

Sumariamente, segundo publicação do Inmetro (2007, pp. 14-15), os principais aspectos que justificam a atuação nesta área podem ser vistos como:

a) Propiciar a justa concorrência;

b) Estimular a melhora contínua da qualidade;

c) Informar e proteger o consumidor;

d) Facilitar o comércio exterior, possibilitando o incremento das exportações;

e) Proteger o mercado interno;

f) Agregar valor às marcas.

Assim, a avaliação de conformidade é um instrumento de coordenação política e de condução da regulação pública de setores determinados e, desta forma, está sujeita a uma série de controles indissociáveis da gestão pública, em especial, no que se refere a alocação de recursos escassos. Nesse sentido, por serem gastos sustentados pelos contribuintes de forma geral, se faz necessário levantar os benefícios (objetivos e subjetivos, diretos e indiretos) de tais procedimentos (manutenção de estrutura física e de pessoal, atuações diversas como fiscalização, expedição de documentos etc.) com vistas de confrontá-los com os custos percebidos ou latentes (de mesma natureza) e os riscos potenciais da atividade regulatória. Tudo isso com o intuito de possibilitar a avaliação transparente e a justificação da relevância e manutenção da atividade reguladora para a sociedade. É possível destacar da literatura que o critério mais utilizado na busca dessa meta é o de eficiência econômica, na sua acepção tradicional, e a metodologia mais difundida é a de análise de custo-benefício, amplamente adotada para a avaliação de impactos de políticas públicas.

Retomando a questão de interesse do presente texto, no caso do regulamento de avaliação da conformidade do etanol biocombustível brasileiro, nota-se que o programa utiliza mecanismos diferentes em combinação para lidar com dois aspectos do mesmo problema: (1) o da qualidade intrínseca do produto final e do impacto socioambiental em distinção do (2) fator de redução das emissões de gases de efeito estufa. Assim, apresenta a peculiaridade de oferecer uma certificação voluntária (terceira parte) para o primeiro aspecto, que deveria, conforme as instruções internacionais, ser concedida a partir de uma norma técnica; e, no caso do segundo aspecto, realiza a avaliação de conformidade a partir da declaração do fornecedor (primeira parte).

Dessa forma, para obter a certificação final, o solicitante precisa, entre outras coisas, apresentar evidências de que seus fornecedores de matéria-prima, cana-de-açúcar no caso brasileiro, respeitam certos critérios com relação à proteção do meio ambiente e do combate das relações desumanas de trabalho, promovendo a tecnologia por meio do aumento da mecanização da colheita e da qualificação da força de trabalho; bem como garantir que cultivam benfeitorias e oferecem contrapartidas de suas atividades às comunidades locais. Alguns outros princípios, critérios e indicadores também utilizados para a avaliação de conformidade da atividade de produção de etanol biocombustível são (Inmetro, 2007):

a) Racionalidade no uso dos recursos naturais em busca da sustentabilidade;

b) Proteção, recuperação e conservação da biodiversidade;

c) Respeito às águas, ao solo e ao ar;

d) Respeito às questões trabalhistas, previdenciárias e de saúde e segurança do trabalhador.

No que tange, inicialmente, os custos envolvidos neste processo de avaliação da conformidade, é possível destacar que o mecanismo de declaração pelo fornecedor apresenta a vantagem de ser menos intrusivo, pois: “é uma intervenção mais branda e menos onerosa nas relações de consumo, já que a interferência externa (terceira parte) é eliminada. Confere, também, maior agilidade no atendimento às demandas da sociedade por avaliação da conformidade” (Inmetro, 2007, p. 24). Por outro lado, a atividade de certificação formal, mais comum, envolve custos específicos que precisam ser avaliados caso a caso de acordo com o foco e cadeia de elementos a serem considerados. No caso do etanol fabricado a partir do bagaço da cana-de-açúcar, desde o plantio, colheita e tratamento do solo até questões de qualificação do pessoal empregado, transporte e amarzenagem portuária, podem ser certificados por órgãos acreditados ou não, e até o momento, em caráter voluntário. Podemos observar que o setor do Inmetro responsável por esta atividade formal de acreditação é a Coordenação Geral de Acreditação (Cgcre), a qual desenvolve estudos da viabilidade desses processos, em um primeiro esforço de levantar os custos institucionais da prática regulatória. Portanto, uma avaliação pormenorizada dos impactos econômicos associados ao regulamento aqui apresentado pressupõe a atuação contínua e eficiente desse setor.

Para o adequado tratamento da questão da relevância social desta atividade típica de Estado, que vai além da mera prestação de um serviço público (uma vez que, como apontam os especialistas indicados nas seções anteriores, a regulação pode ser vista como um bem público), são necessárias algumas definições que cerquem o problema econômico a ser atacado em específico: (1) quanto ao seu foco e aos elementos envolvidos, bem como, (2) quanto a um levantamento detalhado de suas implicações socioambientais e a adequação do aparato analítico utilizado na captura de tal fenômeno, no que abrange inclusive as suas conseqüências. Vale mencionar, contudo, que esta atividade de regulação não deve ser estudada como algo estático, mas sim como algo mutável a partir da interação entre os diversos envolvidos (isto é, organizado em sistema) e que, desta maneira, o método de avaliação de seus impactos deve levar essa característica em conta para não incorrer em sérios erros de análise e prognóstico. Na seção que se segue, procuraremos indicar a maneira mais difundida na literatura para lidar com tal objeto.

## 4.- Análise de Custo-Benefício

No caso de se considerar a análise de custo-benefício como algo relevante para a avaliação de impactos de políticas públicas em geral, podemos elencar os seguintes elementos definidores do método (Farrow e Toman, 1998, pp. 6–7):

a) “linha de jogo”, onde são colocadas todas as condições presentes e futuras do bem em questão, os seus principais usos e a dinâmica sob o regime da nova regulação;

b) considerar as alternativas de regulação;

c) identificação de mudança nos resultados e de risco que envolve elementos mensuráveis (em suas medidas naturais);

d) cálculos de custo-benefício que devem fazer um sumário dos impactos bons e ruins de adoção de determinada política, além de revelar o desejo a pagar dos envolvidos;

e) a taxa de desconto, que ainda é critério controverso da metodologia (quanto à consistência e à lógica), mas deve ser indicada;

f) análise de sensibilidade que estuda a diferença sobre as estruturas (como, por exemplo, de distribuição de renda e equidade) que pode ser atribuída a partir da mudança de certos parâmetros;

g) uma avaliação crítica da qualidade e credibilidade dos dados utilizados no estudo.

Ainda segundo Farrow e Toman, uma preocupação das mais importantes para o analista está na abordagem marginal:

> *Economic benefits and costs are measured as incremental changes relative to the baseline. Economists do not and should not try to measure the total value of environmental or ecological resources: the total value of all such resources is likely unknowable and possibly infinite, and this all or nothing value is irrelevant to any practical policy decision. What is relevant instead is the amount of additional benefit secured from environmental improvement, and the additional cost* (p. 8, itálicos do original).

Assim, a atitude responsável do analista requer uma apreciação crítica desse instrumental, para que fique clara a capacidade da análise de subsidiar qualquer decisão de investimento em infra-estrutura de provimento de bens públicos. Cabe esta ressalva, pois, como vimos anteriormente, caso o Estado se ausente, dificilmente o setor privado assumirá todos os aspectos considerados essenciais em tais mercados.

Com efeito, o esquema de aprimoramento desta prática de confrontar ônus e bônus está em aconselhar certas linhas de princípios ou orientações gerais aos gestores públicos, dentre as quais, a não manipulação de definições apresentadas para aumentar os benefícios da regulação ou diminuir os seus custos percebidos, o que possui influência direta sobre o seu impacto final.

Uma das limitações mais aparentes da análise de custo-benefício na literatura é o fato de que ela lida apenas com aquelas coisas que são precificadas em mercados. Além disto, em nome da caracterização mais isenta possível do objeto, estas escalas de precificação devem levar em consideração a valoração real e completa que diz respeito aos indivíduos envolvidos e não ao que os economistas ou filósofos morais entendem como adequado (seja em termos técnicos, seja em termos subjetivos)[209]. Outra falha identificada na literatura é que, por se basear nas condições de mercado, esta metodologia negligencia os interesses de quem não pode expressá-los pelo mecanismo de preços, principalmente a população pobre de recursos (Davies, 1997, p. 204). O autor aponta que quanto maior a expressão das falhas de mercado maior será a dificuldade de determinar estas diferenças de poder econômico e quais os valores associados ao problema. Isto pode ser exemplificado pelo o que ocorre nos países em desenvolvimento, onde questões semelhantes podem ser avaliadas de forma totalmente diferente, como é o caso do meio-ambiente (Davies, 1997, p. 208). Adicionalmente, tem-se o problema temporal:

> *But even when we are able to determine these values, they will reflect the preferences and constraints of the present. Although economists tend to*

[209] "*To give a stark example, if all the water of the US was to dry up next year, using standard cost-benefit tools one may only register a 2 percent drop in national income, and this would only be because we would account to the facts that plants need water*" (Chichilnisky, 1997, p. 203).

*assume that individual preferences are stable over time, they are unlikely to be so in economies undergoing massive structural transformation and growth* (p. 208).

Easter e Archibald (1998) listam cinco desafios metodológicos para a análise de custo-benefício, em qualquer ramo de aplicação: i) estimar valores fora do mercado; ii) considerar riscos e incertezas claramente; iii) avaliar impactos sobre distribuição de renda; iv) selecionar a taxa de desconto (questões intertemporais); v) preocupações com valores não capturáveis pela mensuração da satisfação da preferência do indivíduo, geralmente de caráter qualitativo. Alguns desses elementos já foram apontados logo acima na caracterização do método realizada por Farrow e Toman (1998).

No primeiro ponto, (i), Easter e Archibald abordam os "*travel cost*", "*hedonic prices*" e a avaliação contingente, enquanto métodos qualitativos de alguma utilidade. E nos demais quesitos, de forma mais ou menos transversal e geral, salientam que toda estimativa está sujeita a erros de cálculo e que toda análise que faça uso desse tipo de informações necessita evidenciar, para o tomador de decisão ou para o usuário, os pressupostos subjacentes, as limitações do modelo, e a acurácia dos dados utilizados (p. 13). Se os resultados da análise de custo-benefício superam certas modificações nos parâmetros, isto é, permanecem relativamente inalterados enquanto pequenas mudanças nas condições iniciais são testadas (análise de sensibilidade), eles são considerados robustos (p. 15). Todavia, e a despeito dos referidos autores não indicarem, não é desnecessário alertar que tais instrumentos não são uma correspondência direta com os mecanismos ou tendências em funcionamento na sociedade e, por esse motivo, não esgotam as possibilidades reais do fenômeno, representando, na melhor das hipóteses, um referencial para a proposição informada de políticas públicas e ações privadas que possam ser revistas diante de novos dados e cenários.

Apesar de serem muito abstratos, tais desafios colocados acima evidenciam este aspecto "aberto" (isto é, impossível de ser artificial e completamente controlado) e "não-neutro" (isto é, que vise sempre atender certos interesses de grupos sociais particulares). Isso é nítido, por exemplo, através da necessária concepção de um sistema de ponderações para cada um dos benefícios e cada um dos custos identificados em separado para a avaliação do impacto sobre a distribuição de renda, desde a visão de algum grupo social mais ou menos afetado com relação a outro. Tal questão é de grande relevância, pois, invariavelmente, terá conseqüências sobre a estrutura da demanda agregada, desenvolvimento humano, desenvolvimento da infra-estrutura social e daí em diante. Ficam claras a real capacidade da metodologia de avaliação de custo-benefício e a necessidade de superar a sua imagem vulgar, de uma ferramenta meramente técnica e, por isso, incapaz de oferecer respostas no âmbito social.

Existe também uma grande discussão sobre a funcionalidade da taxa de desconto para a análise. Segundo alguns autores ela é fundamental para determinar a relação econômica existente entre agentes presentes e de gerações futuras, mas é também um tanto quanto arbitrária em sua definição, pois a especificação nunca pode ser realizada de fato considerando apenas bases objetivas. Sendo assim, é uma questão a ser mais debatida, onde em casos extremos, "*Lower discount rates might be justified if the regulatory policy would create important irreversible changes that have significant impacts on future generation*" (Easter e Archibald, 1998, p. 17).

Por fim, Easter e Archibald (1998) lembram que a análise de custo-benefício não deve ser considerada exclusivamente para a tomada de decisão ou qualquer prática que tenha efeitos em larga escala, mas sim representar uma ferramenta acessória para a atividade de regulação. Boa parte deste cuidado visa evitar a principal fraqueza deste método, que é a falta de rigor: "*While the need for scientific studies is well recognized, too often benefit-cost studies are underfunded, resulting in poor studies that are easily criticized*" (p. 18). Em suma, mesmo que a literatura mostre pouco interesse em aprofundar o estudo da relação existente entre os instrumentos de regulação e os interesses mais gerais da comunidade (ou melhor, suas demandas sociais), não pode escapar aos formuladores e executores deste estudo de avaliação a preocupação em fundamentar razoavelmente suas análises no interesse público, que são particulares em diversas dimensões, como o torna evidente a questão ambiental.

## 5.- Considerações Finais

Diante das duas inquestionáveis e fortes tendências sociais recentes identificadas neste trabalho (quais sejam, por um lado, a crescente relevância dos biocombustíveis como opção energética e vetor de uma nova trajetória tecnológica e de desenvolvimento econômico sustentável, e, por outro lado, a também crescente cobrança pública por ações eficientes advindas dos governos, por meio de suas autarquias e secretarias, nos mercados regulados), procuramos especular em torno da construção de uma estrutura metodológica de avaliação de políticas públicas capaz de lidar com a miríade de questões especificas ao problema da padronização. Tal preocupação busca salientar a natureza complexa do objeto que envolve demandas sociais heterogêneas e os limites inerentes ao ferramental geralmente utilizado para entender o fenômeno econômico que se relaciona com a infra-estrutura da qualidade.

Dessa maneira, o presente estudo evidencia que muita pesquisa ainda precisa ser realizada tanto no aprimoramento do método mais aceito e difundido (análise de custo-benefício) quanto na construção das bases de informação e de dados relacionados às ações públicas em casos específicos de grande relevância nacional (como o da tecnologia de produção de biocombustíveis). Boa parte dos critérios para a avaliação já foram estabelecidos. Porém, a escassa experiência operacional dos programas (para não dizer, inexistente) na prática da certificação da cadeia do etanol (que é mais antigo que o biodiesel) limita enormemente a capacidade de se mensurar impactos quaisquer da padronização *post festum*, tanto sobre produtores, quanto sobre consumidores, mercados relevantes (no sentido econômico), ambiente macroeconômico e institucional em geral, ou mesmo de fomento à inovação.

Em suma, revela-se que trabalhar no campo das projeções pode ser arriscado, ou mesmo precipitado, se a atividade não for suficientemente refletida e planejada e empiricamente fundamentada em estudos aplicados, pois a análise de custo-benefício é muito sensível às condições definidas como iniciais e outros detalhes, precisando ser mais discutida e desenvolvida no sentido de atender as especificidades da atividade avaliada. Atividade regulatória esta que a cada momento lida com a estrutura produtiva de setores-chaves sob vários aspectos, no interior de uma realidade social sistêmica, marcada pela complexidade de requisitos e efeitos (abertura e não-neutralidade), geralmente, não negligenciáveis e de natureza incontrolável.

## 6.- Referências Bibliográficas


- CGEE – Centro de Gestão de Estudos Estratégicos. 2005. *Estudo sobre as possibilidades e impactos da produção de grandes quantidades de etanol visando à substituição parcial de gasolina no mundo – Fase 1*. Campinas: Nipe/Unicamp e Centro de Gestão de Estudos Estratégicos.
- CGEE – Centro de Gestão de Estudos Estratégicos. 2007. *Estudo sobre as possibilidades e impactos da produção de grandes quantidades de etanol visando à substituição parcial de gasolina no mundo – Fase 2*. Campinas: Nipe/Unicamp e Centro de Gestão de Estudos Estratégicos.
- Chichilnisky, Graciela (1997). "The Cost and Benefit of Benefit-Cost Analysis". *Environment and Development Economics* 2. Cambridge University Press.
- David, Paul A. (1985), "Clio and the economics of QWERTY", *American Economic Review*, 75(3):332-337.
- Davies, Rob (1997). "Environmental Regulation, Benefit-Cost Analysis and the Policy Environment in Less Developed Countries". *Environment and Development Economics* 2. Cambridge University Press.
- Easter, K. W.; Archibald, S. O. (1998). "Benefit-Cost Analysis in US Environmental Regulatory Decisions". *VI Joint Conference on Food, Agriculture and the Environment*. Minneapolis, Minnesota – September 2.

- Farrow, Scott; Toman, Michael (1998). “Using Environmental Benefit-Cost Analysis to Improve Government Performance”. *Resources for the Future*. Discussion Paper 99-11. Washington, DC.
- Haimowitz, Joseph; Warren, Joanne (2007). “Economic Value of Standarlization. Submitted to the Standards Council of Canada”. *The Conference Board of Canada*. July.
- INMETRO – Instituto Nacional de Metrologia, Normalização e Qualidade Industrial. 2007. *Avaliação da Conformidade*. 5ed. Rio de Janeiro: 50 p.
- MME – Ministério de Minas e Energia (2008). *Balanço Energético Nacional: (ano base de 2007)*.
  Disponível em

  http://www.mme.gov.br/site/menu/select_main_menu_item.do?channelId=1432&pageId=17036.
- Swann, G. M. P. 2000. *The Economics of Standardization*. Final Report for Standard and Technical Regulations Directorate, Department of Trade e Industry. Manchester. December.

**C. Recalde†, M. Echeverría, J. Muños, A. Haro, I. Escudero, Patricio Londo, Luis**

## 59. Use energy and some topic about alternate energy sources Riobamba Municipality Ecuador.

Proyecto: “Balance Energético, Diagnostico del Potencial de Energías alternativas y ahorro energético del cantón Riobamba” (ESPOCH – CONESUP)

Escuela Superior Politécnica de Chimborazo, Facultad de Ciencias.

Universidad Nacional de Chimborazo, Facultad de Ingeniería.

†Av. La Prensa 45-95 y Manuel Elicio Flor; Movil 098598161; crecalde672000@yahoo.com

Chaos, energy, Ecuador, alternate energy sources, renewable, biomass, biodiesel, fractal, statistical

Abstract: The Alternative Energies project was developed by the Faculty of Science in ESPOCH and financed by the Higher Education National Council (CONESUP) as a part of the research project contest; it took place in Riobamba canton, Chimborazo province, Ecuador. The worldwide environmental problems, as well as the global warming is because of the free consumption of fossil fuels, and for mitigating this problem, we have encouraged the use of alternative energies, and bio fuels are an option, however, it has lost some impulse due to the fact that the areas to be cultivated will compete with agricultural lands. under this context and with the goal of facilitating the taking of decisions, ECOLOGICAL MODELS FOR BIODIVERSITY STUDIES are applied, by filtering the protected areas, national parks and cities, we use as input data the census of the eleanisse guinesis producers (ANCUPA); the software looks for the common characteristics of the places that participated in the census and infers the possible new areas which fulfill with these characteristics. The biodiesel was produced in laboratory the red oil of African Palm in Riobamba city (altitude 2700 m, 15 °C), and we are to

do proof in motor bank. The hydraulic energy finds to predict the potential. The development of other prediction methods like the theory of the chaos, incentivate to carry out comparisons with models of excellent trajectory such as ARIMA de BOX – Jenkins. The hydraulic energy potential of Rio Blanco Quimiag -Riobamba-Ecuador has been modeled in order to predict the flows in L/s starting from the registrations stored in the station 2 of the Empresa Electrica Riobamba SA . The pattern ARIMA (SPSS 11) was applied and the theory of the chaos (TISEAN 2.1). The precision of the prediction was determined by the analysis of residuals or errors, correlation and test of Tukey.

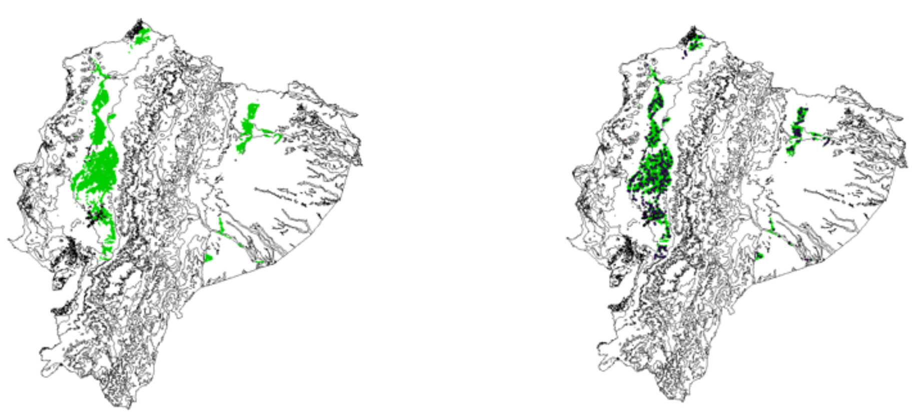
The biomass, the solid residues in the Riobamba city of Equator there are generated from 88 to 90 tons of solid residues for day, was observed that it exists 70 % of organic matter and 30 % of inorganic, since is important analyze the decomposition of the organic matter of Riobamba's solid residues using efficient microorganisms with different doses of magnetic fields. Also, the primary information of the use of energy in the sector economic activities of the Riobamba Municipality.

Determination of the potential zones for the cultivation of eleanisse guinesis

We have encouraged the use of alternative energies, and bio fuels are an option, however, it has lost some impulse due to the fact that the areas to be cultivated will compete with agricultural lands.

Figure 1

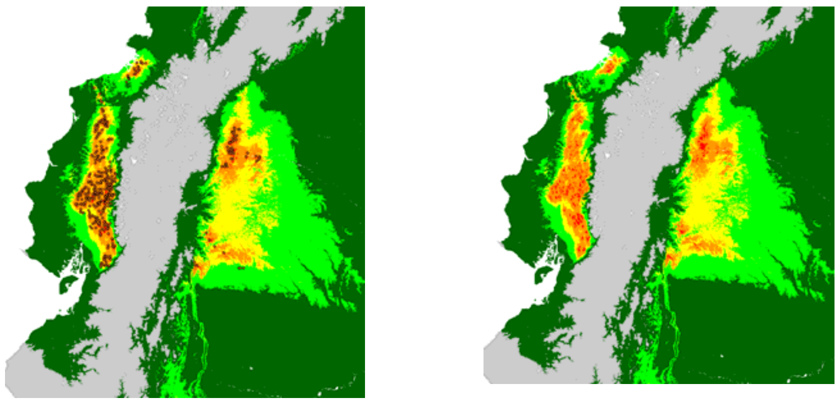
Area and points inputs



Ecuador exports red oil African palm (eleanisse guinesis), this is one of the oil plants used in the production of bio diesel; under this context and with the goal of facilitating the taking of decisions, ECOLOGICAL MODELS FOR BIODIVERSITY STUDIES are applied (Jesús Muñoz, Angel M. Felicísimo, Tania Delgado, Rubén G. Mateo, Alicia Gómez Muñoz), by filtering the protected areas, national parks and cities.

Figure 2

Inputs and outputs



We use as input data the census of the eleanisse guinesis producers (ANCUPA); the software looks for the common characteristics of the places that participated in the census and infers the possible new areas which fulfill with these characteristics. After identifying the places having the conditions for the cultivation of eleanisse guinesis in Ecuador, its competence with other cultivations will be analyzed. It will allow us to evaluate the major possible surface for the cultivation in Ecuador, this will be economic, rapid in which several stages could be represented and they will facilitate a better planning of the resource.

Figure 3

Ecuador mask, output points with ecologyc erea and cities filtered.

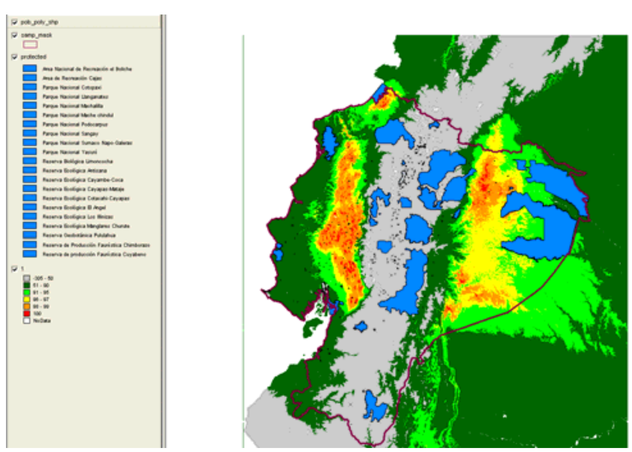
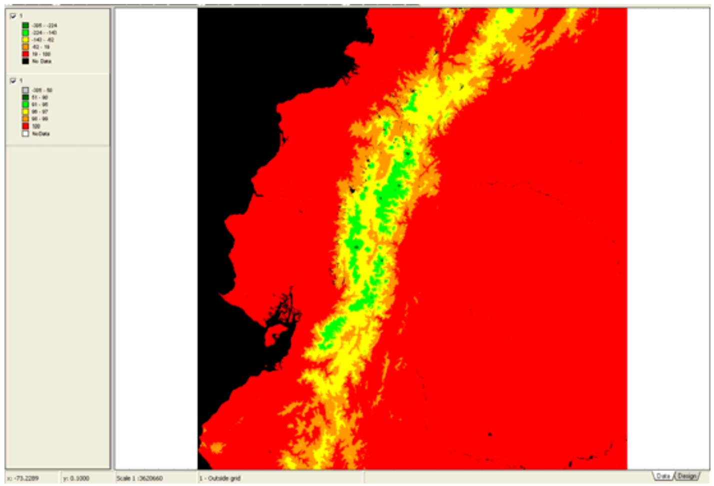


Figure 4

Future 50 years

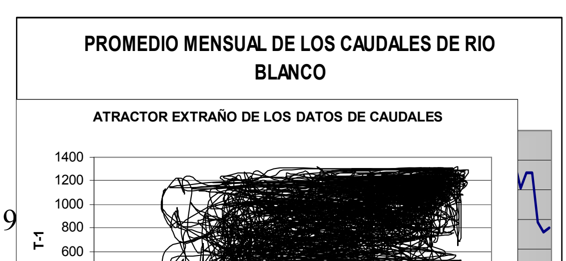


Prediction of the hydraulic energetic potential of the Blanco River using the chaos and ARIMA theories.

Figure 5

To predict with certainty and precision the future behavior of a system, physical, biological or social it is one of the maximum(most) aspirations of the classic science. The development of other prediction methods like the theory of the chaos, incentivate to carry out comparisons with models of excellent trajectory such as ARIMA de BOX – Jenkins.

The hydraulic energy potential of Rio Blanco Quimiag -Riobamba-Ecuador has been modeled in order to predict the



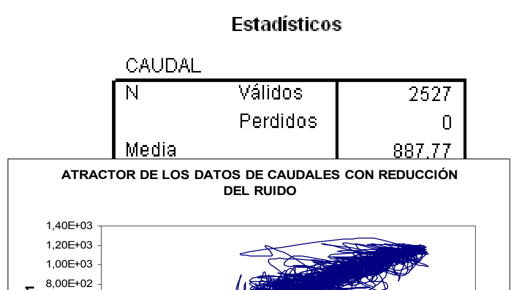






Figure 7

Attractor

Figure 8

Attractor with noise reduction

flows in L/s starting from the registrations stored in the station 2 of the Empresa Electrica Riobamba SA . The pattern ARIMA (SPSS 11) was applied and the theory of the chaos (TISEAN 2.1). The precision of the prediction was determined by the analysis of residuals or errors, correlation and test of Tukey.

The period of prediction with significant correlation is among 14 days with the theory of the chaos and 17 days with the pattern ARIMA.

Table 2

Correlation N=14

| | | REAL |
|---|---|---|
| REAL | Correlación de Pearson | 1 |
| | Sig. (bilateral) | . |
| | N | 14 |
| ARIMA | Correlación de Pearson | ,685** |
| | Sig. (bilateral) | ,007 |
| | N | 14 |
| T.CAOS | Correlación de Pearson | ,631* |
| | Sig. (bilateral) | ,016 |
| | N | 14 |

**. La correlación es significativa al nivel 0,01 (bilateral).

*. La correlación es significante al nivel 0,05 (bilateral).

Table 3

Correlation N=11

| | | REAL |
|---|---|---|
| REAL | Correlación de Pearson | 1 |
| | Sig. (bilateral) | , |
| | N | 11 |
| ARIMA | Correlación de Pearson | ,761** |
| | Sig. (bilateral) | ,007 |
| | N | 11 |
| T.CAOS | Correlación de Pearson | ,746** |
| | Sig. (bilateral) | ,008 |
| | N | 11 |

**. La correlación es significativa al nivel 0,01 (bilateral).

*. La correlación es significante al nivel 0,05 (bilateral).

The test of Turkey shows that significant differences don't exist among the predictions with both theories and the real data, the measures of the predictions of

Table 4

Turkey N=17 (caudal)

HSD de Tukey

| MODELO | N | Subconjunto para alfa = ,05 1 |
|---|---|---|
| ARIMA | 17 | 586,2441 |
| T. CAOS | 17 | 638,1964 |
| REAL | 17 | 648,3529 |
| Sig. | | ,082 |

Se muestran las medias para los grupos en los subconjuntos homogéneos.

Table 5

Turkey N=14 (caudal)

HSD de Tukey

| MODELO | N | Subconjunto para alfa = ,05 | |
|---|---|---|---|
| | | 1 | 2 |
| ARIMA | 14 | 580,288 | |
| T. CAOS | 14 | 622,988 | 622,988 |
| REAL | 14 | | 665,714 |
| Sig. | | ,385 | ,384 |

Se muestran las medias para los grupos en los subconjuntos homogéneos.

the hydraulic energy potential of river found with the inferred flows with the two methods are statistically similar to the potential obtained with the real data during 11 days to 95% of certainly, however, starting from the 12th day it has been determined that the theory of the chaos is more precise than ARIMA.

Figure 9

Real data, T. Caos and Arina prediccion

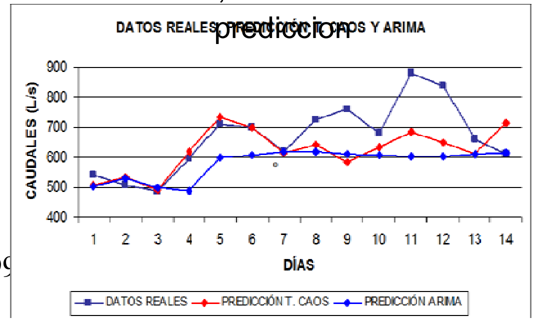



Table 6

Turkey N=14 (potential)

HSD de Tukey

| MODELO | N | Subconjunto para alfa = ,05 1 |
|---|---|---|
| ARIMA | 17 | 1306,5488 |
| T. CAOS | 17 | 1422,3335 |
| REAL | 17 | 1445,0512 |
| Sig. | | ,082 |

Se muestran las medias para los grupos en los subconjuntos homogéneos.

For the handling of information of the flows and studies of the Hydroelectric potential it should be applied cheap models of prediction and easy for handling, it is important tool in taking decisions.

Table 7

Error Arima and T. Caos

| | | |
|---|---|---|
| 1.- Error porcentual medio | ARIMA | 7,88% |
| | T. CAOS | 3,52% |
| 2.- Error medio cuadrático | ARIMA | 0,016 |
| | T. CAOS | 0,010 |

Table 8

Hydroelectric Potential

| Nº | POTENCIAL HIDROELÉCTRICO (kW) | | |
|---|---|---|---|
| | REALES | T. CAOS | ARIMA |
| 1 | 1114,34 | 1114,34 | 1114,34 |
| 2 | 1208,87 | 1130,59 | 1123,81 |
| 3 | 1128,82 | 1188,23 | 1181,91 |
| 4 | 1085,64 | 1100,32 | 1112,68 |
| 5 | 1324,58 | 1376,66 | 1089,58 |
| 6 | 1581,71 | 1634,48 | 1338,24 |
| 7 | 1560,54 | 1563,79 | 1354,14 |
| 8 | 1381,32 | 1374,46 | 1376,60 |
| 9 | 1615,88 | 1429,27 | 1376,20 |
| 10 | 1696,95 | 1301,80 | 1362,02 |
| 11 | 1518,10 | 1410,93 | 1354,85 |

| | | | |
|---|---|---|---|
| 12 | 1965,32 | 1522,21 | 1348,15 |
| 13 | 1869,40 | 1452,35 | 1349,55 |
| 14 | 1471,48 | 1361,29 | 1364,32 |
| 15 | 1364,23 | 1591,76 | 1373,81 |
| 16 | 1227,54 | 1595,70 | 1376,44 |
| 17 | 1294,40 | 1624,28 | 1365,87 |
| MEDIA | 1445,05 | 1422,33 | 1306,55 |

Decomposition of the organic matter of Riobamba's solid residues using efficient microorganisms with different doses of magnetic fields.

In the Riobamba city of Equator there are generated from 88 to 90 tons of solid residues for day, of which by means of a random simple sampling was observed that it exists 70 % of organic matter and 30 % of inorganic. The same ones are arranged in a botadero located to 7 Km from the city, nevertheless, constituting a risk for the health of the persons and the environment.

Treatments and processes to which there can be submitted the solid residues of organic origin; the anaerobic digestion is as well as also the aerobic one, allowing in both processes the obtaining of a residual material called bio fertilizer, organic rich material in nutrients, as well as products of energetic use.

Before such a situation, it becomes necessary to evaluate new methods or alternatives of treatment to the garbage of the solid Organic residues with the zeal to obtain a major acceleration of the process of decomposition of the organic matter, by means of new applicable and cheap technologies as they are the application of magnetic fields, useful to promote to the efficient microorganisms, with the purpose of which these increase their activity.

When 15 arrange Kg for booth of experimentation, with different doses of efficient microorganisms (75 mL, 150 mL, 300 mL, 600 mL), and its posterior application of different intensities of magnetic fields, one concludes that the best dose I turn out to be of 600 mL with an intensity of magnetic field of 1.11 Gauss, accelerating the process of decomposition in a third part, corresponding to 24 days of decomposition of 60 days the other case.

Primary information of the use of energy in the economic sector activities of the Riobamba city 2007.

Objective:

The use of the conventional and alternative energy of the economic activities (Commercial, Services and Production) of the Riobamba city.

The Canavos formula:

$$n = \frac{NPQZ_{\alpha}^{2}}{(N-1)e^{2} + PQZ_{\alpha}^{2}}$$

n : Sample size

N : Population size

P : Positive Variability

Q : Negative Variability

e : Error

$Z_{\alpha}$ : Confiability

The commercial activities and services obtained a sample n = 118, with a population of 9.285 commercial activities and 4.486 of services (with 13.771 activities). For the productive activities n = 110, with a population size of 1.517.

With p = 0.5, q=0.5 and error of 0.09 for both samplings.

To determine the size of sample for strata of every zone (parroquia) the formula was in use:

$$n_h = \frac{N_h}{N} \cdot n$$

$n_h$ : Sample size for zone (parroquia)

$N_h$ : Population size for (parroquia)

N : Total population size (Riobamba city) n : Sample size

Table 9

ACTIVIDADES COMERCIALES Y PRESTACIÓN DE SERCICIOS

| ZONA | PARROQUIAS | TOTAL | | COMERCIAL | SERVICIOS | DISTRIBUCION DE ENCUESTAS | | |
|---|---|---|---|---|---|---|---|---|
| | | COMERCIAL | SERVICIOS | | | COMERCIAL | SERVICIOS | TOTAL |
| URBANA | Lizarzaburu | 3721 | 2008 | 40% | 45% | 32 | 17 | 49 |
| | Velasco | 2687 | 1185 | 29% | 26% | 23 | 10 | 33 |
| | Maldonado | 1879 | 699 | 20% | 16% | 16 | 6 | 22 |
| | Veloz | 853 | 477 | 9% | 11% | 7 | 4 | 11 |
| | Yaruquies | 54 | 9 | 1% | 0% | 1 | 0 | 1 |
| | RE-00600 | 71 | 100 | 1% | 2% | 1 | 1 | 1 |
| RURAL | Cacha | 0 | 2 | 0% | 0% | 0 | 0 | 0 |
| | Calpi | 1 | 0 | 0% | 0% | 0 | 0 | 0 |
| | Cubijíes | 3 | 0 | 0% | 0% | 0 | 0 | 0 |
| | Flores | 0 | 0 | 0% | 0% | 0 | 0 | 0 |
| | Licto | 6 | 1 | 0% | 0% | 0 | 0 | 0 |
| | Pungalá | 0 | 0 | 0% | 0% | 0 | 0 | 0 |
| | Punín | 1 | 0 | 0% | 0% | 0 | 0 | 0 |
| | Quimiag | 2 | 0 | 0% | 0% | 0 | 0 | 0 |
| | San Juan | 4 | 5 | 0% | 0% | 0 | 0 | 0 |
| | San Luis | 3 | 0 | 0% | 0% | 0 | 0 | 0 |
| TOTAL | | 9285 | 4486 | 100% | 100% | 80 | 38 | 118 |

FUENTE: Ilustre Municipalidad de Riobamba, INEC, Proyecto energías alternativas

Table 10

ACTIVIDADES PRODUCTIVAS

| ZONA | PARROQUIAS | POBLACIÓN | REPRESENTACION PORCENTUAL | Nº ENCUESTAS |
|---|---|---|---|---|
| | Lizarzaburu | 477 | 31% | 35 |
| | Velasco | 471 | 31% | 34 |
| | Maldonado | 250 | 16% | 18 |
| | Veloz | 147 | 10% | 11 |
| | Yaruquies | 13 | 1% | 1 |
| | RE-00600 | 35 | 2% | 3 |
| | PIR | 76 | 5% | 6 |
| URBANA | CAPICH | 29 | 2% | 2 |
| | Cacha | 0 | 0% | 0 |
| | Calpi | 3 | 0% | 0 |
| | Cubijíes | 3 | 0% | 0 |
| | Flores | 0 | 0% | 0 |
| | Licto | 0 | 0% | 0 |
| | Pungalá | 2 | 0% | 0 |
| | Punín | 1 | 0% | 0 |
| | Quimiag | 3 | 0% | 0 |
| | San Juan | 5 | 0% | 0 |
| RURAL | San Luis | 2 | 0% | 0 |
| TOTAL | | 1517 | 100% | 110 |

FUENTE: Ilustre Municipalidad de Riobamba, INEC, Proyecto Energías Alternativas.

RESULTS :

What activity do you do?

Figure 10

ACTIVITIES

How many personnel work it?

Table 11

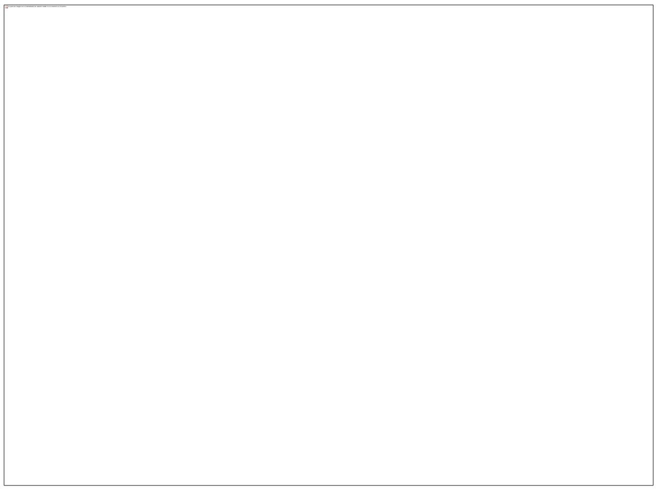
STATISTICS

| ESTADISTICAS | | | |
|---|---|---|---|
| TIPO DE ACTIVIDAD | MEDIA | MAXIMO | MINIMO |
| COMERCIAL | 3 | 30 | 1 |
| PRODUCCION | 4 | 38 | 1 |
| SERVICIOS | 5 | 44 | 1 |

Do you have electrical generator?

Figure 11

INSTALLED GENERATOR



What kind of fuel use in the generator?

Figure 12

FUEL USED BY GENERATOR

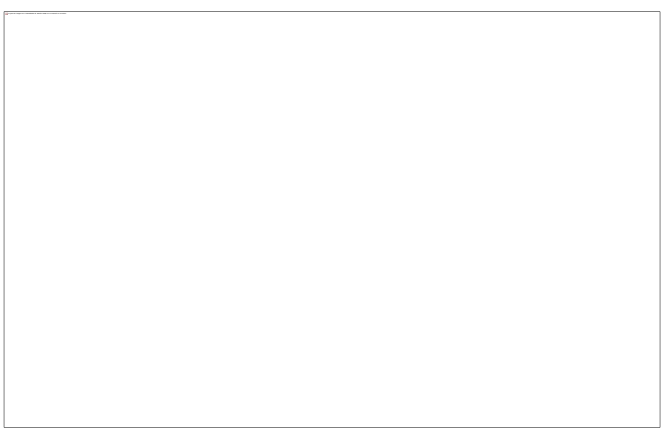
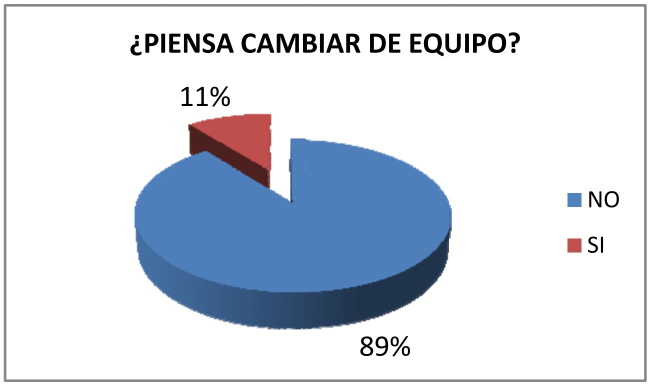


Figure 13




Do you think to change equipment?

Do you think to buy an electrical generator?

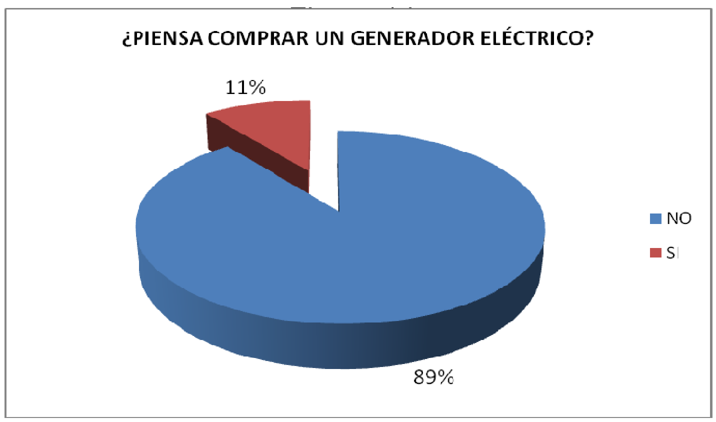
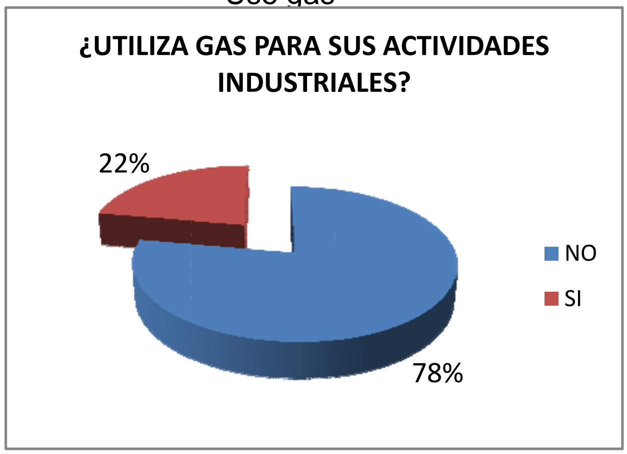


Figure 15

Use gas




Do you use gas for your industrial activities?

How many cylinders (15 kg) do you use monthly?

Table 12

| MEDIA | MAXIMO | MINIMO |
|---|---|---|
| 12 | 150 | 1 |

How much cost include by transport in each cylinder?

Table 13

| MEDIA | MAXIMO | MINIMO |
|---|---|---|
| $ 1,88 | $ 2,10 | $ 1,50 |

Do you think that the cost of gas is?

Figure 16

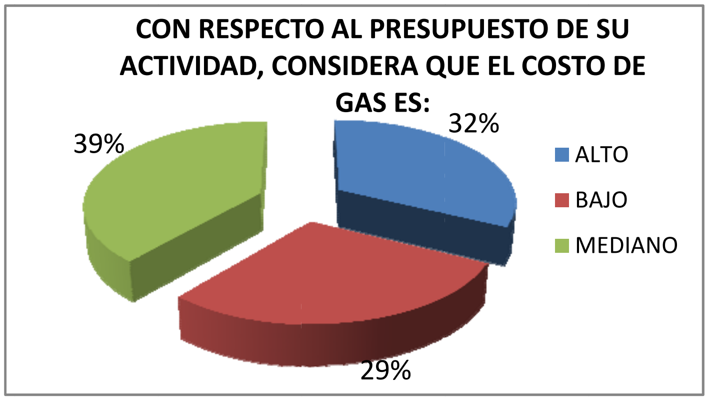



Figure 17

The use of gas

What does gas use for?

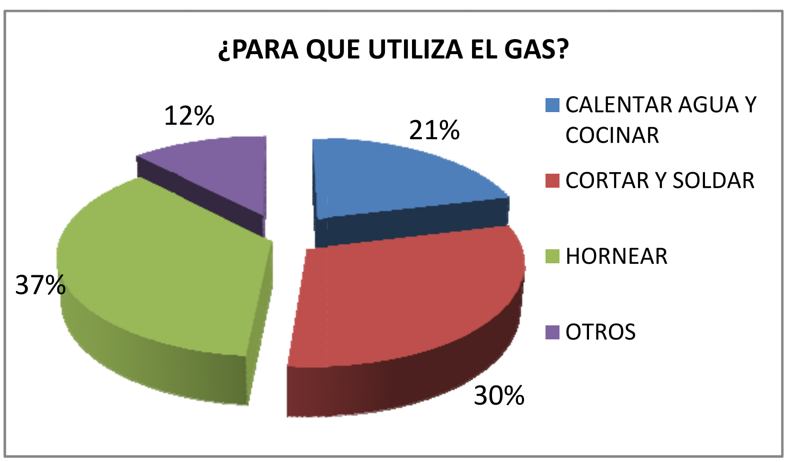
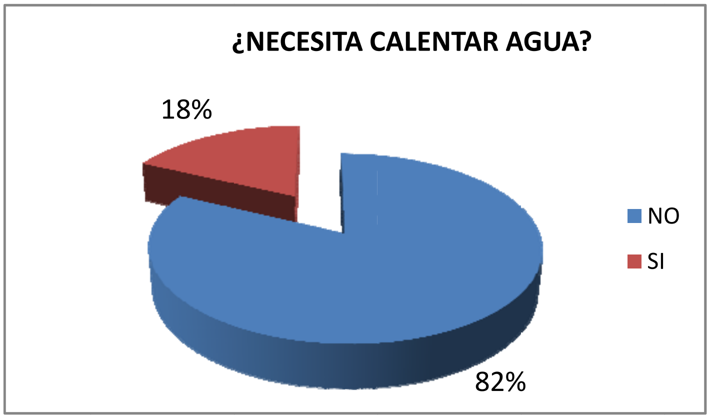





Figure 18

Do you need to warm water?




That temperature

Table 13

| MEDIA | MAXIMO | MINIMO |
|---|---|---|
| 47º C | 160º C | 10º C |

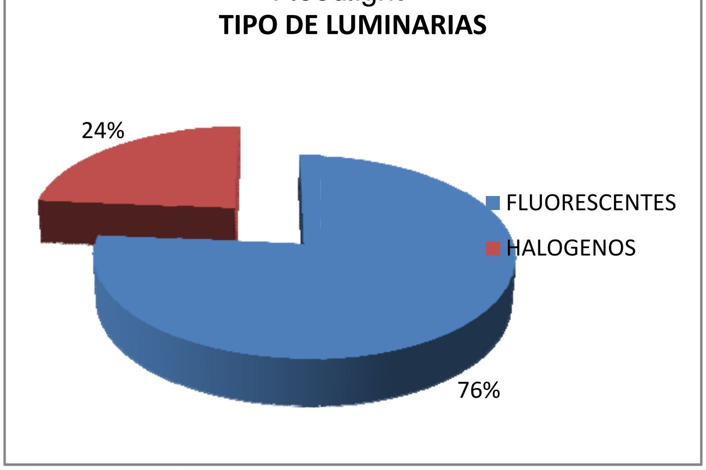
How many Kw do you use monthly?

Table 13

| TIPO DE ACTIVIDAD (KW) | MEDIA | MAXIMO | MINIMO |
|---|---|---|---|
| COMERCIAL | 199 | 655 | 40 |
| PRODUCCION | 542 | 7200 | 41 |
| SERVICIOS | 286 | 1920 | 73 |

Figure 19

Floodlight




6.- References

Roques, F.A., W. J. Nuttall, D.M. Newbery, R. de Neufville and S. Connors (2006b). “Nuclear Power: a Hedge against Uncertain Gas and Carbon Prices?” *The* Energy Journal 27(4): 1-23.

A. Felicísimo, A. Gómez, J. Muñoz, T. Delgado, R. Mateo, IMPACTO DEL CAMBIO CLIMÁTICO EN LA BIODIVERSIDAD: EL CASO DE ECUADOR. Universidad de Extremadura, Real Jardín Botánico.

http://www.ipcc.ch/

**http://www.ipcc.ch/pub/un/ipccwg1s.pdf**

http://www.ancupa.org.ec

Richard A. Brealey, Stewart C. Myers. 2006. *Principles of Corporate Finance*, McGraw-Hill/Irwin Series in Finance, Insurance, and Real Estate, 8th edition.

Cabrera J. Carlos y Jaramillo J. Jorge, Estadística Inferencial, Loja: Universidad Técnica de Loja. s.f. (Documento).

Daza P. Jorge F. Análisis Estadístico con SPSS 14. ed. Lima: Megabyte, 2006.

Freedman David H., Chaos Theory Inc. ed. Boston: s.e. Oct 20, 1998.

Gujarati Damodar N. Econometría. 4ta, ed. McGraw-Hill, s.f. (Fotocopias)

Hayles, La Evolución del Caos, El Orden Dentro del Desorden en las Ciencias Contemporáneas. ed. Barcelona: Gedisa N. K. 1993.

Honke John E., Reitsch Arthur G., Pronósticos en los Negocios. 5ª. ed. Presentice Hall, s.f.

Kathleen T. Alligood, Chaos an Introduction to Dynamical Systems Springer-Verlag. ed. New York, 1996.

Mª De Juana José (coordinador), Energías Renovables para el Desarrollo, Cooperación Internacional. s.e. Madrid, s.f.

Madrid, Cedeti, Ministerio de Industria y Energía, Pequeñas Centrales Hidroeléctricas, Centro para el Desarrollo Tecnológico Industrial. ed. Progensa, 2000, (Documento)

CONGACHA Jorge, Estadística aplicada a la educación, ESPOCH, Riobamba Ecuador 1999.

http://www.fao.org/DOCREP/005/AC693S/AC693s08.htm#TopOfPage

http://www.fao.org/docrep/X5684s/x5684s04.htm

http://www.uaq.mx/matematicas/estadisticas/xu5.html

# 60. Who switches to gas? A study of a fuel conversion program in Colombia[†]

**C. Adrián Saldarriaga-Isaza[a†], Carlos Vergara T.**

[a]Departamento de Economía, Universidad Nacional de Colombia – Sede Medellín,

Estudiante Doctorado en Economía, Pontificia Universidad Católica de Chile
[†]Corresponding autor: Avda. Vicuña Mackenna 4860, Facultad de Ciencias Económicas y Administrativas, Piso 3, Santiago – Chile;

Tel. (56 2) 3547103, Fax (56 2) 5531557; e-mail: casaldarriagai@unal.edu.co, casaldar@uc.cl

Key words: natural gas vehicles, switch, determinants.

Abstract: Air pollution from mobile sources is an important environmental problem in larger cities in Colombia, as well as in other Latin-American countries. In 2001, a program was implemented to encourage the use of natural gas in vehicles in the Aburrá Valley in Colombia, with incentives to convert small cars from gasoline and diesel to hybrid engines with natural gas, most notably a cash subsidy. Using a survey administered to both commercial and private car owners we study the determinants of conversion under this fuel conversion program. We thus obtain

[†] This paper was carried out with the aid from a grant from the Latin American and Caribbean Environmental Economics Program (LACEEP). We are very thankful for the important comments received from the LACEEP's scientific committee, and specially to Fredrik Carlsson for his very important suggestions.

information about the reasons for adoption of new technologies in vehicles. This allows us to discuss the possible outcomes of this type of policy. Results show that a large part of owners who switched would have done it anyway without the subsidy. Based on the findings, commercial vehicles are most likely to be converted to natural gas vehicles.

## 1.- Introduction

Natural gas vehicles (NGV) are a cleaner alternative to conventional diesel and gasoline vehicles, because of a number of advantages: low amount of emissions of particulate matter and airborne toxins, negligible $SO_x$ emissions, and a quieter engine operation (Kojima, 2001). Therefore, bearing in mind the high social costs of air pollution from motor vehicles (Small & Kazimi 1995), alternative fuels can be competitive with conventional fuels in urban traffic, if the environmental impact of emissions are taken into account (Johansson 1998). For example, in a study of Southern California (USA), Kazimi (1997) investigated the benefits of using and switching to alternative-fuel vehicles. She found that price reductions of alternative fuels like compressed natural gas and methanol are effective in reducing emissions, and that conversion reduces the negative health effects from mobile sources.

Technology substitution or engine switching in vehicles has been analyzed to some extent in the literature. Anderson and Cavendish (1992) examined three possibilities for reducing pollution from vehicles in urban areas in United States: first, the use of clean fuels and engine technologies that represent a substitution effect; second, raising vehicle fuel taxes as a demand effect; last and congestion pricing. They found that it is the substitution of clean fuels and emission control technologies that have the decisive effect on pollution abatement. Additionally, in the Netherlands Rouwendal and de Vries (1999) theoretically and empirically modeled the choice of alternative fuels (diesel and LPG), taking into account the number of kilometers driven and the tax system for fuels in that country. They found that the prejudice against diesel and liquefied petroleum gas that most drivers had could be overcome by a sufficiently high monetary benefit. Similarly, Dagsvik et al. (2002) analyzed the potential demand of alternative fuel vehicles in Norway. Applying probabilistic choice models to a stated preference survey, they found that in addition to purchase price and km driven, suitable infrastructure for maintenance and refueling are important attributes. The studies named above thus show that alternative fuel vehicles are competitive alternatives compared to conventional gasoline vehicles. Parker et al. (1997) assessed the interest and the future adoption of alternative fuels by sending a mail questionnaire to trucking firms. They found that the main conversion criteria for switching to compressed natural gas were conversion costs, availability of refueling facilities, fuel cost per mile, down time, and maintenance cost per mile. Lastly, Haller et al. (2007) found that fueling infrastructure was important for the cost-effectiveness of a vehicle conversion program to reduce greenhouse gas.

Nevertheless, in very few studies ex-post analysis of fuel or technology choice in motor vehicles have been done, particularly in developing countries. It is known that emissions from mobile sources are an important environmental problem in the main Latin-American cities. For example, in the Aburra Valley[210] (*Valle de Aburrá*) in Colombia there are persistent high levels of air pollution. In some parts of the area the legal maximum levels of emissions are exceeded, with a high impact on human well-being (Bedoya et al. 2004, 2005a, 2005b; AMVA 2006). It is estimated that around 65% of the total emitted pollutants are from mobile sources. For instance, in 2005, 66% of total emitted pollutants came from vehicles, and of this 70% was CO emissions (AMVA 2006). Because of this it is relevant to study the determinants of the choice of fuel and engine technology in motor vehicles, when an alternative like NGV exists. It may be argued that the fuel cost differential should be the most relevant factor to explain this decision. This might be true, bearing in mind the lower cost of natural gas compared to the cost of gasoline. In general, there is fuel cost savings between 45% and 55%, savings that depend on the good mechanical conditions of the car. However, we think this is not the only relevant factor that could explain the adoption of NGV technology, and there could be others, which are tested considering a fuel conversion program in Colombia.

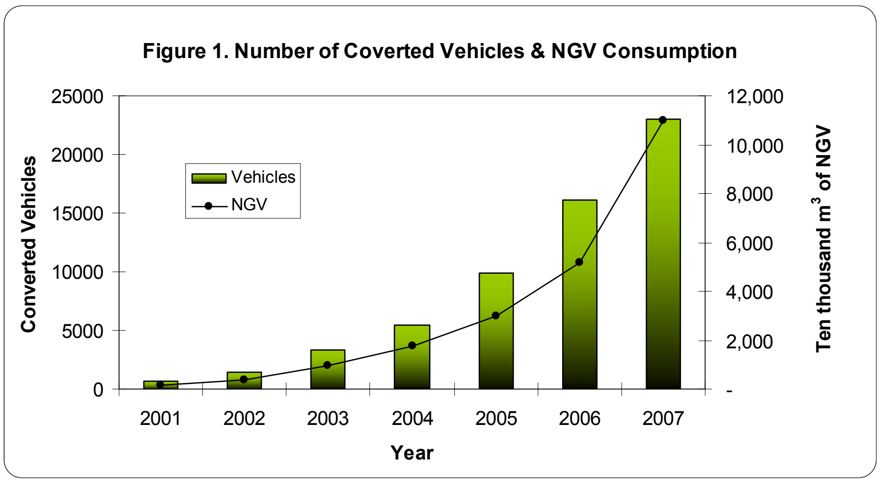
Empresas Públicas de Medellín (EPM) is a public enterprise that provides public domestic services: energy, water, water disposal and telecommunications. In 2001, the EPM, together with ECOPETROL[211], started a program to encourage the use of natural gas in vehicles (NGV) in the Aburra Valley, with incentives to convert light-duty cars from gasoline and diesel to hybrid engines with both NGV and gasoline or diesel. During the seven years the program was running, about 7% of small vehicles in the study area were converted. In this period the total amount of the number of converted vehicles increased exponentially (see Figure 1), from

---

[210] This area includes Medellín (the main city of the metropolitan area and one of the most important in Colombia) and nine municipalities: Barbosa, Girardota, Copacabana, Bello, Itagüí, Sabaneta, Envigado, La Estrella and Caldas.
[211] This is the national enterprise in charge of the management of the production and marketing of petroleum and natural gas in Colombia.

652 vehicles in 2001 to 16,089 in 2006. This is to be correlated with the increment in the subsidy (called "conversion bonus"), from $400,000 (US$200) in 2004, through $600,000 (US$300) in 2005 and 2006, to $1,000,000 (US$500) in 2007.[212] Despite this incentive, 20% of the vehicles have converted without the subsidy. The increase in the number of converted cars means more consumption of natural gas (see Figure 1), which also means reduced emissions of some pollutants like particulate matter (PM), CO, $SO_2$ and $NO_X$.

Figure 1




Source: EPM (2007)

The objective of this paper is to explain the decision to convert small vehicles to bi-fuel technologies, under the EPM's fuel conversion program in the Aburrá Valley, from an ex-post perspective. Hence, this work aims to give some insights into the adoption of this type of technology in vehicles, and also to offer some information for a discussion of the implication of this kind of policy, i.e, encouraging the use of alternative fuels through the offer of economic incentives. The analysis is based on the collection of primary information in the field, from face-to-face interviews with both commercial and private owners of either converted or non-converted vehicles. In the next section we explain the methodology and data collection process, and in Sections 3 and 4 the results and conclusions are presented, respectively.

[212] There is also an 100% financing option incentive offered by EPM to encourage the use of NGV, with an interest rate between 1.09% and 1.3% (much lower than the market interest rate), and with credit terms of up 30 months.

2.- Method And Data Collection

The decision to convert can be analyzed in the framework of a random utility model (Green 2000). An individual is willing to invest in a hybrid engine as long as the utility of having a hybrid car (natural gas and diesel or gasoline) is greater than the utility of having a conventional car. Assuming a random utility function, the decision to convert can be appraised in terms of the difference in the utility of not-switching, and converting either with or without the subsidy. The utility function for individual *i* depends on three vectors: vehicle characteristics (*x*), owner characteristics (*y*), and on the program characteristics (*z*):

$$v_{ij} = x_{ij}\alpha + y_{ij}\beta + z_{ij}\gamma + \mu_{ij} \qquad (1)$$

where $v_{ij}$ is the utility for individual *i* taking the decision *j* (no conversion, or conversion either with or without the subsidy), and $\mu_{ij}$ is the error term or stochastic part. It should be noted that besides the lower fuel cost and the subsidy offered, there are other factors that could explain the decision to convert; factors not easily identified in an *a-priori* analysis. For instance, car owners with a medium income level could be more prone to participate in the program given their need to save in fuel costs. However, high income owners might prefer not to participate in the program because of the possible transactions costs underlying the process of obtaining the benefits of the program. Additionally, whether a car is used for commercial or private purposes, and the number of kilometers driven could be factors that explain the conversion decision (Rouwendal and de Vries 1999).

The car owner decides to convert if the utility of the converted car ($v_{ic}$) is greater than the utility of not converting the car ($v_{ig}$). Then, the probability of switching to a hybrid engine is:

$$\text{Prob(Convert)} = P(v_{ic} \geq v_{ig}) = P(\mu_{ic} - \mu_{ig} \geq x_{ig}\alpha + y_{ig}\beta + z_{ig}\gamma - x_{ic}\alpha - y_{ic}\beta - z_{ic}\gamma) \qquad (2)$$

where the vectors of parameters $\alpha$, $\beta$ and $\gamma$ can be estimated by either a probit or logit model, depending on the assumption regarding the distribution of errors. It should be noted that, taking into account the structure of the program described above, this is a restricted version of a model in which we can split between those owners who got the subsidy and those who did not.

The explanatory variables included in each one of the vectors are:

(a) Car Characteristics (x): from the studies by Parker et al. (1997) and Fullerton and West (2000), we decided to include car attributes such as brand, engine size, age, conversion cost and the type of use of the car (commercial transport or not). The cost of conversion for each car was computed with the support of a mechanical engineer who worked for one the workshops. Considering the findings of Rouwendal and de Vries (1999) and Dagsvik et al. (2002), we also asked about the number of kilometers driven.

(b) Owner Characteristics (y): it includes some socioeconomic variables normally employed in surveys such as the number of people in the household, number of adults, number of cars per adult, and education level. Additionally, location of the vehicle owner (home and job sites) in relation to natural gas fueling stations is considered. It was expected that, for example, the farther the fuel station is from the home or the job site, the lower the probability of converting. At the time of the survey there were around 31 fueling stations in the whole valley, most of them located in the southern area.

(c) Program Characteristics (z): knowledge of the program, expectations on natural gas price respect to the current price of this fuel, and perception of each respondent on whether the number of refueling stations with natural gas is suitable or not, i.e., respondent's perception about the availability of gas stations in the area, what is done considering the results in other previous studies (Parker et al. 1997, Stoneman and Battisti 2000, Janssen et al. 2006, Haller et al. 2007).

Other questions concerned the decision to convert assuming no-existence of the subsidy (for those who received the subsidy), and the reason why owners with non-converted car have not adopted this technology. Questions about owners' participation in the program were also asked; for instance, a question on why they had converted or not were posed to every respondent. Those who had converted and those who had not converted were asked if they would have switched in the presence of a subsidy 50 % lower or higher, respectively, than existed at the time of the survey. We also asked for the reasons why some of the converters switched without the subsidy. In addition, both types of owners were asked about the minimum subsidy they would have required to take the decision to switch.

In the survey there were three sections of questions. Two sections concerned with socioeconomic and car characteristics were posed to both those who converted and those who did not. A third section consisted of questions as to whether the car was either converted or not.

The entire population for this survey consisted of small cars (light-duty cars), vans, and pick-ups. The total number of units in this population was around 220,000 (Área Metropolitana del Valle de Aburrá 2006). Of these, about 16,300 cars had been converted at the time of the survey, of which almost 20% were converted without the subsidy. All the data were collected in a field study, with a pilot study in April 2007 and the main face-to-face survey in June 2007. Prior to the pilot study and the main survey, a focus group session was developed with people who owned either converted or non-converted cars. The number of sample units was 673. If we were kept the proportions of each group within the whole population of light-duty cars, the sample size for converted cars would be very low. Instead, in order to have representativity and variability in the sample, the sample proportions for each group were: 60% for non-converters (nn=400), 30% for converters with the subsidy (ncw=206) and 10% for converters without the subsidy (nco=67), which is close to the outcome of a statistical sample design. Out of 673 interviewed owners 581 are considered because of the quality of answers.

The survey was conducted by eleven trained raters at stations with gasoline, diesel and natural gas, and only at stations where we were allowed to administer it (14 out of 31), as stated above, most of them located in the southern area This fact obviously biases the survey results, but we think not much given that NGV are supposed to be homogenously distributed throughout the study site, assumption that may be reinforced by the fact that just about a 30% of owners live in the southern area. The availability of more refueling stations in the south of the study site might trigger more conversions in this zone, but we do not have a benchmark that allows us to estimate this bias. The estimation of such a possible bias is outside the scope of this paper.

3.- Results

In order to analyze the determinants of conversion we estimate a probit model, in which the dependent variable is equal to one if the owner has converted the car. A number of owner, car and program characteristics are included as independent variables. In Table 1 there is a description of the variables, as well as some descriptive statistics. For the models estimated below exogeneity is assumed, i.e. we assume that none of the variables are correlated with the error term. Because we suspected that the number of kilometers driven could be an endogenous variable due to the way it was measured, a test for exogeneity was done. From this test the null hypothesis that *Km* is exogenous could not be rejected. We also suspected collinearity between some variables. For instance, commercial vehicles are expected to be driven over a longer range of distance. On the other hand, the conversion cost would depend to some extent on the year of the car. Nevertheless, there was not evidence of this problem after computing the specific correlation coefficients in STATA (StataCorp 2006).

Table 1

| Table 1. Description of variables | | | | | |
|---|---|---|---|---|---|
| Description | Variable | Mean | Standard deviation | Min | Max |
| Number of cars in the household | *Number of Cars* | 1.34 | 0.69 | 0 | 4 |
| Engine size (thousand cubic centimeters)[a] | *Engine Size* | 18.74 | 9.42 | 8 | 85 |
| Average of kilometers driven per week | *Km* | 0.75 | 0.68 | 0.01 | 4 |

| Table 1. Description of variables | | | | | |
|---|---|---|---|---|---|
| Description | Variable | Mea n | Standard deviation | Min | Max |
| (thousand)[a] | | | | | |
| *Dummy* for a commercial vehicle | *Commercial Vehicle* | 0.59 | 0.49 | 0 | 1 |
| Conversion cost (million COP$)[a] | *Cost* | 3.51 | 0.48 | 2.63 | 5.4 |
| Grade of NG price expectations: 1 lower, 2 the same, 3 higher. | *Price Expectation* | 1.4 | 0.6 | 1 | 3 |
| *Dummy* for suitable number of gas stations | *Station* | 0.6 | 0.5 | 0 | 1 |
| *Dummy* for knowledge of the program | *Knowledge* | 0.8 | 0.4 | 0 | 1 |
| Year of the car (hundred) | *Year* | 19.9 5 | 0.08 | 19.5 | 20.1 |
| Level of education | *Education* | 4.7 | 2.2 | 1 | 9 |
| Number of people who earn money in the household | *Heads* | 1.3 | 0.8 | 0 | 5 |
| People who do not earn money in the household | *No-heads* | 1.5 | 0.6 | 1 | 4 |
| Distance from sampled gas station to home (km)[a, b] | *Distance_home* | 5.8 | 4.7 | 0.17 | 24.59 |
| Distance from sampled gas station to job (km)[a, b] | *Distance_job* | 3.8 | 4.24 | 0 | 25.97 |
| Distance from home to closest gas station | *Distance_home_clo sest* | 2.53 | 1.87 | 0.17 | 12.12 |

| Table 1. Description of variables | | | | | |
|---|---|---|---|---|---|
| Description | Variable | Mean | Standard deviation | Min | Max |
| (km)[a, b] | | | | | |
| Distance from job to closest gas station[7] (km)[a, b] | *Distance_job_closest* | 1.74 | 1.93 | 0 | 12.12 |

[a] Rescaled variable.

[b] This a linear distance from the gas station where the owner was surveyed or closest gas station (point [$X_1$, $Y_1$]) to both home and job sites (point [$X_2$, $Y_2$]). It is computed according to the formula: *Distance* = $[(X_1\text{-}X_2)^2 + (Y_1\text{-} Y_2)^2]^{1/2}$ meters. In this case, home and job sites do not consider the point addresses, but the centroid of the area where these places are located.

In Table 2 the results of the probit model are presented. The significant variables are the engine size, commercial vehicle, number of kilometers driven, conversion costs, knowledge of the program and the education level. All the coefficients have the signs we expected and are significant at least at the 1% level, except for the coefficient for *Knowledge* which is significant at least at the 4% level. Older and larger (engine size) vehicles are more likely to be converted. From an environmental viewpoint this is a good thing because the older and larger the vehicle, the more pollutants it emits. However, this is not firmly concluded in this study because of the insignificance of the variable *Year*, which could be explained by the high concentration of observations for the 1993-1999 period. On the other hand, from the results we can also see that in respect to the probability of switching the effect of the number of kilometers driven decreases as the vehicle is driven for a longer distance during the week.[213] In fact, there is a turning point for which the number of kilometers driven has a negative effect on the probability of switching. Thus, when a car is driven for more than 2900 Km/week, for this group of light-duty cars, the probability of switching starts to decrease, but the number of cars with this driving distance is very low. Note that there could be a rebound effect of the lower fuel cost of switching that reduces the positive environmental effect because the lower fuel cost for the household could mean that the subjects drive more, hence counteracting the environmental effect of the conversion.

---

[213] This would also be the case if the model is estimated with the log *Km*, but this model has a lower Pseudo $R^2$.

Besides these determinants, the car's use is an important consideration. A car used for commercial transport of goods and people is more likely to be converted. In fact, the bulk of converted cars are taxis. One socioeconomic variable that explains the decision to convert is the level of education. Its negative effect highlights the fact that most of switched vehicles are driven by people who do not have a high level of education and are employed to drive commercial vehicles. However, because of the high level of unemployment of professional people in Colombia, sometimes some of them opt to drive a taxicab at times. Nonetheless, one can argue that taking into account the positive relationship between income and education levels that has been found for Latin-American countries (Beyer 2000), and the evidence of income underreporting in surveys administered in Colombia (Nuñez & Sánchez1999), the negative sign of the coefficient of education in the estimated model indicates that most of switched vehicles are converted by owners who not only have a medium level of education but who also have a low or medium income level. They are the owners who want to achieve fuel cost savings by switching to hybrid cars.

The marginal effects[214] show that the conversion cost, engines size and km driven have a considerable impact on the probability of conversion. Among the discrete variables the one with a great impact on this probability is *Commercial Vehicle*; i.e. those cars used for commercial transport of goods and passengers are more likely to be converted.

Table 2

| Table 2. Probit Estimates for NGV Conversion | | | | | | | |
|---|---|---|---|---|---|---|---|
| Variable | Coefficie nts | t- valu e | Margin al effects | Coefficie nts | t- valu e | Coefficie nts | t- valu e |
| Number of Cars | 0.073 | 0.9 | 0.02 | 0.09 | 0.9 7 | 0.091 | 0.9 8 |

[214] The marginal effects are estimated by computing $f(\hat{\beta}'\mathbf{x}) * \hat{\beta}$, where $f(.)$ is the probability density function and $\hat{\beta}$ is the vector of estimated parameters. The marginal effect show the change in the probability of conversion when an independent variable changes by one unit (Greene 2000).

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Engine Size | 0.033* | 5.45 | 0.012 | 0.05* | 6.61 | 0.05* | 6.6 |
| Km | 0.75* | 3.25 | 0.29 | 0.83* | 3.24 | 0.83* | 3.23 |
| Km$^2$ | -0.14*** | -1.84 | -0.05 | -0.15*** | -1.67 | -0.14*** | -1.66 |
| Dummy (*if* Km=*0*) | -0.27 | -1.1 | -0.13 | -0.32 | -1.16 | -0.32 | -1.17 |
| Commercial Vehicle | 0.6* | 4.05 | 0.2 | 0.58* | 3.86 | 0.58* | 3.85 |
| Cost | -0.4** | -2.84 | -0.15 | -0.48* | -3.22 | -0.48* | -3.2 |
| Price Expectation | -0.18*** | -1.81 | -0.07 | -0.2*** | -1.83 | -0.2*** | -1.82 |
| Station | -0.12 | -1.02 | -0.04 | -0.12 | -0.95 | -0.12 | -0.95 |
| Knowledge | 0.25*** | 1.8 | 0.09 | 0.12 | 0.81 | 0.12 | 0.8 |
| Year | -0.33 | -0.41 | -0.13 | -0.15 | -0.17 | -0.16 | -0.18 |
| Education | -0.1* | -3.39 | -0.04 | -0.12* | -3.61 | -0.12* | -3.59 |
| Heads | -0.01 | -0.13 | -0.004 | -0.01 | -0.14 | -0.01 | -0.14 |
| No-heads | -0.03 | -0.2 | -0.01 | -0.07 | -0.6 | -0.07 | -0.6 |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | 6 | | 5 | | 4 |
| Constant | 3.49 | 0.22 | 3.59 | 0.21 | 3.75 | 0.22 |
| Distance_home | | | -0.015 | -1.14 | -0.01 | -0.84 |
| Distance_job | | | -0.03*** | -1.64 | -0.03 | -1.23 |
| Distance_home_closest | | | | | -0.004 | -0.11 |
| Distance_job_closest | | | | | 0.05 | 0.13 |
| Number of observations | 631 | | 584 | | 584 | |
| Likelihood ratio | 145.1 | | 168.2 | | 168.2 | |
| Pseudo-$R^2$ | 0.17 | | 0.21 | | 0.21 | |

* significant at 1%; **significant at 5%; *** significant at 10%

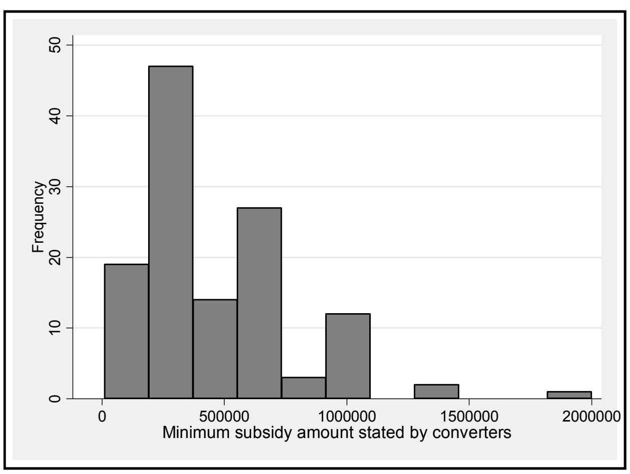
We also estimated a probit model to investigate whether the distance between either the owners' home or job location to the gas station is important. We computed the linear distances (in meters) from each of these places to that gas station where the owner was surveyed and from the nearest station to both home and job locales. Since we did not ask about the address of these sites, the computed distance is the linear length between the gas station and the center of the town or the municipality the owner lives or works in. This method did not allow for a computation of distance that took into account access routes; instead only a proxy for these distances was estimated considering the linear length to the zone stated in the survey. In addition, because many cars are used as taxis, there is no specific job site. In those cases we assumed a distance equal to zero, since they are usually driven along the valley and therefore pass near gas stations. The results of this estimation show that it might be important to have a gas station near the job site, in order to take the decision to adopt this technology (see Table 2).

That is, the existence of fueling stations near the job's location is important for the owner who decides to switch to NGV.

We also asked a number of other questions regarding conversion to the respondents. Of those owners with converted vehicles (273 owners), 82% knew about the program, but only 77% of the drivers who converted say that they received the subsidy. Of those who received the subsidy 57% said that they would have converted even without the subsidy, and 79% answered "Yes" to the question "If the amount of the subsidy had been lower, say, only a $300,000 bonus, would you still have taken the decision of conversion?", which is a remarkable result. In addition, to the question "Which is the minimum amount of subsidy you would have required to take the decision to convert?," 40% answered zero. Thus, many owners say that they did not need the subsidy to make the conversion. Taking into account only positive answers, the mean minimum subsidy is COP$454,320, and the median COP$300,000 (see Figure 2). Among these, there are some owners who stated amounts higher than the actual subsidy offered by the time the survey was done, which shows some inconsistency in their answers.

Figure 2. Distribution of Minimum Subsidy Required for

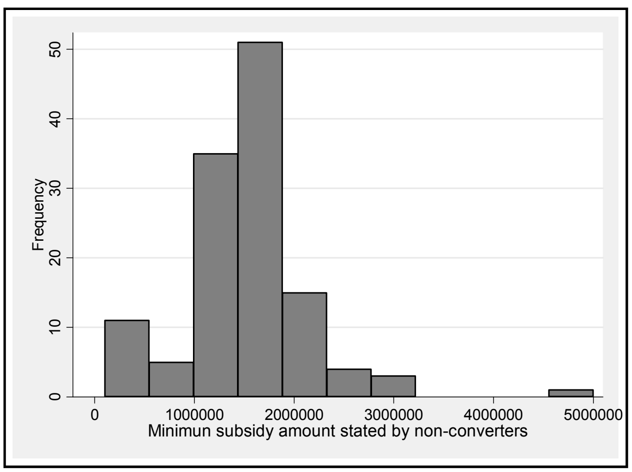
Switching Stated by Converters



On the other hand, 31% of the non-converters replied “Yes” to the question “Would you convert if the subsidy in the fuel conversion program is $1,500,000?” They were also asked “Which is the minimum amount of subsidy you would have required to take the decision to convert?” Of the 312 interviewees who answered this question, 185 (59%) said zero Colombian pesos. The mean amount of those who gave a positive amount is COP$1,391,200 and the median is COP$1,500,000 (see figure 3). In most of the cases, we might argue that the ones who did not answer anything or answered zero were owners who basically did not want to convert.

Figure 3. Distribution of Minimum Subsidy Required for

Switching Stated by Non-converters




We estimated two tobit models to analyze what the determinants were for the minimum amount of subsidy required for converting, in the case of both converters and non-converters. A tobit model is suitable since the dependent variable is continuous and censored below zero. The results are presented in Table 3. There are few significant coefficients of variables that explain the amount stated by those who have not converted. The only significant variables are coefficients for the number of persons who share expenses in the household (*heads*), the perception of a suitable number of gas stations (*station*), and for what purpose the car is used (*commercial vehicle*). The coefficient of *Price Expectation* is also significant but with a counterintuitive sign (see Table 3). What one would expect is that owners state a higher amount because they expect a higher natural gas price, provided that the higher the expected price of natural gas the lower the probability of switching (see Table 2). Other variables that showed a low level of significance are *Number of Cars* and *No-heads*.

The variables that affect the amount stated by those who convert are the number of kilometers driven (*Km*) and the level of education (*education*). Surprisingly, the model has an overall poor fit. Another variable, *knowledge,* is almost significant.

Table 3

| Table 3. Tobit estimates for minimum amount of subsidy required for switching. | | | | |
|---|---|---|---|---|
| | Non-converters | | Converters | |
| Variable | Coefficients | t-value | Coefficients | t-value |
| Constant | -340.1 | -0.1 | 438.98 | 0.41 |
| Number of Cars | 26.8 | 1.8 | -10.11 | -1.52 |
| Engine Size | -0.58 | -0.46 | -0.01 | -0.03 |
| Km | 18.9 | 1.07 | -11.05** | -1.9 |
| Commercial Vehicle | 56.34** | 2.21 | 14.9 | 1.56 |
| Cost | -42.13 | -1.47 | -0.63 | -0.06 |

Table 3. Tobit estimates for minimum amount of subsidy required for switching.

| | Non-converters | | Converters | |
|---|---|---|---|---|
| Variable | Coefficients | t-value | Coefficients | t-value |
| Price Expectation | -41.84** | -2.14 | 2.54 | 0.37 |
| Station | -43.62** | -1.92 | 4.01 | 0.54 |
| Knowledge | -21.21 | -0.82 | 21.91*** | 1.71 |
| Year | 19.82 | 0.11 | -22.52 | -0.52 |
| Education | -2.18 | -0.36 | -4.19** | -1.96 |
| Heads | 33.64** | 2.47 | 2.77 | 0.61 |
| No-heads | 34.72 | 1.71 | 2.89 | 0.43 |
| Number of observations | 242 | | 203 | |
| LR (13) | 30.87 | | 17.1 | |
| Pseudo-$R^2$ | 0.023 | | 0.012 | |
| $\sigma$ | 138.72 | | 45.73 | |

* significant at 1%; **significant at 5%; *** significant at 10%

We also asked why owners had not converted yet. The main reason for those owners who did not receive the subsidy was that they did not know about it in particular or the program in general (52%). In the first years of the program when the subsidy was not offered, 16% made the the switch, and 28% gave other reasons, the most common being that they bought a car that already had a hybrid engine (see Table 4). The main reason for switching to natural gas is because it is cheaper than the other available alternatives: 90% of owners chose this option between all the options. Of all the owners who took the decision of switching, 6% said they converted because NGV polluted less, with just 2% doing it because of the subsidy (see Table 4).

Of those owners with non-converted cars, 75% say they knew about the program, but only 68% said they knew about the subsidy. Of all these owners, 25% say they have not converted simply because they did not want to, 18% said that the car would lose performance, and 17% argued that the costs are greater than the benefits. However, there are other reasons such as lack of money for the investment, lack of knowledge about the program, distrust in the system, or mundane ones, such as the owner's plan to sell the car (see Table 4).

Table 4

Table 4. Reasons for Conversion, Non-conversion, and Receiving the Subsidy

| Reasons for not Converting | % | Reasons for converting to NGV | % | Reasons for not receiving the subsidy | % |
|---|---|---|---|---|---|
| Costs greater than benefits | 17 | Cheaper fuel | 91 | Wasn't worth the effort | 3 |
| Shorter lifetime of car's engine | 10 | The subsidy | 2 | No knowledge | 52 |
| Few gas stations | 3 | Less pollution | 6 | Other | 27 |
| Distrust in the system | 11 | Other | 1 | There was no subsidy | 15 |
| Lost of performance | 18 | | | Effort wasn't worth | 3 |
| Simply do not want to | 26 | | | | |
| Another | 1 | | | | |

| | | |
|---|---|---|
| 5 | | |

4.- Conclusions

This work aims to appraise which factors are more significant at the moment of deciding to convert from a car with a standard engine to a hybrid one that includes both fuels, natural gas and gasoline (or diesel). Those who received the subsidy were asked if they would have converted without this incentive, of whom 57% answered "Yes." This is a remarkable result from a policy viewpoint in the encouragement of alternative fuels. Bearing in mind that such an economic incentive may have considerable social opportunity cost, and adding to this the fact that almost 20% of the converted vehicles did it without the subsidy, this policy could be thought to not be cost-effective. This is reinforced by the fact that 90% of interviewees with a converted car stated that they switched because natural gas is a cheaper fuel, which is an economic incentive *per se*; it is also underscored by the finding that a 79% would have converted with a lower subsidy. Despite the fact that a large number of vehicles have been converted, and that this may have brought environmental benefits in the form of avoided emissions from gasoline or diesel, such a target could have been reached at a lower social cost. We are aware, however, that this conclusion should be supported with a sort of cost-benefit analysis where several of these and other aspects are involved.

Among the reasons for not converting to NGV, most people say that they simply are not interested in this technology either because of preference, lack of trust in the system, or because they think the costs of the switch and of having a car with those features are greater than the expected benefits. On the other hand, among the reasons for converting, the main reason is that natural gas is cheaper than the others; and the lack of information about the fuel conversion program has been an important justification for not receiving the subsidy.

One of the main determinants for the switch to NGV is the type of use for the car. Thus, those vehicles used for commercial transport of people or goods are more likely to be converted, which is linked to the fact that fuel costs savings of these cars are much greater than those of used just for commuting. Additionally, among these light-duty cars, vehicles with larger sized engines are more likely to be converted, as are those with lower conversion costs. We also found that older vehicles are likely to be converted. This might be explained by the higher energy efficiency of new cars, yielding the switch as a infinancially convenient decision, in particular if it is a low power car. However, this variable was not significant into the estimated model, an outcome due to high concentrations of observations in the 1993-1999 period.

The mean of the minimum amount required for switching for converters and non-converters are COP$454,320 and COP$1,391,200, respectively. The first figure suggests that there is no need to establish a subsidy as high as has been done in the last years. In fact, the initial amount of this incentive (COP$400,000 in 2004) could have been kept constant, and instead an incentive to the supply might be established. The building of more and better infrastructure in terms of gas stations and workshops is another option that policy makers have in their set of alternatives.

The reason for the high minimum amount of required subsidy stated by those who have not switched could be twofold: they simply do not want to convert and they already have a high discount rate. This might be linked to a cultural change required to convert to NGV, in the sense that a well-maintained vehicle is required for the switch. Moreover, these owners would demand a short payback period; i.e., they would require recovering the investment in a very short period of time.

Given that most of the converted vehicles have a medium engine size and are old (i.e., they are more than 10 years old), it can be argued that the program could have a great effect in terms of avoided emissions of air pollutants. Therefore, environmental policy that aims to improve air quality or encourage alternative fuels should focus on changing the behavior of owners in the type of fuel technology they use. There are some options to reach this target. One of them, usually pointed out in the literature, is the use of economic incentives, such as subsidies or taxes, for the final users; subsidies for the alternative fuel; or more taxes for traditional, highly pollutant fuels. As this study suggests, a subsidy may not be necessary given that the bulk of owners would have switched even though no subsidy had been offered. However, the subsidy might be important for those owners who are ambivalent about making the change. For instance, some owners may have considerable significant monetary constraints and would not be able to convert without such an incentive. In addition, the reduction of some subsidies that have in the past been applied to some fuels like gasoline or diesel is another option. This reduction would make the relative price of natural even lower and therefore, a bigger economic incentive might take place for the encouragement of this alternative fuel.

Finally, other links of the natural gas chain such as the distribution of this fuel and the kind of information provided to users, might be borne in mind. We concluded that the existence of fueling stations near the job site is key for the decision to switch. A corollary to this notion is the call for more stations in places where there are few or no stations at all, a move that could trigger more conversions. Besides, from this study we saw that many owners have not switched simply because of some misunderstandings about the working of this technology. Thus, the provision of more and better information could dispel some ongoing myths among the non-converters, and lead them to switch to a hybrid car.

## 5.- References


AMVA. 2006. *Actualización de inventario de emisiones atmosféricas en el Valle de Aburrá, con georeferenciación de éstas*. Colombia: Área Metropolitana del Valle de Aburrá.

Anderson, D. and W. Cavendish (1994). “Efficiency and substitution in pollution abatement”. United States: *World Bank Discussions Paper* 186.

Dagsvik, J.K., T. Wennemo, D. Wetterwald, and R. Aberge (2002). “Potential demand for alternative fuel vehicles”. *Transportation Research Part B* 36: 361–384.

Bedoya, J., C.M. Sepúlveda and W. Girarldo (2004). “Calidad del aire en el Valle de Aburrá en el cuatrimestre I del 2004”. Boletín Red Aire 15: 6-16.

Bedoya, J. and C.M. Sepúlveda (2005a). “Calidad del aire en el Valle de Aburrá en el 2004”. *Boletín Red Aire* 16: 5-15.

Bedoya, J., C. Zapata and C.M. Sepúlveda (2005b). “Calidad del aire en el Valle de Aburrá enero-mayo de 2005”. Boletín Red Aire 17: 5-15.

Beyer, H. (2000). “Educación y desigualdad de ingresos: una nueva mirada”. *Estudios Públicos* 77: 97-130.

EPM. (2007). *Seguimiento del programa de GNV*. Personal communication with engineers of Empresas Públicas de Medellín. Medellín, Colombia.

Fullerton, D. and S. West (2000). "Tax and subsidy combinations for the control of car pollution". Working Paper 7774, *National Bureau of Economic Research*, USA.

Funk, K. and A. Rabl (1999). "Electric versus conventional vehicles: social costs and benefits in France". *Transportation Research Part D* 4: 397-411.

Greene, W.H. 2000. *Econometric Analysis*. Prentice-Hall, Inc. New Jersey.

Haller, M., E. Welch, J. Lin and S. Fulla (2007). "Economic costs and environmental impacts of alternative fuel vehicle fleets in local government: An interim assessment of a voluntary ten-year fleet conversion plan". *Transportation Research Part D* 12: 219–230.

Johansson, B. (1999). "The economy of alternative fuels when including the cost of air pollution". *Transportation Research Part D* 4: 91-108.

Kazimi, C. (1997). "Evaluating the environmental impact of alternative-fuel vehicles". *Journal of Environmental Economics and Management* 33: 163-185.

Kojima, M. (2001). "Breathing clean: considering tie switch to natural gas buses". World Bank Technical Report No. 516.

Nuñez, J. and F. Sanchez (1999). "Estimaciones trimestrales de la línea de pobreza y sus relaciones con el desempeño macroeconómico colombiano (1977-1997)". Archivos de Macroeconomía No. 110. Colombia: Departamento Nacional de Planeación.

Parker, R., H. Fletchall and C. Pettijohn (1997). "Truck operators' perspectives on use of alternative fuels". *Transportation Research Part E* 33(1): 73-78.

Rouwendal, J. and F. De Vries (1999). "The taxation of drivers and the choice of car fuel type". *Energy Economics* 21: 17-35.

Small, K. and C. Kazimi (1995). "On the costs of air pollution from motor vehicles". *Journal of Transport Economics and Policy* 29: 7-32.

Statacorp. (2006). *Intercooled STATA 9.2 for Windows*. Licensed to Universidad Nacional de Colombia, at Medellín.

Wooldridge, J. 2002. *Econometric Analysis of Cross Section and Panel Data*. Cambridge: MIT Press.

# 61. Greenhouse Gas Cost, External Costs and Energy Options in Brazil

**Martha Barata[a), D.Sc.; Philipp Preiss [b), M.Sc.; Emilio Lèbre La Rovere[c), D.Sc.; Amaro Olimpio Pereira Júnior[d), D.Sc.; Sandra de Castro Villar[d), M.Sc.; Silvia Helena Pires[d], M.Sc.**

Authors:

Affiliation:

a) Fiocruz Researcher D.Sc. and Centro Clima collaborator researcher;

b) Institute of Energy Economics and the Rational Use of Energy, Department of Technology Assessment and Environment, University of Stuttgart, Researcher;

c)Head of Centro Clima/COPPE/Federal University of Rio de Janeiro;

d)Centro Clima /COPPE/Federal University of Rio de Janeiro collaborator researcher.

Three-words: Brazilian energy scenarios, external cost of energy system

Abstract:

The present study is based on results of the European research project CASES (Cost Assessment of Sustainable Energy System) for Brazil. CASES had the aims to compile coherent and detailed estimates of both, external and internal costs of energy production for different energy sources up to the year 2030. The results where used to evaluate policy options for improving the efficiency of energy use, taking account of full cost data.

External costs occur when an economic subject causes a loss of welfare to another one and does not compensate this change of welfare. A compensation for this change of welfare due to external costs would eliminate the market imperfection caused by externalities.

The ExternE methodology (External costs of Energy) provides a framework for transforming impacts that are expressed in different units (e.g. global warming potential [CO2equivalents], human health impacts [DALY] or damage to the biodiversity due to acidification [loss of biodiversity) into a common unit, namely "monetary values".

It has the following principal stages:

1) Definition of the activity to be assessed and the background scenario where the activity is embedded; definition of the important impact categories and externalities.

2) Estimation of the impacts or effects of the activity (in physical units). In general, the impacts allocated to the activity are the difference between the impacts of the scenario with and the scenario without the activity.

3) Monetization of the impacts, leading to external costs.

4) Assessment of uncertainties, sensitivity analysis.

5) Analysis of the results, drawing of conclusions.

Marginal damages have to be calculated because the creation of secondary pollutants like sulfates, nitrates and ozone depends also on the background concentration of NOx, SO2, NH3, NMVOC, etc.

Evaluation of climate change due to greenhouse gases: The optimal point of emissions is the one where marginal damage costs are equal to marginal avoidance costs. Since marginal damage costs estimates have very high uncertainties, and with regard to the precautionary principle values that reflect the marginal avoidance costs for reaching a certain emission target can be used.

The objective of this article is to determine the increment cost of the expansion of the electric section in Brazil in scenario where external costs of each technology are taken into account. It is verified that the penalties for the emissions of greenhouse gases and other pollutants makes renewable sources more competitive.

# 62. The Energy and Environment Challenges.

**Dr. José Antonio Gómez Reyna, Dr. Boris Voronin,**

**Dra. Lioudmila Oleinikova,**

**Mtro. Juan José Cárdenas Grajeda**

Cuerpo Académico de Energías Renovables

División de Ingenierías

Centro Universitario de Ciencias Exactas e Ingenierías

Universidad de Guadalajara, México.

Av. Revolución 1500 Guadalajara, Jalisco, México

gomezrey@yahoo.com, boris.voronine@cucei.udg.mx,

<loleinik_l@bk.ru>,

cardenasgrajeda@yahoo.com.mx

America our continent is rich in natural resources. The technology developed in the earlier 1900 was hydrocarbons, petroleum, gas and coal based.

Through a century the non discriminated use, by the great consumers had affected the atmosphere with the effects of greenhouse gases and because that the global warming arose.

The social, economical, and scientist-technological politics can't go alone in a globalize environment; the macroeconomics, the economics in development and the poverty of many countries are influenced by vital elements for its development, such as energy do.

In several cases, wrong energy politics used by the countries in possession of natural resources had brutally exploded their wealthy and the relation cost-benefit give us a deficit and to rebuild those areas looks almost impossible by the relation cost-time. These situations force us as Latino Americans countries to work counter clockwise on application, research and development of new clean energy based technologies as the solar energy(photovoltaic and high, medium, low temperatures).

The eolic energy (in land and sea), Biomass, (biofuel, ethanol).Geothermic energy (very important in our countries with a high manifestation produced by volcanism and plates tectonic), besides the hydrogen energy. We have too a great potential of clean energies such as hydroelectric whit great dams turbo generators or with micro turbines for small fluxes. A major problem exists in the construction of macro dams and the impact environment studies because most of them are not well done.

The majority of the first world countries consider water, meals, energy territory and other items as national security elements. There is not a country which not considers energy as a vital affair for its social, economical security to avoid foreign dependence.

The scientific, technological, economical and social development is notoriously retarded. The link among government, business men, society and scientific researchers, will be vital, for the Latino American countries future.

In this conference we present a panoramic view about what energy is, its different manifestations, the political ways in order to take advantage of it, so as the hydrocarbons research to a global level, which are decreasing and the new challenges of clean and renewable energy, for a best carrying capacity world.

**Ruben Chaer**

## 63. Simulation of wind farms on the optimal dispatch policy of Uruguayan hydro-thermal electricity system.

Simulación de granjas eólicas en el despacho óptimo del sistema hidro térmico de generación de energía eléctrica del Uruguay.

Facultad de Ingeniería y Administración del Mercado Eléctrico del Uruguay.

Yacó 1478, C.P. 11400 Montevideo-Uruguay. Tel.:(+598)2.6135833

email: rchaer@fing.edu.uy

Keywords: Wind Optimal Dispatch

Abstract: Taking into account the world's energy crisis and not having Uruguay neither oil nor natural gas fields, the government is encouraging the development of renewable energy projects for generating electricity. The goal is to diversify the energy dependence by reducing the weight of oil in the country's energy matrix. In this context, a number of bids are being made for the purchase of energy from new power plants to generate electricity using biomass, waste from industrial parks, wind and small rivers.
The plan is to incorporate approximately 400MW from wind power to the system in the next six years. The peak demand is now around 1400MW.
One characteristic of wind energy is its high variability of power due to changes in then wind speed.
The Uruguayan system has a high component of hydroelectric generation, having a lake with a capacity of 90 days and three others with capacity of around 7 days. In this scenario, it is necessary to consider the wind power in the system's dispatch, and then evaluate the way in which such inclusion can bring changes in

the policy of optimal use of the country’s resources. This paper presents the model developed for this purpose. The model takes into account the temporal autocorrelation of wind speeds and its annual and daily seasonality.

The annual seasonality in Uruguay is important because there are few months in the year in which there is plenty of water and others where there are shortages, so the possible correlation between wind and water availability must be represented.

The daily seasonality is also important for its tuning with the consumption curve of the system.

Comparative results of the use of water from the reservoirs are presented for a scenario in which the expansion of the system is based on wind energy versus a scenario in which the expansion of the system is based on fuel oil fired generators.

## Introduction.

Uruguay ha decidido al igual que muchos otros países diversificar las fuentes de generación de energía eléctrica para disminuir su vulnerabilidad ante la volatilidad de los precios del petróleo. El país no cuenta con yacimientos de combustibles fósiles explotables actualmente. La política energética alienta por tanto a la instalación de energías renovables. Esta política ha sido llevada a cabo mediante licitaciones de contratos de compra de la energía generable por plantas basadas en micro y mini aprovechamientos hidráulicos, plantas de generación en base a biomasa (residuos, de madera, cáscara de arroz, etc.) y plantas de generación eólicas.

En este trabajo se analiza la expansión en la siguiente década considerando una fuerte componente de energía eólica. El análisis se centra sobre las posibles implicancias sobre los procedimientos y criterios seguidos para el despacho óptimo de los recursos del sistema y sobre los efectos que puede tener sobre los costos de operación del sistema y sobre los precios del mercado mayorista. Se desarrolla una metodología sencilla para modelar la expansión eólica y poder incluir dicho modelo en el simulador de sistemas de energía eléctrica SimSEE [1].

El enfoque realizado es desde el punto de vista del despacho energético y no se consideran en este trabajo las posibles restricciones que seguramente impondrá el sistema de transmisión.

La metodología seguida es considerar un conjunto de datos históricos de medidas de velocidades de viento, distribuidos en el territorio nacional y en base a ellos construir una serie de viento equivalente (SVE) que nos permita simular el conjunto de parques eólicos como si estuvieran distribuidos en el territorio nacional. La idea es que a los efectos de los estudios de planificación de largo plazo, no es posible conocer las ubicaciones de los parques ni las velocidades de viento reales y por lo tanto se intenta captar en la SVE lo que darían el conjunto de parques si se instalan en forma distribuida.

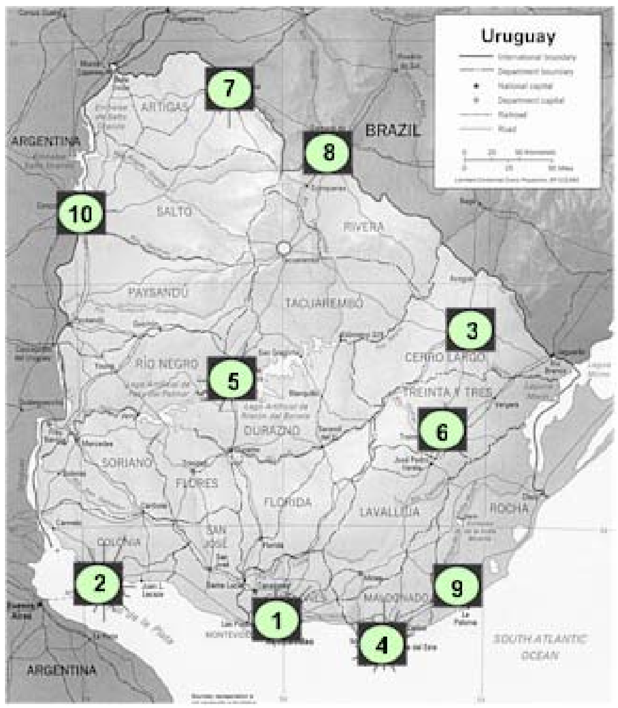
Una vez obtenido el modelo, se incorpora a SimSEE y se realizaron una serie de simulaciones de las que se presentan los resultados más relevantes.

## Determinación del "Viento Equivalente".

Se consideraron los registros horarios de 3 años de la velocidad del viento en 10 estaciones del servicio meteorológico nacional distribuidas sobre el territorio nacional tal como se marca en la figura 1.

La idea es que los parques eólicos se instalarán en diferentes ubicaciones del territorio nacional. Estas ubicaciones serán las determinadas por cada proyecto teniendo en cuenta las características del entorno que lleven a velocidades de viento elevadas y cuestiones de viabilidad económica como la inversión necesaria en el sistema de transmisión para conectarse al sistema eléctrico nacional.

Fig. 1. Ubicación de las series de datos usadas.




A los efectos de este estudio supondremos que los lugares se eligen de forma tal que el factor de planta de los parques es 30%. Las series de datos se escalaron de forma tal que un aerogenerador Vestas V80-2M generaría con esas velocidades de viento la energía correspondiente a un factor de uso de 30%.

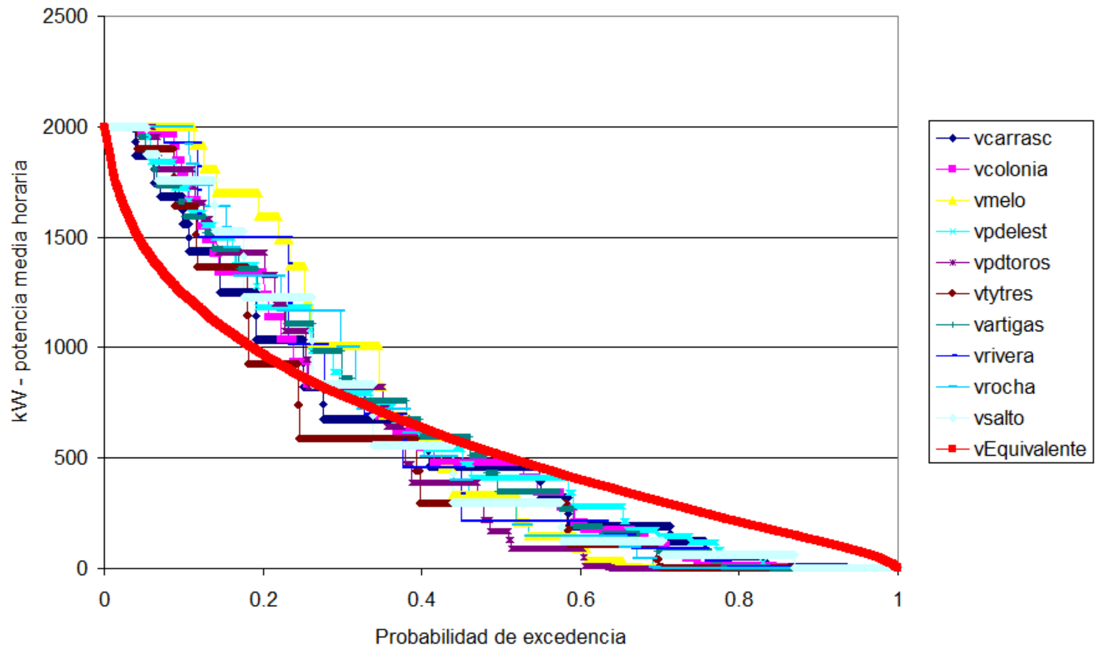
La separación geográfica de los parques implicará que las fluctuaciones del viento no se produzcan en todos a la vez y por lo tanto es de esperar que las fluctuaciones de la potencia generada por el conjunto de parques eólicos esté en parte atenuada por la separación geográfica de los mismos. A priori no sabemos cuál será la ubicación de cada parque ni la potencia instalada en cada uno. A los efectos del estudio se supuso que los parques se instalan en las 10 posiciones marcadas en el mapa de la fig 1 y que las velocidades de viento son las series de datos escaladas para obtener un factor de planta 0.3 como se mencionó ene el párrafo anterior.

Con este esquema, utilizando la curva potencia-velocidad característica del aerogenerador se construyó la serie de potencias generadas por 10 aerogeneradores (colocados uno en cada ubicación) y se calculó la serie promedio de dichas series. Utilizando nuevamente la curva potencia-velocidad del aerogenerador (pero a la inversa) se construyó la serie de viento equivalente. Esta serie tiene menos dispersión que cada una de las 10 series considerada por separado y es la que reproduce la potencia promedio de las 10 instalaciones.

Esta serie se construyo para facilitar el simulado de la expansión eólica sin necesidad de considerar 10 parques e ir agregando máquinas a cada uno de los parques. Consideramos un único parque en una ubicación inexistente en la que el viento es la serie equivalente.

La fig 2. muestra la probabilidad de excedencia de la potencia (media horaria) del aerogenerador colocado en cada una de las 10 posiciones y la correspondiente al aerogenerador atacado por la serie equivalente de vientos.

Fig. 2 Producción de aerogenerador de 2MW colocado en 10 puestos diferentes del Uruguay a una altura suficiente para asegurar un fp=0.3 y promedio de las potencias



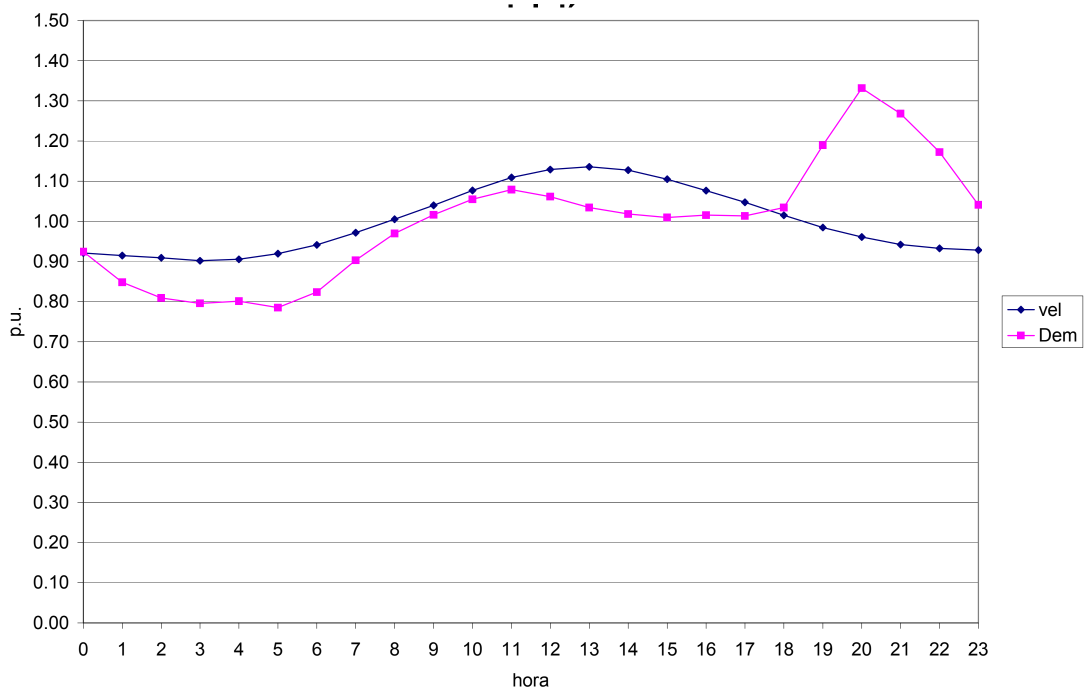

Como se puede observar, con la serie equivalente la probabilidad de excedencia de 1500 kW es 5% mientras que para cada serie aislada, dicha probabilidad es entre 10 y 20%. Esto muestra que es menos probable encontrar vientos que lleven a potencias superiores a 1500 kW en todos los parques a la vez que en cada uno por separado. Por el lado de las velocidades bajas, tenemos que es prácticamente improbable que la velocidad del viento sea tan baja en todos los parques a la vez como para que la potencia sea cero, mientras que si observamos las series por separado, vemos que dependiendo de la serie, la probabilidad de potencia cero va entre 35 y 15%.

A los efectos de las simulaciones con SimSEE se identificó un modelo de Correlaciones en Espacio Gaussiano con Histogramas (CEGH ver [2]). El modelo se construyó con funciones de deformación que tienen en cuenta las variaciones de probabilidad de ocurrencia de las velocidades de viento según la hora del día y se consideró la variación estacional mediante 12 coeficientes (uno para cada mes) . La variación según la hora del día es importante por su eventual correlación con la curva de demanda. La variación según el mes del año es importante por la correlación con la demanda y con el régimen de lluvias de Uruguay. Los aportes a las centrales hidráulicas son importantes Primavera, algo menos en Otoño, menos en el Invierno y bajos en el Verano.

La fig. 3 muestra la variación diaria del valor esperado de velocidad de viento y de la demanda.

Como se puede apreciar, la calma de la mañana coincide con el valle de la demanda, pero el pico de demanda se da en la calma del viento en la noche.

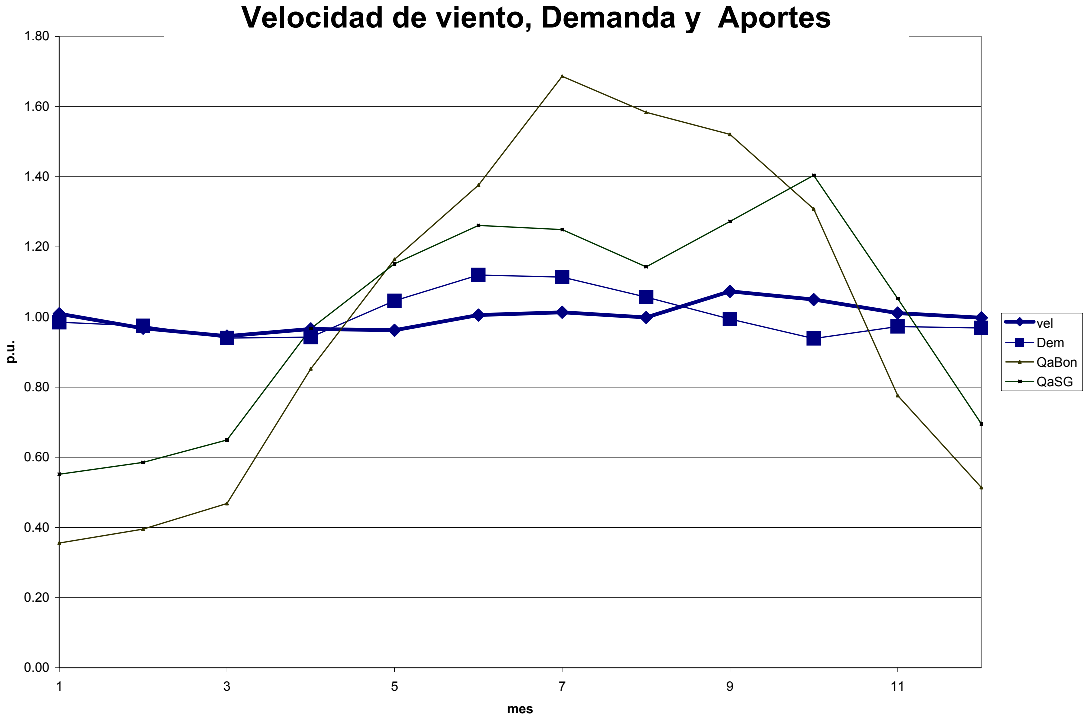
**Fig. 3. Velocidad de viento y demanda esperada según la hora**




La fig 4 muestra la variación estacional de la velocidad de viento junto con la estacionalidad de la demanda y de los aportes a las dos principales represas del país.

Como se puede observar, la estacionalidad del valor esperado de la velocidad de

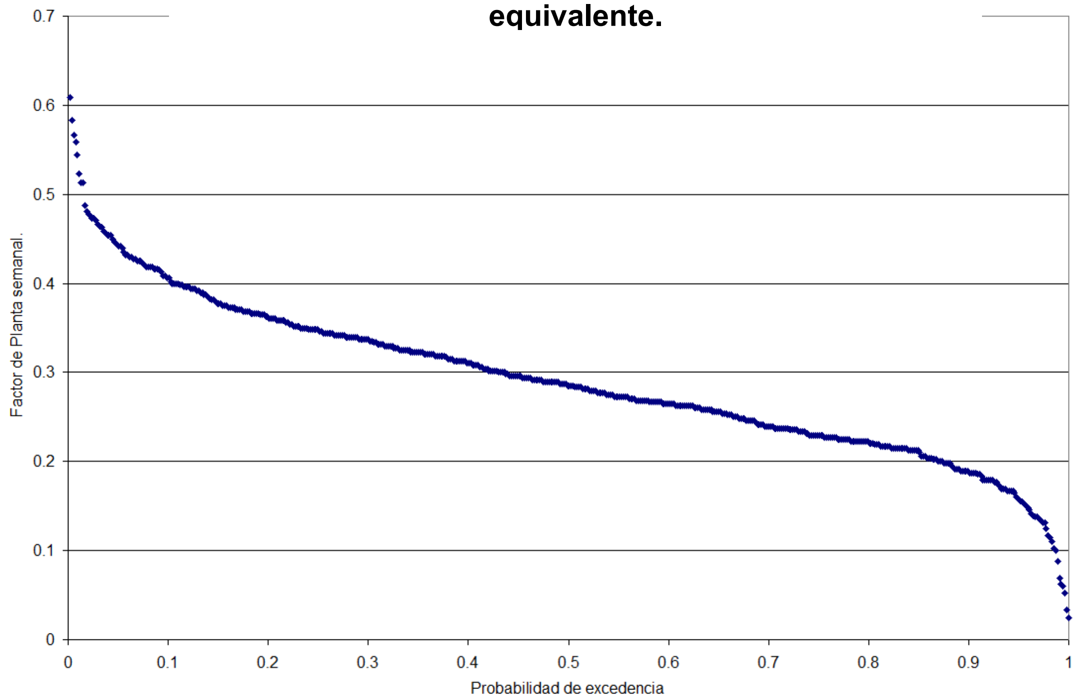
**Fig. 4. Estacionalidad anual.**




viento es muy inferior a la estacionalidad que presentan los aportes a las represas. Como era de esperar, los vientos son algo superiores en primavera al igual que los aportes hidráulicos a las represas. El mayor consumo de energía en el sistema se verifica en el invierno. La menor disponibilidad de recursos se verifica entonces en el verano y la gestión del principal lago del sistema es básicamente guardar el máximo posible de agua de los meses 8-10 para su uso en el verano.

Si calculamos el factor de planta de un parque con el viento equivalente sobre la

**Fig. 5. Factor de planta de un parque con el viento equivalente.**




energía que entrega en una semana obtenemos la distribución que se muestra en la fig. 5.

Esta curva tiene importancia pues es de esperar que en Uruguay sea posible regularizar las fluctuaciones de la potencia de los parques eólicos con potencia de origen hidráulico. La centrales hidráulica con más potencia instalada y que por lo tanto puede mejor actuar en este sentido tiene embalse con capacidad de almacenamiento del orden de una semana. Para una mejor interpretación de la fig ... obsérvese que para un aerogenerdor de 2 MW, la misma indica que al considerar la energía entregada en un semana, el 90% de las semanas va a entregar la energía correspondiente a un factor de planta de 0.2 aproximadamente lo que significa una potencia promedio equivalente de 400 kW durante toda la semana.

En la metodología de identificación de un modelo CEGH [2] se identifican un conjunto de funciones de deformación que transforman las series de datos a un espacio gaussiano en el que se realiza la identificación de un filtro recursivo lineal que luego es utilizado para la generación de series sintéticas. Para el caso de la series horarias de viento, el único coeficiente significativo del filtro es el de orden 1. Para el caso de la serie de viento equivalente, este coeficiente resultó ser:

0.930 lo que significa, que en el espacio gaussiano, la velocidad de viento de la hora siguiente se puede aproximar por la velocidad de la hora actual multiplicada por 0.930 más un ruido blanco gaussiano multiplicado por 0.372. El coeficiente 0.930 es “la memoria” del proceso aleatorio. Si consideramos las series aisladas (las delas diez ubicaciones de datos) tendremos valores del orden de 0.7 a 0.8 para este coeficiente. Esto simplemente indica que es más predecible la serie del viento equivalente que cada una de las series de datos por separado.

Corresponde aclarar que el modelo así obtenido, permite ser utilizado para sintetizar series de velocidades de viento que generan potencias como serían las del promedio de parques instalados en forma distribuida, pero el modelo no está pensado para predecir la producción de electricidad proveniente de los parques en las siguientes horas, lo que sería útil para la operación en tiempo real del despacho del sistema. Ha otras líneas de trabajo con metodologías específicas para este tipo de modelos como la presentada en [3].

Casos de estudio.

Para analizar el efecto de la expansión de la generación eléctrica del sistema utilizando granjas eólicas se estudiaron dos casos de expansión del parque generador. Un caso que llamaremos “PTE” en el que la expansión se realiza utilizando solamente unidades de generación en base a fuel oil y otro caso “WTE” en el que la expansión utiliza 400 MW de aerogeneradores y plantas a fuel oil.

Para el caso PTE, el cronograma de instalación de las centrales de generación se realizó de forma tal que los proyectos se rentabilizan con los ingresos que obtendrían si vendieran su energía al costo marginal del sistema y su costo de generación fuera 250 USD/MWh. Se consideró un costo de 2000 USD/kW instalado (incluyendo inversiones, impuestos y O&M) y una tasa de descuento de 12% anual.

Para el caso WTE, se supuso un cronograma de ingreso de los aerogeneradores de forma de alcanzar los 400 MW para el 2015 y se completó la expansión con el mismo criterio utilizado para el PTE.

Los dos plantes se resumen en la tabla 1.

| | case WTE Wind | case WTE Thermal | case PTE Thermal |
|---|---|---|---|
| | *MW* | *MW* | *MW* |
| 2009 | 40 | 66 | 80 |
| 2010 | 160 | 33 | 90 |
| 2011 | 240 | 35 | 120 |
| 2012 | 300 | 93 | 200 |
| 2013 | 340 | 179 | 300 |
| 2014 | 380 | 205 | 340 |
| 2015 | 400 | 218 | 360 |
| 2016 | 400 | 278 | 420 |
| 2017 | 400 | 338 | 480 |
| 2018 | 400 | 408 | 550 |
| 2019 | 400 | 468 | 610 |

Tabla 1. Expansión de la generación para los dos casos de estudio.

Hipótesis del estudio.

Las siguientes hipótesis son comunes a ambos casos.

Demanda de energía.

La tabla 2 muestra la demanda considerada para el estudio. El crecimiento de 5.4% del año 2009 (respecto de la demanda del 2008) se debe a que durante el 2008 se verificó un crecimiento negativo debido a restricciones energéticas.

Tabla 2. Demanda del sistema eléctrico.

| | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| GWh | 9157 | 9523 | 9856 | 10201 | 10558 | 10928 | 11310 | 11706 | 12116 | 12540 | 12979 |
| fc % | 5.40% | 4.00% | 3.50% | 3.50% | 3.50% | 3.50% | 3.50% | 3.50% | 3.50% | 3.50% | 3.50% |

El racionamiento de energía (esto imposibilidad de cubrir la demanda) se modela en SimSEE mediante la especificación de costos de racionamiento según la profundidad del mismo. Se consideró un costo de 500 USD/MWh para el primer 5% de racionamiento, 800 USD/MWh para el siguiente 7.5%, 2400 USD/MWh para el siguiente 7.5% y 4000 USD/MWh para los racionamientos de energía por encima del 20% de la demanda.

Centrales hidro-eléctricas.

Uruguay tiene cuatro centrales de generación hidroeléctricas: ”Bonete”,”Baygorria” y ”Palmar” sobre el ”Río Negro” y la planta bi-nacional ”Salto Grande” sobre el ”Río Uruguay”. Las tres plantas sobre el Río Negro están encadenadas, Bonete aguas arriba de Baygorria y ésta aguas arriba de Palmar. Los parámetros más relevantes se resumen en la tabla 3.

Table 3 Hydroelectric plants of Uruguay.
(*): ELEVATION IS MEASURED ABOVE SEA LEVEL; (**): THIS VALUES CORRESPOND TO THE 50% OF THE PLANT OWNED BY URUGUAY.

| | *Bonete* | *Baygorria* | *Palmar* | *Salto-UY* | |
|---|---|---|---|---|---|
| Minimum elevation of the lake [m] | 70 | 53 | 36 | 30 | * |
| Maximum elevation of the lake [m] | 81 | 56 | 44 | 35.5 | * |
| Discharge elevation [m] | Baygorria | Palmar | 7.5 | 5 | * |
| Storage capacity of the lake [Hm3] | 8210 | 216 | 2575 | 3058 | ** |
| Mean inflow to the basin [m3/s] | 567 | 0 | 290 | 2358 | |
| Maximum discharge flow [m3/s] | 680 | 828 | 1373 | 4200 | ** |
| Installed power [MW] | 155 | 108 | 333 | 945 | ** |

Centrales de generación térmicas.

La tabla 4 muestra las centrales de generación térmicas. Actualmente se utiliza Gasoil, FuelOil pesado y algo de Biomasa.

Table 4 Centrales de generación térmicas.

| *Nombre* | *Combus-tiblel* | *Tipo* | *MW* | *USD/MWh* | *fd %* | *unidades* |
|---|---|---|---|---|---|---|
| Botnia | BM | ST | 20 | 2 | 83.5% | 1 |
| CB_5ta | FO | ST | 75 | 126.1 | 83.5% | 1 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| CB_5ta | FO | ST | 120 | 130 | 83.5% | 1 | |
| CTR_1 | GO | GT | 100 | 237.9 | 84.5% | 1 | |
| CTR_2 | GO | GT | 100 | 237.9 | 84.5% | 1 | |
| Gendis | BM | ST | 4 | 1 | 83.5% | 1 | * |
| Motores | FO | Mo | 10 | 112 | 84.5% | 0 | ** |
| PTI | GO | GT | 49 | 187 | 84.5% | 6 | |
| SalaB | FO | ST | 48 | 162.6 | 55.6% | 1 | |
| TGAA | GO | GT | 15 | 317.9 | 46.9% | 1 | |

BM= Biomasa, FO= Fueloil, GO= gasoil

ST= steam-turbine, GT= gas-turbine, Mo= motor

* en junio de 2009 se incrementa a 5 unidades

** la cantidad de unidades depende del caso de estudio

Detalles del cálculo.

Para ambos casos se utilizó el programa SimSEE[1] con paso de tiempo de 168 horas (una semana) dividido en 4 postes. El primer poste correspondiente a las horas de mayor demanda se consideró de 7 horas de duración. Los siguientes postes (en orden decreciente de demanda) se consideraron de 28, 91 y 42 horas.

De las centrales hidráulicas, la única que se consideró con embalse fue Bonete, el resto se consideraron como centrales de pasada. Como estado del sistema se consideró el volumen embalsado en el lago de Bonete y el estado hidrológico. Para el volumen de Bonete se consideraron una discretización en 10 valores para el rango de cotas de operación (70 a 81m). Para el estado hidrológico se consideró una discretización en 5 valores.

Para el algoritmo de Programación Dinámica Estocástica que calcula la política de operación se consideraron 50 sorteos para cada paso de tiempo. Para la etapa de simulación se consideraron 1000 crónicas sintéticas de los procesos estocásticos del sistema. Los procesos estocásticos considerados son básicamente, los caudales de aportes hidráulicos a las represas, la velocidad del viento equivalente y la disponibilidad de las centrales de generación y de las interconexiones internacionales.

Cuando se comentan los resultados, se presentan los valores esperados ( promedio en el conjunto de las 1000 crónicas simuladas) y/o el valor con determinada probabilidad de excedencia (en el conjunto de los 1000 valores resultantes de la simulación con cada una de las 1000 crónicas utilizadas).

Resultados.

Firmeza de la generación eólica.

A los efectos del respaldo del sistema, los 400 MW de generación eólica son equivalentes a 120 MW de generación térmica. El reglamento del mercado mayorista de energía uruguayo establece una metodología para el reconocimiento de potencia firme a las centrales de generación hidroeléctricas y térmicas. De acuerdo a este resultado se podría pensar que el reconocimiento de potencia firme a las eólicas puede rondar el 30%. Esto es aproximado y seguramente ese porcentaje disminuya en la medida en que aumente el porcentaje de MW de origen eólico en el sistema, dado que el efecto de filtrado que pueden hacer las centrales hidroeléctricas se saturará.

Reducción en los costos de operación del sistema.

La tabla 5 resume los costos de operación esperados para los dos casos estudiados y la diferencia entre ambos casos, para cada año a partir del 2010.

| | *Costos esperados caso PTE* | | | | *Costos esperados caso WTE* | | | | *Diferencia costos PTE-WTE* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Impo.* | *Comb.* | *Falla* | *Total* | *Impo.* | *Comb.* | *Falla* | *Total* | *Impo.* | *Comb.* | *Falla* | *Total* |
| | *[MUSD]* | *[MUSD]* | *[MUSD]* | *[MUSD]* | *[MUSD]* | *[MUSD]* | *[MUSD]* | *[MUSD]* | *[MUSD]* | *[MUSD]* | *[MUSD]* | *[MUSD]* |
| 2010 | 18.4 | 406.4 | 24.0 | 448.9 | 17.6 | 374.4 | 20.2 | 412.2 | 0.8 | 32.0 | 3.9 | 36.7 |
| 2011 | 21.3 | 450.2 | 25.3 | 496.9 | 20.1 | 393.5 | 23.0 | 436.6 | 1.2 | 56.7 | 2.3 | 60.2 |
| 2012 | 19.7 | 470.2 | 25.8 | 515.7 | 19.4 | 400.1 | 26.2 | 445.7 | 0.3 | 70.1 | -0.4 | 70.0 |
| 2013 | 13.8 | 484.6 | 19.4 | 517.7 | 15.4 | 418.6 | 19.4 | 453.4 | -1.6 | 66.0 | -0.1 | 64.3 |
| 2014 | 12.9 | 525.7 | 22.1 | 560.6 | 13.3 | 442.6 | 15.1 | 471.0 | -0.4 | 83.0 | 7.0 | 89.6 |
| 2015 | 16.9 | 573.6 | 20.9 | 611.4 | 18.3 | 484.7 | 31.4 | 534.4 | -1.4 | 88.9 | -10.5 | 77.0 |
| 2016 | 19.8 | 589.8 | 21.9 | 631.5 | 22.3 | 498.6 | 37.4 | 558.3 | -2.4 | 91.2 | -15.6 | 73.2 |

Tabla 5. Costos esperados de operación óptima del sistema.

La columna “Impo.” se refiere a los costos incurridos en importar energía (desde Brasil y Argentina), la columna “Comb.” se refiere a costos de combustibles (Gasoil y Fueloil) en las centrales térmicas de generación. La columna “Falla” indica el costo del país contabilizado por racionamientos de energía. La columna “Total” es la suma de los costos de importación, combustible y falla.

La columna “Total” del bloque “Diferencia” corresponde a los beneficios para el sistema por reducción de costos de operación asignables a la instalación de los generadores eólicos en lugar de parte de la expansión con centrales térmicas.

Generación de las granjas eólicas.

La tabla 6 resume los resultados de generación de las eólicas para el caso WTE.

| | *Energía generada de origen eólico.* | | | | | | *Factores de planta de los molinos* | | | | | *Beneficios* |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Prom* | *Pe10%* | *Pe30%* | *Pe70%* | *Pe90%* | *Molinos* | *Prom* | *Pe10%* | *Pe30%* | *Pe70%* | *Pe90%* | *Prom* |
| | *[GWh]* | *[GWh]* | *[GWh]* | *[GWh]* | *[GWh]* | *N* | *[%]* | *[%]* | *[%]* | *[%]* | *[%]* | *[USD/MWh]* |
| 2010 | 287 | 402 | 332 | 242 | 179 | 60 | 27% | 38% | 32% | 23% | 17% | 128 |
| 2011 | 516 | 722 | 595 | 434 | 324 | 106 | 28% | 39% | 32% | 23% | 17% | 117 |
| 2012 | 681 | 946 | 782 | 574 | 433 | 140 | 28% | 39% | 32% | 23% | 18% | 103 |
| 2013 | 795 | 1106 | 913 | 669 | 507 | 163 | 28% | 39% | 32% | 23% | 18% | 81 |
| 2014 | 899 | 1246 | 1031 | 756 | 577 | 183 | 28% | 39% | 32% | 24% | 18% | 100 |
| 2015 | 962 | 1340 | 1107 | 810 | 600 | 197 | 28% | 39% | 32% | 24% | 17% | 80 |
| 2016 | 974 | 1357 | 1121 | 820 | 607 | 200 | 28% | 39% | 32% | 23% | 17% | 75 |

Tabla 6. Resultados de generación de las granjas eólicas.

La tabla muestra para cada año a partir del 2010 la energía generada de origen eólico, la cantidad promedio de molinos de 2 MW en operación, los factores de planta de los molinos y los beneficios para el sistema expresados en [USD/MWh]. Las columnas etiquetadas “Prom” corresponden al valor esperado y las columnas “Pe10%”, “Pe30%”, “Pe70%” y “Pe90%” corresponden a los valores con probabilidad de ser excedidos en 10, 30, 70 y 90% respectivamente.

La columna de beneficios muestra la reducción de costos de operación (última columna de la tabla ... ) dividida la energía promedio de origen eólico para cada año.

Cambios en la política de uso del agua del embalse de Bonete.

La política de uso del agua del embalse Bonete se expresa como una tabla de valores asignados al agua. Esta tabla permite considerar a los efectos del despacho del sistema a la central hidráulica como si fuese una térmica con un costo de combustible asignado. Los valores del agua dependen del estado del sistema (cota del lago y condición hidrológica) y se obtienen en SimSEE mediante programación dinámica estocástica.

La tabla 7 resume los valores del agua para los casos estudiados para diferentes

**Tabla. 7. Valores del agua de Bonete.**

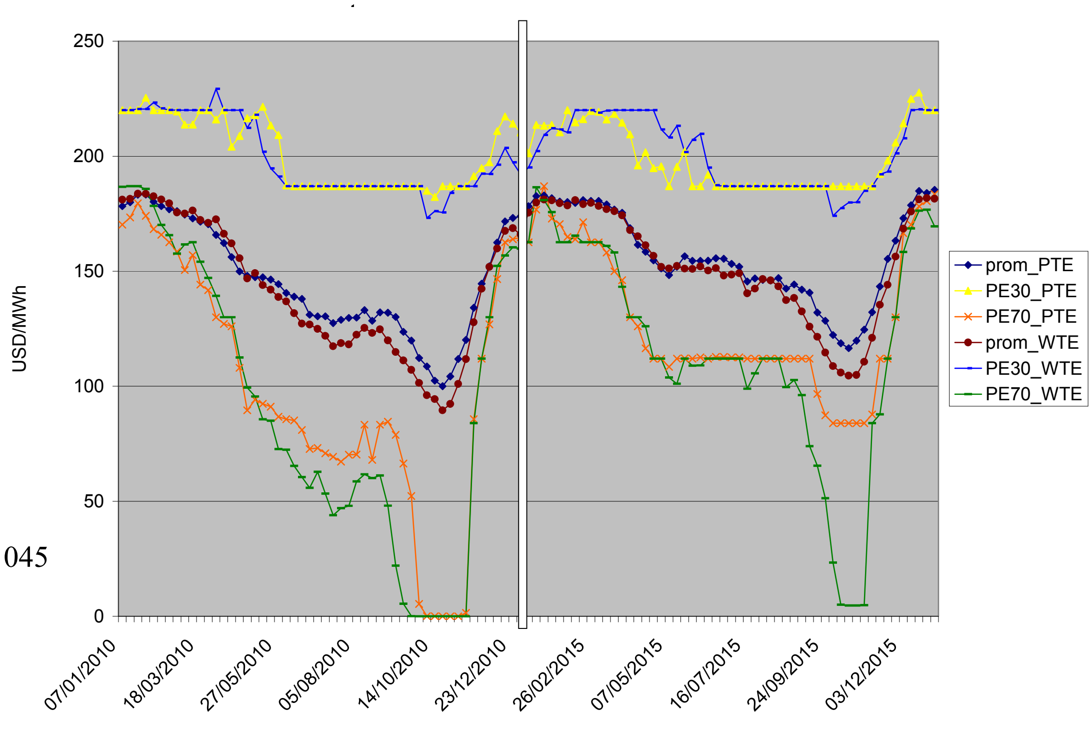
| | | 72.4 | 74.1 | 75.4 | 76.6 | 77.6 | 78.6 | 79.4 | 80.2 | 81.0 |
|---|---|---|---|---|---|---|---|---|---|---|
| PTE | DIC-FEB | 223 | 181 | 158 | 143 | 128 | 114 | 97 | 69 | 6 |
| WTE | DIC-FEB | 237 | 189 | 163 | 144 | 128 | 112 | 94 | 65 | 0 |
| PTE | MAR-ABR | 104 | 92 | 79 | 66 | 54 | 41 | 28 | 14 | 5 |
| WTE | MAR-ABR | 111 | 92 | 76 | 62 | 48 | 35 | 22 | 8 | 0 |
| PTE | MAY-SEP | 112 | 91 | 72 | 54 | 37 | 22 | 11 | 5 | 4 |
| WTE | MAY-SEP | 106 | 85 | 66 | 48 | 32 | 17 | 6 | 0 | 0 |
| PTE | OCT | 254 | 209 | 178 | 150 | 119 | 83 | 45 | 13 | 7 |
| WTE | OCT | 238 | 200 | 172 | 145 | 114 | 78 | 38 | 6 | 0 |
| PTE | NOV | 303 | 237 | 201 | 181 | 162 | 139 | 106 | 51 | 6 |
| WTE | NOV | 293 | 233 | 200 | 179 | 160 | 137 | 103 | 47 | 0 |

períodos del año y para las distintas cotas del lago ( de 72.4 a 81m ) respecto del nivel del mar. Los valores de la tabla 7 corresponden a una condición hidrológica media.

La conclusión es que no hay un cambio significativo en la política de operación del embalse por consecuencia de las granjas eólicas (por lo menos hasta los 400 MW instalados).

Igualmente, observa que en verano (DIC-FEB) con cotas bajas del lago (lo que

Fig. 6. Promedio semanal del precio



significa menos recursos disponibles), la política es un poco más conservadora con el agua en el caso WTE que en el caso PTE. Esto es razonable pues al ser baja la probabilidad de lluvias (por la época) y al tener el caso WTE parte de la expansión del sistema con generadores eólicos, el optimizador que calcula la politica de operación ve riesgoso quedar con poca agua en el embalse que no le permita responder con la central hidráulica en caso de rotura de alguna de las centrales térmicas del sistema. En el caso PTE al haber más centrales térmicas, la rotura de una máquina puede ser cubierta por otra térmica con mayor facilidad. Para cotas altas del lago, se observa que en general el valor del agua en el caso WTE es inferior al caso PTE (unos 5 USD/MWh). Esto es razonable dado que al usar el lago como filtro de las eólicas, si hay mucho viento, habrá que disminuir la generación hidráulica aumentando el riesgo de vertimiento y por lo tanto el optimizador prefiere ser menos conservador con el agua para cotas altas del lago, disminuyendo así el riesgo de vertimiento.

Cambios en el Precio Spot del mercado mayorista.

En Uruguay el precio spot del mercado mayorista es igual al costo marginal de generación de corto plazo con un tope de 250 USD/MWh.

La fig. 6 muestra el promedio semanal del precio spot para el año 2010 y 2015 en valor esperado (curvas etiquetadas “prom”) y para probabilidades de excedencia 30 y 70% en los dos casos estudiados. Se muestran solamente los años 2010 y 2015 pues en los años intermedios el comportamiento es similar. En reglas generales, vemos que la generación con eólica (caso WTE) implica unos precios levemente inferiores al del caso PTE. La diferencia máxima se produce en el mes de octubre que es cuando los precios son menores (por la abundancia de agua en las represas) y es de aproximadamente 10 USD/MWh.

Conclusiones y futuros trabajos.

Del estudio realizado se desprende que desde el punto de vista energético, sin ir al detalle de las posibles restricciones que podría imponer la red eléctrica, el sistema uruguayo puede integrar sin problemas 400 MW de energía eólica.

Antes de analizar las posibles restricciones de la red eléctrica cabría hacer un análisis similar al realizado pero considerando un paso de tiempo de simulación horario (en lugar de semanal) y considerando todos los embalses del sistema. Seguramente este estudio llevará a aumentar la capacidad e incorporación de energía eólica al sistema dado que se aumentará la capacidad de “filtrado” de la variabilidad eólica.

Referencias.

[1] Sitio del Simulador de Sistemas de Energía Eléctrica SimSEE http://iie.fing.edu.uy/simsee.

[2] Ruben. Chaer y Raúl Zeballos, Modelo Simplificado de Central con Embalse con fines didácticos. IEEE LATIN AMERICA TRANSACTIONS, VOL. 4, NO. 3, MAY 2006.

[3] Ventura Nunes, José Cataldo, Pablo Santero, Alejandro Gutierrez. 2009. *Despacho de parques eólicos: primeros avances sobre predicción de corta duración*, Encuentro de Potencia Instrumentación y Medidas IEEE-URUGAY 2008.

# 64. The feasibility of wind power face other alternative sources of energy in Brazil

**Edilaine Venancio Camillo**

Department of Technological and Scientific Policy – Geoscience Institute – UNICAMP – edilaine@ige.unicamp.br

*André Tosi Furtado* - Department of Technological and Scientific Policy – Geoscience Institute – UNICAMP – furtado@ige.unicamp.br

Address: Rua Pandiá Calógeras, 51 – Cidade Universitária – Campinas – SP-Brazil – CEP 13083-870 - Fone: 55 19 3521 5124/Fax: 55 19 3521 4555

Key words: alternative sources, wind power, incentives

Abstract : The main objective of this paper is to analyze the feasibility of the wind power in Brazil, under the economic perspective as well as the technology development and diffusion, comparing with the other alternatives sources for electricity generation, specifically biomass and small hydroelectric. These sources were encompassed PROINFA – Incentive Program for Alternative Electric Generation Sources, settled in March 2004. This work is part of a broader research which aims to answer if the implementation of mechanisms of market creation is the more suitable way for the expansion of wind energy in countries like Brazil, which have no tradition in the wind technology.

Despite the great potential, the alternative sources in Brazil have always been associated to programs of electrification of distant communities. The main institutional initiative is the PROINFA, which main to increase the participation of the alternative sources – wind energy, small hydroelectric and biomass – in the energy generated autonomous independent produce. The Program was composed by two stages and the system initially chosen to guarantee market stability is the feed-in: a price (based on the economic value of each source) is fixed and the buy of the energy is guaranteed through long term contract. PROINFA also brings other specific determinations like the claim for a level of nationalization of the equipments and services (60% in the first phase).

About the wind energy, as a result of the first phase of PROINFA only 17 of the 54 authorized projects (1.423 MW that should be installed until the end of 2006) are operating. There are 5 MW of wind energy authorized by ANEEL, but nowadays the country counts only with 272 MW of wind power installed capacity which means only 0,27% of the total electricity installed capacity of Brazil.

The execution of the PROINFA was compromised due to the changes in the regulations of the electric sector in 2003 focusing new priorities (as the guarantee of a minor tariff). The feed-in system was replaced for the bidding systems which do not favor the more expensive renewable energies as emphasizing the studies about policies for promoting alternative sources. In Brazil, the wind energy competes with small hydroelectric and biomass, both at a more competitive stage and lower costs. It was proved at the first renewable bidding (in June 2007) when it was commercialized 638,64 MW of electricity from biomass and small hydroelectric and any quota of wind energy. The medium price of hydro power reached € 55,00/MW/h and the contracts of biomass were traded to € 55,00/MW/h in such bidding. It worth be observing the economic values for wind energy in the first phase of PROINFA were between € 80,83 and € 91,67 o MW/h. The price was one of the main reasons for the lack of interest of the turbine manufacturers to install their facilities in the country – the price was considered unattractive – and consequently one of the main obstacle for reaching the PROINFA wind power goals, considering Brazil does not have any tradition in the development of wind power technology and there is not a local industry of turbines.

Authors' CV

*Edilaine Venancio Camillo* graduated in Economy by Paulista State University-UNESP-Brazil in 2002 and has been Master in Scientific and Technological Policy by the State University of Campinas-UNICAMP-Brasil since 2005; had a scholarship as researcher of Technological and Industrial Development from CNPq for 2 years (2006-2008); nowadays is PhD student at Department of Scientific and Technological Policy – Geoscience Institute – UNICAMP – Brazil and works as researcher in three research projects focused on evaluation of research programs of energy sector and attraction of foreign direct investments.

*André Tosi Furtado* concluded the PhD in Economy at Universite de Paris I (Pantheon-Sorbonne) in 1983. Nowadays is Professor at State University of Campinas – UNICAMP – BRAZIL; has published 55 papers in specialized periodicals and 74 articles in conferences' memories; has 15 chapters of books and 1 published book; has supervised 15 master dissertation and 5 PhD theses; has received 2 awards and/or honor; has interacted with 65 collaborators as co-author of scientific works; his research activities are focused on the follow fields: evaluation of large technological programs; oil industry (PETROBRAS); supplier of oil industry;  Economy of innovation

# 65. Feasibility Study for the Implementation of an Aeolian Power Station for the Universidad Técnica Particular de Loga (U.T.P.L.)

**Patricio Alejandro Orellana Arévalo, César Cristian Carrión Aguirre**

djporellana@gmail.com cesarcristianc@gmail.com

Ing. Raúl Castro / Thesis Director

jrcastro@utpl.edu.ec

(593-7) 2570275 ext. 2656

GESE, Universidad Técnica Particular de Loja

Loja – Loja – Ecuador

Patricio Alejandro Orellana Arévalo

djporellana@gmail.com

(593) 98428473

Universidad Técnica Particular de Loja

Loja – Loja – Ecuador

## ABSTRACT

At present the production of alternative energies is becoming an innovating option to produce electricity in clean form. Our project is focused to the feasibility study for the installation of aerogenerators, where the energy produced by the same will supply in partial form the electrical needs of The Universidad Técnica Particular de Loja. The study involves vital subjects like analysis of environmental impact, analysis of wind speed, technical characteristics of the load and costs of the aerogenerators and their parts.

The meteorological analyses that have been done for to determine the temperature, air density, speed and wind direction, in addition to analyze the Aeolian potential of the zone of interest. The place where it will implement east project after his study and acceptance is in the facilities of the U.T.P.L. in the city of Loja, Ecuador.

## GENERAL MISSION

To determine feasibility for the implementation of aerogenerators, which are destined to satisfy in partial form the electrical demand of The Universidad Técnica Particular de Loja and thus to be able to reduce the expenses by power consumption.

## SPECIFIC OBJECTIVES

To equip with a complete study of the environmental impact in the construction area.

To make a detailed study of the characteristics, costs and installation of the different types from aerogenerators, and to determine most suitable for the project.

To determine the Aeolian potential in the zone of implementation, through a study of resource of the wind, taking into account parameters like the temperature, air density, speed and wind direction.

To resist margins of investment with determining aspects like reaction time and recovery of the investment.

METHODOLOGY

The organization of the project makes reference to the following stages of development:

Study of the Aeolian potential in the zone of implementation (sampling of the temperature, relative humidity, speed and wind direction).

To determine the feasibility of the project based on the Aeolian production of the zone, the economic investment and the specific electrical demand within that area of the University.

INSTALLATION PLACE.

The appropriate place but for the installation of the power station of Aeolian energy in The Universidad Técnica Particular de Loja is located in the high part but from the campus to 03°59'11" of South latitude and 79°11'47" of West longitude to a height of 2144 meters on the level of the sea.

*Figure 1 Installation Place*[215]*.*

[215] **Google Earth,** *Imagen Satelital de la Ciudad de Loja*, [en línea], 2008, [citado 02–10–2008].


WIND SPEED AVERAGE IN LOJA.

The wind currents that cross the of Loja city, derived from the great Front of the East or Trade winds, undergo local modifications mainly, due to the action of the relief, but they conserve in general terms some of the common characteristics of the Regional Component, mainly as far as direction and humidity.

The local relief lessens the wind force and contributes to turn aside towards the North the predominant direction of high trade winds.

These antecedents allow us to emphasize the following thing:

The annual average of the wind speed in the Loja valley is of 2.983 m/s.

During the months of June, July and August, the greater wind force is registered, with maximum majors between 9 and 10 meters per second (m/s) in July and August. But generally, the wind speed stays stable acceptably around 40% of the time.

In the Loja valley the winds of North direction, Northeast and East, formed by the hydrographic opening of the Zamora River predominate towards the Amazonia. Fact that also contributes to that the winds with smaller frequency has western southern and south directions.

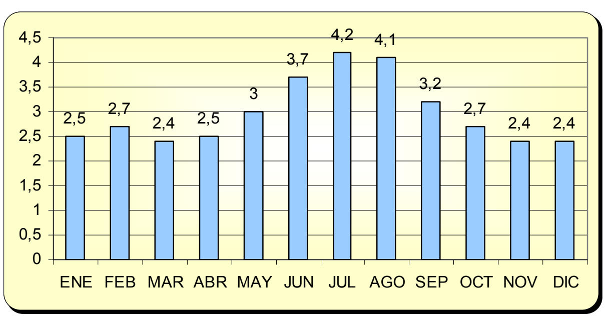
*Table 1 Average* Speed of the Wind in Loja (Period 1964-2004).

| Especif | ENE | FEB | MAR | ABR | MAY | JUN |
|---|---|---|---|---|---|---|
| MEDIA | 2,5 | 2,7 | 2,4 | 2,5 | 3 | 3,7 |
| MAX | 5,3 | 4,4 | 4,7 | 5,8 | 6,2 | 8,1 |
| MIN | 1,2 | 1 | 1,1 | 0,6 | 1,3 | 1,6 |

| Especif | JUL | AGO | SEP | OCT | NOV | DIC | MEDIA |
|---|---|---|---|---|---|---|---|
| MEDIA | 4,2 | 4,1 | 3,2 | 2,7 | 2,4 | 2,4 | 2,98 |
| MAX | 10 | 9,4 | 6,5 | 5,4 | 4,1 | 5,2 | 6,26 |
| MIN | 1,6 | 1,3 | 0,9 | 1,1 | 0,9 | 0,8 | 1,12 |

These data were provided by the provincial advice and the I. Municipality of Loja that counts on measurements from 1964. As we can observe in table 1 the months that register a smaller average speed of the wind are: March, November and December, however those that present/display a greater average speed of the wind are: June, Julio and August. These data are vitally important, since they allow us to make projections in other points of the city, and thus to be able to calculate their Aeolian potential.

*Figure 2 Average speed of the Wind in Loja*[216].

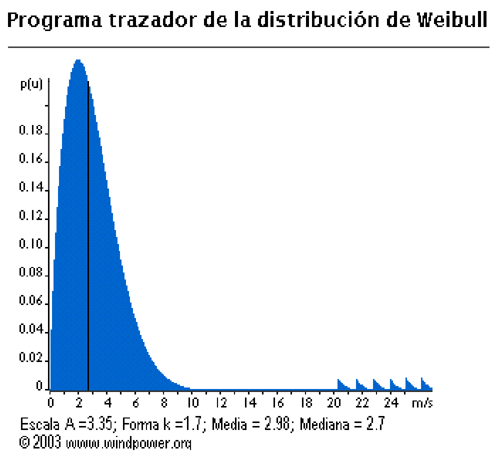



[216] **Mario Jaramillo,** *Perspectivas del Medio Ambiente Urbano – Geo Loja*, [en línea], Publicado por el Programa de las Naciones Unidas para el Medio Ambiente, Oficina para América Latina y el Caribe, la Municipalidad de Loja y Naturaleza y Cultura Internacional, 2007, [citado 02–10–2008], Formato pdf, Disponible en Internet: http://www.municipiodeloja.gov.ec

Elaborado por los Autores.

THE DISTRIBUTION OF WEIBULL IN LOJA.

*Figure 3 Distribution of Weibull in Loja*[217].




For the accomplishment of these calculations the software online proposed by the Danish Wind Industry Association proposed for the accomplishment of studies of Aeolian Energy was used.

Figure 3 shows a probability distribution, where the area under the curve always is worth exactly 1, since the probability that the wind blows to anyone of the speeds, including the zero, must be of the 100 percent.

Half of the blue area is to the left of the vertical black line to 2.7 meters per second. The 2.7 m/s are the median of the distribution. This means that half of the time the wind will blow to 2.7 less than m/s and the other half will blow more than 2.7 m/s.

As we can observe, the distribution of the wind speeds is not symmetrical. Sometimes it will have very high speeds of wind, but they are very rare.

---

[217] **Jan Serup Hylleberg, Jakob Lau Holst,** *Programa Trazador de la Distribución de Weibull*, [en línea], Copenhagen V, Denmark, Danish Wind Industry Association, 2000, [citado 02–10–2008], Formato html, Disponible en Internet:
http://www.windpower.org/es/tour/wres/weibull/index.htm
Elaborado por los Autores.

VARIATION OF THE WIND SPEED IN PARTICULAR THE TECHNICAL UNIVERSITY OF LOJA.

*Figure 4 Panoramic View of the Loja City*[218].


*Table 2 Location of the U.T.P.*

| PLACE | LOCATION IN UTM COORDINATES | |
|---|---|---|
| | LATITUDE | LENGTH |
| Particular Technical of Loja University | 03º 59' 11'' SUR | 79º 11' 47'' OESTE |
| Nacional of Loja University | 04º 02' 15'' SUR | 79º 12' 12'' OESTE |

ESTIMATION OF THE AVERAGE SPEED IN THE U.T.P.L.

*Table 3 Estimation of the Average Speed of the Wind in the U.T.P.L. (Period 1964-2004).*

| Especif | ENE | FEB | MAR | ABR | MAY | JUN |
|---|---|---|---|---|---|---|

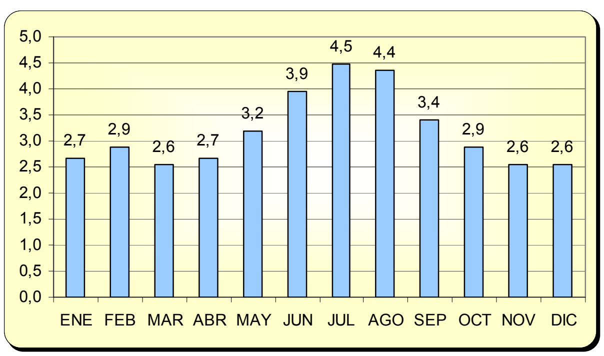
[218] **Google Earth,** *Imagen Satelital de la Ciudad de Loja*, [en línea], 2008, [citado 02–10–2008].

| | | | | | | |
|---|---|---|---|---|---|---|
| MEDIA | 2,7 | 2,9 | 2,6 | 2,7 | 3,2 | 3,9 |
| MAX | 5,6 | 4,7 | 5,0 | 6,2 | 6,6 | 8,6 |
| MIN | 1,3 | 1,1 | 1,2 | 0,6 | 1,4 | 1,7 |

| Especif | JUL | AGO | SEP | OCT | NOV | DIC | MEDIA |
|---|---|---|---|---|---|---|---|
| MEDIA | 4,5 | 4,4 | 3,4 | 2,9 | 2,6 | 2,6 | 3,18 |
| MAX | 10,7 | 10,0 | 6,9 | 5,8 | 4,4 | 5,5 | 6,67 |
| MIN | 1,7 | 1,4 | 1,0 | 1,2 | 1,0 | 0,9 | 1,19 |

As we can observe in table 3 the months in which a smaller average speed of the wind would take place are: March, November and December, however those that would present/display a greater average speed of the wind are: June, Julio and August. These data are vitally important, since they allow us to make approaches of the Aeolian potential in that location.

*Figure 5 Estimation of the Average Speed in the U.T.P.L*



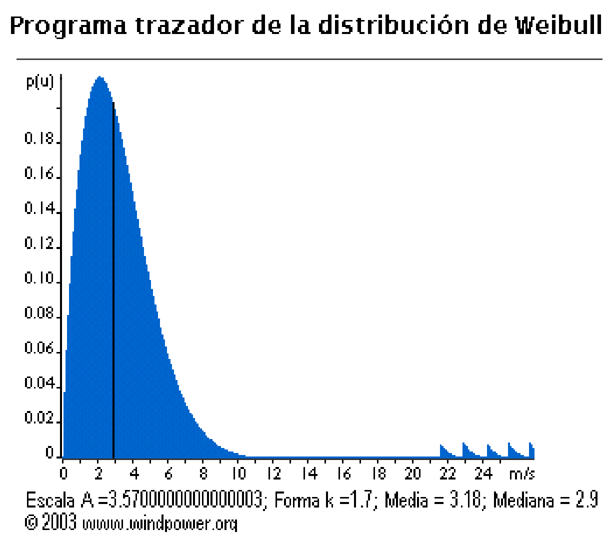

ESTIMATION OF THE DISTRIBUTION OF WEIBULL IN THE U.T.P.L.

When measuring the wind speeds throughout a year will be observed that the strong winds are not very frequent, whereas the fresh and moderate winds are quite common.

Figure 6 sample that half of the blue area is to the left of the vertical black line to 2.9 meters per second. The 2.9 m/s are the median of the distribution. This means that half of the time the wind will blow to 2.9 less than m/s and the other half will blow more than 2.9 m/s.

As we can observe, the distribution of the wind speeds is not symmetrical. Sometimes it will have very high speeds of wind, but they are very rare.

*Figure 6 Estimation of the Distribution of Weibull in the U.T.P.L.*[219]




DESCRIPTION OF THE PROJECT

The idea of this project responds to the necessity to obtain electrical energy cleaning and of low cost, which will supply specific areas of the University as

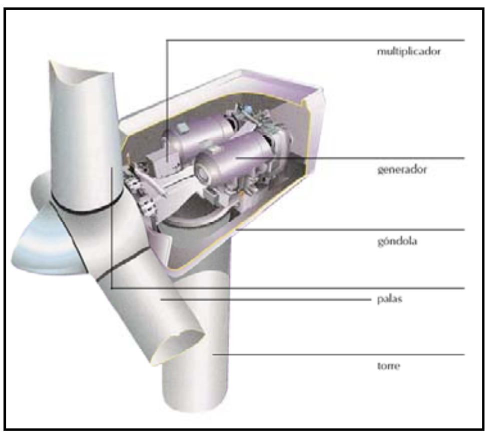
[219] **Jan Serup Hylleberg, Jakob Lau Holst,** *Programa Trazador de la Distribución de Weibull*, [en línea], Copenhagen V, Denmark, Danish Wind Industry Association, 2000, [citado 02–10–2008], Formato html, Disponible en Internet: http://www.windpower.org/es/tour/wres/weibull/index.htm
Elaborado por los Autores.

they are classrooms and outer illumination, where the electrical demand is relatively low.

This project is of great importance because it supplies an increasing demand of electrical energy in the campus of the University, being useful an inexhaustible source as it is the wind, which implies an ecological generation, economic and inexhaustible.

The implementation of Aeolian aerogenerators of median has set out power in the selected zone, the same that are destined to partially equip the energy consumed by the University and of this form to obtain benefits, economics as much environmental.

*Figure 7 Parts of the Aerogenerator*[220].




In figure 7 the same are described to the parts of an aerogenerator that are fundamental for the energy generation.

[220] **Jan Serup Hylleberg, Jakob Lau Holst,** *PicturesIndustry*, [en línea], Copenhagen V, Denmark, Danish Wind Industry Association, 2000, [citado 02–10–2008], Formato html, Disponible en Internet: http://www.windpower.org/en/pictures.htm

*Figure 8 Scheme of Installation[221].*

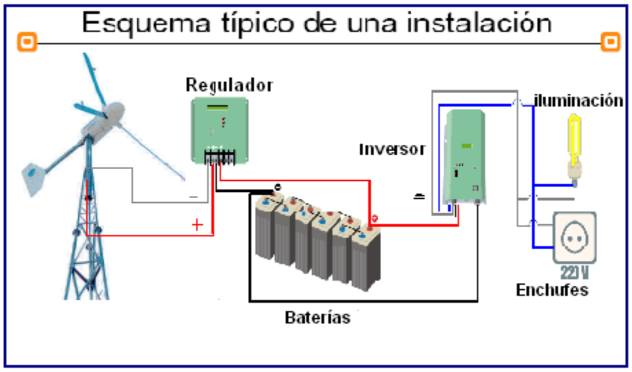



Figure 8 indicates the generation principle and distribution of Aeolian energy, the project is based on this type of configuration using like main element the aerogenerator, where its main function is to transform the kinetic energy of the wind into electrical energy of DC which happens to a voltage regulator stops of this form to eliminate the tips and to maintain it stable in a level of suitable DC. This energy is stored in a bank of batteries to be able to make use of her we need when it.

Next the DC happens to an investor or converter called thus so that it transforms the stored DC in the bank of batteries in AC voltage and elevates it at levels 110 or 220 V. to feed loads like pumps on water, electric home appliances and illumination, etc.

SUGGESTION

Another alternative is the use of a hybrid system (fig 9); that is to say, photovoltaic and Aeolian generation which is but efficient and stable, tells on the advantage that when not existing wind the energy of the sun can be used to load the bank of batteries.

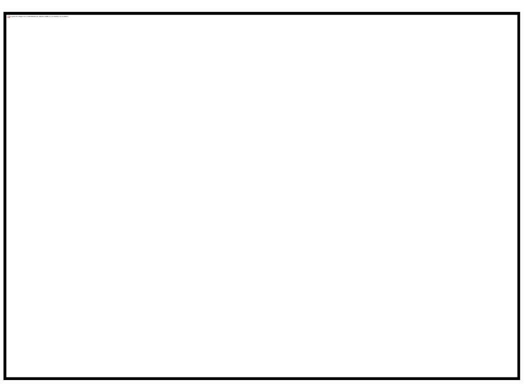
---

[221] **Jan Serup Hylleberg, Jakob Lau Holst,** *PicturesIndustry*, [en línea], Copenhagen V, Denmark, Danish Wind Industry Association, 2000, [citado 02–10–2008], Formato html, Disponible en Internet: http://www.windpower.org/en/pictures.htm

*Figure 9 Hybrid system of Energy[222].*

Next in figure 10 the block diagram is indicated that describes all the stages of a hybrid system:

*Figure 10 Block diagram of a Hybrid System of Energy[223].*



[222] **Eozen,** *Bujes*, [en línea], Asociación de Promotores y Productores de Energía Eólica de Andalucia, 1999, [citado 02–10–2008], Formato html, Disponible en Internet: http://www.eozen.es/esp/sitemap.htm
[223] **Eozen,** *Diseño Tecnológico*, [en línea], Asociación de Promotores y Productores de Energía Eólica de Andalucia, 1999, [citado 02–10–2008], Formato html, Disponible en Internet: http://www.eozen.es/esp/sitemap.htm

MATERIALS:

Regulators

*Figure 11 Regulators*[224]*.*

Shippers of batteries

*Figure 12 Shippers of bateries*[225]*.*

Investors

[224] **Eozen,** *Reguladores*, [en línea], Asociación de Promotores y Productores de Energía Eólica de Andalucia, 1999, [citado 02–10–2008], Formato html, Disponible en Internet: http://www.eozen.es/esp/sitemap.htm

[225] **Eozen,** *Cargadores de Baterías*, [en línea], Asociación de Promotores y Productores de Energía Eólica de Andalucia, 1999, [citado 02–10–2008], Formato html, Disponible en Internet: http://www.eozen.es/esp/sitemap.htm

*Figure 13 Investors*[226]*.*

Towers

*Figure 14 Towers*[227]*.*

RESULTS

[226] **Eozen,** *Inversores*, [en línea], Asociación de Promotores y Productores de Energía Eólica de Andalucia, 1999, [citado 02–10–2008], Formato html, Disponible en Internet: http://www.eozen.es/esp/sitemap.htm

[227] **Eozen,** *Torres*, [en línea], Asociación de Promotores y Productores de Energía Eólica de Andalucia, 1999, [citado 02–10–2008], Formato html, Disponible en Internet: http://www.eozen.es/esp/sitemap.htm

## Social Impact

The development of the project will drive a new model of electrical generation in the Loja city, its process takes advantage of the limitless potential the wind, the University also will see beneficiary of the same because their expenses by concept of electrical consumption will be reduced and it would consolidate like the first University of the region in incorporating a system of these characteristics.

## Economic Impact

The yield that produces east project this based on the life utility of the aerogenerators, which have a guarantee of 5 years by manufacture defects, but its operation with a suitable maintenance will extend of 20 to 25 years, generating a very considerable saving during this time, since there will be no important expenses by concept of electrical consumption of lights to the electrical company.

## Environmental Impact

This type of generation systems does not affect the environment, are efficient equipment and of very low noise levels which benefits the existing fauna in the area.

## CONCLUSIONS

The Aeolian potential in the region is favorable for the implementation of a Aeolian system of generation by means of aerogenerators

The project is profitable, since the source energy is limitless making the investment in the purchase of the aerogenerator and its parts.

The environmental impact is much reduced because the median aerogenerators power has low noise level; therefore its electrical generation is ecological.

It is contributed to the development of the operation of the Aeolian energy in Ecuador, like alternative electrical power plant and without contamination.

It is considerably reduced the expenses of electrical consumption in The Universidad Técnica Particular de Loja, and allows an economic saving that can be used for other productive aims.

## RECOMMENDATIONS

It is suggested to extend the capacity of the Aeolian system to cover areas as plants with production, offices and the centers of development like the U.P.S.I., U.C.G., laboratories, etc.

A recommendation to increase the efficiency of the electrical generation is the one to use a hybrid system, which would compensate the lacking originating energy of the wind with solar energy.

## APPENDIX

### Applications

Hybrid Systems:

The Aeolian resource is variable and can have periods of calm. The solar energy is a perfect complement to the Aeolian energy insofar as it offers a basic load in these periods. These systems are common in commercial applications or residential applications.

*Figure 15 Installed Systems*[228]*.*

*Figure 16  Installed Systems*[229]*.*

[228] **Jan Serup Hylleberg, Jakob Lau Holst,** *Manual de Referencia*, [en línea], Copenhagen V, Denmark, Danish Wind Industry Association, 2000, [citado 02–10–2008], Formato html, Disponible en Internet: http://www.windpower.org/es/stat/unitsw.htm#calc

[229] **Jan Serup Hylleberg, Jakob Lau Holst,** *Manual de Referencia*, [en línea], Copenhagen V, Denmark, Danish Wind Industry Association, 2000, [citado 02–10–2008], Formato html, Disponible en Internet: http://www.windpower.org/es/stat/unitsw.htm#calc

Aeolian Cooling Systems

Figure 17 Cooling Sistems[230].

At the moment or this implementing system of cold quarters with the help of the Aeolian energy, the same that gives very beneficial advantages as far as costs and Infrastructure, many uses a bank of batteries to stabilize the energy but the principle is the same in the first place gets up a PLC or a MINIPLC for the control, which feeds an air compressor and finally coolant whose function is the one to drastically descend the temperature from the pressurized air.

Domestic applications

The Aeolian energy also is used in the homes, generally in rural places or difficult, the same that allow enjoying the benefits of the electric home appliances like in any place hydroelectric feeding.

[230] **Jan Serup Hylleberg, Jakob Lau Holst,** *Manual de Referencia*, [en línea], Copenhagen V, Denmark, Danish Wind Industry Association, 2000, [citado 02–10–2008], Formato html, Disponible en Internet: http://www.windpower.org/es/stat/unitsw.htm#calc

The Aeolian generators transform the energy of the wind into direct current to 12 or 24 volts DC and are connected directly to the bank of batteries.

It owns a sophisticated electronic controller of voltage that permanently watches the state of load of the batteries, maintains a rigorous control on its speed of turn and compensates the losses of tension in the line of conduction.

Figure 18 *Installed Systems*[231].

*Table 3 Table of the Power Produced based on the Average Speed of the Wind*[232].

| Wind speed average (mph) | Description | Considered in KWH/month | Considered in KWH/day |
|---|---|---|---|
| 8 | Intermittent smooth breeze | 60 | 2.0 |
| 9 | Smooth and | 90 | 3.0 |

[231] **Jan Serup Hylleberg, Jakob Lau Holst,** *Manual de Referencia*, [en línea], Copenhagen V, Denmark, Danish Wind Industry Association, 2000, [citado 02–10–2008], Formato html, Disponible en Internet: http://www.windpower.org/es/stat/unitsw.htm#calc

[232] **Pinilla Álvaro,** *Manual de Aplicación de la Energía Eólica*, Instituto de Ciencias Nucleares y Energías Alternativas Universidad de los Andes, Library Association, 1997.

| | | | |
|---|---|---|---|
| | constant breeze | | |
| 10 | Intermittent moderate breeze | 125 | 4.2 |
| 11 | Constant moderate breeze | 160 | 5.3 |
| 12 | Moderate breeze to intermittent fort | 190 | 6.3 |
| 13 | Moderate breeze to strong constant | 215 | 7.2 |
| 14 | Strong breeze | 265 | 8.8 |

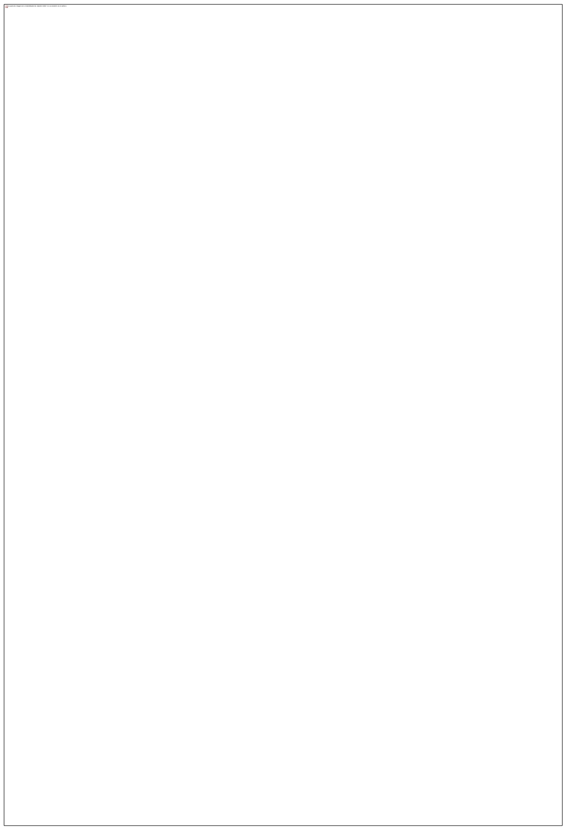
Aeolian energy to pump water

Wind energy to pump water the wind is often used as a source of energy to operate water pumps and provide water for livestock. Due to the large amount of water needed for crops, wind energy can be used for this purpose.

*Figure 19 Installed Systems* [233].

---

[233] **Jan Serup Hylleberg, Jakob Lau Holst,** *Manual de Referencia*, [en línea], Copenhagen V, Denmark, Danish Wind Industry Association, 2000, [citado 02–10–2008], Formato html, Disponible en Internet: http://www.windpower.org/es/stat/unitsw.htm#calc



REFERENCES

[1] Pedro Fernández, Iván Fernández, *Tipos de Aerogeneradores*, [en línea], Santander-España, Departamento de Ingeniería Eléctrica y energética – Universidad de Cantabria, 2002, [citado 02–10–2008], Formato pdf, Disponible en Internet: http://libros.redsauce.net/EnergiasAlternativas/eolica/index.html

[2] Jan Serup Hylleberg, Jakob Lau Holst, *Generadores Asíncronos*, [en línea], Copenhagen V, Denmark, Danish Wind Industry Association, 2000, [citado 02–10–2008], Formato html, Disponible en Internet: http://www.windpower.org/es/tour/wtrb/indirect.htm

[3] Eozen, *Diseño Tecnológico*, [en línea], Asociación de Promotores y Productores de Energía Eólica de Andalucia, 1999, [citado 02–10–2008], Formato html, Disponible en Internet: http://www.eozen.es/esp/sitemap.htm

[4] Weather Buffs, *Estaciones Meteorológicas*, [en línea], Pro Wireless Home Digital Weather Station, California-USA, 2004, [citado 02–10–2008], Formato html, Disponible en Internet: http://www.weatherbuffs.com/

[5] Pinilla Álvaro, *Manual de Aplicación de la Energía Eólica*, Instituto de Ciencias Nucleares y Energías Alternativas Universidad de los Andes, Library Association, 1997.

# 66. Propuesta de una Herramienta Integrada para la toma de Decisiones de Plantas de Energía Eólica en la Región del Bío Bío

**Felipe Cattarinich Araya**

Universidad del Desarrollo

García Hurtado de Mendoza 481 Lomas de San Andrés Concepción.

Fono: (56) 041-2794059, e-mail: fcattarinicha@udd.cl

Key words: macro location, eolic, methodology.

Abstract:

The growth in global demand for energy has become necessary to generate new sources of sustainable energy in time. In Chile, the proposed alternatives are primarily renewable energy (RE). The RE has two classifications: "Conventional" (CRE), such as hydro and "Non Conventional" (NCRE), such as wind and solar among others. This work is focused on wind energy, specifically managing its macro location since the early starting up of wind farm's projects.

Problems like noise, size, visual impact, high cost in accessibility are typically associated to wind farms. This paper seeks to establish a methodology to select areas where these problems can be avoided or reduced, considering three ways to set a wind farm as: area's wind potential, its accessibility and the land's opportunity cost. These three methods are not sufficient by themselves alone; for instance, if only it's considered the wind in such area, there is a probability to incur in higher costs for accessing the wind towers' installation site, either because an additional investment building roads, or because of problems that

might mean transportation of heavy machinery required for the construction and installation.

The proposed methodology here mentioned, aims to standardize the conditions for selection in the counties of the Biobio Region, making possible to systemically compare them by prior accessibility, land's opportunity cost and prevailing winds. This will provide an extensible model for other regions of the country, because there were measurable or are available in good shape. The results should be considered as a reference guide and not as the final solution to the problem, due to the considered variables can change their values in short term, but not the way the model works.

Introducción.

Debido al aumento poblacional, desarrollo económico y crecimiento industrial, hoy en día el crecimiento de la demanda energética es una tendencia mundial, lo que conlleva la necesidad de generar energía en forma sustentable y en el tiempo. Peritos en el tema y grandes empresas del rubro sostienen que las energías convencionales no serán capaces de suplir las necesidades futuras. La evolución del entorno de las fuentes energéticas convencionales es cada día más complicado. Mientras cada día la demanda por energía aumenta, los problemas de contaminación, el calentamiento global y el impacto sobre la salud y futuro de las personas, son temas que toman más importancia.

El complejo contexto energético y sus efectos negativos - como la destrucción de suelos nativos y contaminación - crean numerosos conflictos con los grupos de interés. Afortunadamente, la existencia de fuentes energéticas no convencionales puede ser una solución que permita el crecimiento sustentable para la región y el país. Entre las alternativas energéticas que son de interés evaluar, se encuentran aquellas que no necesitan grandes transformaciones en su proceso productivo, como por ejemplo las proveniente de biomasa forestal, corrientes y mareas, combustible fósil, geotérmica, eólica y solar, entre otras. La energía creada por los vientos está disponible en región.

A nivel mundial, la selección de sitios para la instalación de los parques eólicos se ejecuta mediante tres modelos: a) costos de accesibilidad, b) potencial eólico del lugar, c) costo oportunidad de los suelos. Sin embargo, en Chile éstos no se usan, mas bien se selecciona previamente un sitio para luego evaluar el potencial eólico necesario para desarrollar un proyecto. Esa selección no considera los costos de accesibilidad, ni los asociados a imagen pública. Por otra parte, en el costo total de un parque eólico el valor de los equipos de generación es fijo, por tanto los costos que se pueden disminuir son los relacionados con el sitio, su acceso, la construcción, tendido y conectividad a la red, por nombrar algunos. Como éstos son los costos gestionables, utilizar una herramienta que considere la interacción entre ellos permitirá, en primera etapa, buscar la mejor combinación entre costos y rendimiento del parque, lo que se traduce en una importante reducción en costo de inversión de un proyecto tipo.

Para contextualizar este trabajo, es necesario decir que la energía eólica es producida por el desplazamiento de masas de aire de alta presión atmosférica hacia áreas adyacentes de baja presión, estos gradientes son el producto del calentamiento no uniforme de la superficie terrestre por medio de la radiación solar, transformando entre 1 y 2% de la energía en vientos, aproximadamente 20,5 $J/m^2$ irradiado, una cantidad considerable. La tecnología eólica no contamina y no agota el recurso viento, por lo que se considera una fuente de energía verde y renovable.

Aunque la operación de los generadores eólicos no produce residuos, la instalación de estas grandes estructuras, por normativa legal, requiere una evaluación de impacto ambiental, en una análisis técnico-científico, cuyo objetivo es la identificación, predicción y evaluación de los impactos (positivos o negativos) que pueden producir acciones de origen antrópico sobre el medio ambiente físico, biológico y humano.

Finalmente, se debe reconocer lo importante de diversificar la matriz energética de la región, puesto siendo una de las mayores productoras de energía eléctrica en Chile, debe buscar alternativas que, en el caso país, logren ser parte de la solución para resolver los problemas de suministro energético y reducir su dependencia de naciones vecinas. Para ello se propone un modelo sencillo, que trabaja con factores medibles y que en general son posibles de obtener.

Metodologías actuales.

En cuanto a metodologías actuales se pueden identificar tres modelos guías para localizar parques eólicos:

Localización según potencial eólico de la región.

Localización según impacto costo oportunidad del suelo.

Localización según costos de accesibilidad.

Como ya se nombró, la más utilizada está relacionada con el potencial eólico del sector donde se realizará el proyecto, lo que a veces implica dejar de lado algunas variables que pueden tener relevancia según la configuración del terreno, o en otros casos, la población residente.

Es importante aclarar que estas metodologías, así como la que se propone, deben utilizarse para parques de gran tamaño (sobre 200 MW), puesto que es en estos casos cuando los costos asociados son altos. Además, si se desea alcanzar un desarrollo energético mediante energía eólica importante, el tamaño de los parques deberá crecer, traduciéndose en turbinas más grandes, con mayores costos de transporte en el largo plazo.

Localización según potencial eólico de la región.

Este es el criterio más utilizado en el mundo, especialmente en Europa. Algunos autores sostienen en varias publicaciones[234] que este método demuestra ser eficaz en lugares donde se conoce el comportamiento del viento; esta característica encarece este método, puesto que muchos esfuerzos van dirigidos a determinar el patrón del viento de las regiones que se analizan. “Power & Energy Solutions”[235], una publicación Europea, sostiene que la eficacia del criterio es indiscutible en ese continente, puesto que las metas de producción de electricidad con aerogeneradores de países como Dinamarca y Alemania han sido alcanzadas y superadas en algunos casos.

Al considerar únicamente el potencial eólico, los costos de instalación así como el de la imagen pública se analizan una vez seleccionado el sitio, lo que significa que no hay una reducción de alternativas posibles según estos dos costos; esto elimina la posibilidad de reducirlos, debido a que deben asumirse una vez se pone en marcha el proyecto.

El criterio de localización es simple - estimar los lugares donde el viento posee mayores velocidades - combinando factores como la geografía y variabilidad del viento. Sin embargo, la metodología con que se identifican estos lugares

[234] Christian Kjaer, Jefe Ejecutivo de EWEA. 2002
[235] P&G Media Ltd, 2006.

puede variar según el investigador, puesto existen diferentes modelos que simulan vientos e intentan describir el comportamiento de éste. Aún así, es posible identificar una serie de pasos que la mayoría de estos modelos siguen.

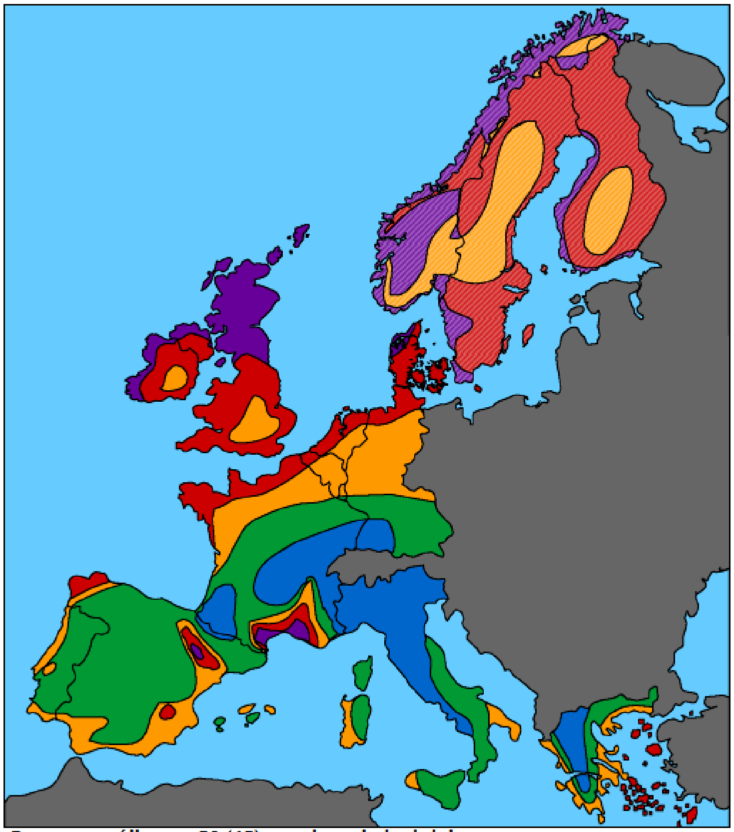
Algunos de estos modelos son desarrollados por empresas privadas o por los gobiernos de los países interesados, pero en general el desarrollo y análisis de éstos es el mismo.

El primer paso es recolectar datos de la zona de interés; estos datos pueden ser recientes o históricos. Lo importante de la toma de datos es considerar la altura en que se miden las velocidades y dirección del viento. Los datos se registran en tablas que indican: localización, fecha y hora, dirección, velocidad, entre otros.

Los datos obtenidos son analizados e introducidos en distintos modelos; un ejemplo de éstos es uno muy utilizado en Estados Unidos el Geografical Information System (GIS)[236]. Los resultados generalmente son presentados en mapas que mediante colores indican la velocidad del viento de la zona analizada. En la figura 1 se puede ver un ejemplo claro de esto.

Figura 30. Mapa eólico de Europa.

[236] ESRI; GIS and mapping Software,



**Recursos eólicos a 50 (45) m sobre el nivel del mar**

| Color | Terreno accidentado m/s | Terreno accidentado W/m² | Plano abierto m/s | Plano abierto W/m² | En la costa m/s | En la costa W/m² | Mar abierto m/s | Mar abierto W/m² | Colinas y crestas m/s | Colinas y crestas W/m² |
|---|---|---|---|---|---|---|---|---|---|---|
| | >6.0 | >250 | >7.5 | >500 | >8.5 | >700 | >9.0 | >800 | >11.5 | >1800 |
| | 5.0-6.0 | 150-250 | 6.5-7.5 | 300-500 | 7.0-8.5 | 400-700 | 8.0-9.0 | 600-800 | 10.0-11.5 | 1200-1800 |
| | 4.5-5.0 | 100-150 | 5.5-6.5 | 200-300 | 6.0-7.0 | 250-400 | 7.0-8.0 | 400-600 | 8.5-10.0 | 700-1200 |
| | 3.5-4.5 | 50-100 | 4.5-5.5 | 100-200 | 5.0-6.0 | 150-250 | 5.5-7.0 | 200-400 | 7.0-8.5 | 400-700 |
| | <3.5 | <50 | <4.5 | <100 | <5.0 | <150 | <5.5 | <200 | <7.0 | <400 |
| | | | >7.5 | | | | | | | |
| | | | 5.5-7.5 | | | | | | | |
| | | | <5.5 | | | | | | | |

Fuente: Risoe National Laboratory, 2006.

Localización según impacto costo oportunidad del suelo.

Este criterio es relativamente nuevo, puesto que las plantas antiguas no consideraban factores como el impacto en la comunidad al localizarse en ciertas zonas, por lo que fracasan desde el punto de vista del desempeño frente a la comunidad. El criterio es utilizado principalmente en regiones donde las personas tienen un alto nivel de incidencia en las decisiones de los organismos regionales que otorgan los permisos de instalación y edificación respectivos para este tipo de proyecto. Es así como el costo asociado al uso del suelo que las personas residentes de la zona perciben, incide en la decisión de instalación del parque. El criterio es abordado en "Parámetros Medioambientales de un Parque Eólico y Opinión Pública"[237]. En este texto exponen algunos de los aspectos y parámetros técnicos que deben considerarse en un proyecto eólico, del que se espera tener una buena imagen en el entorno público, así como cuáles son los aspectos más relevantes para localizar un parque en zonas de alta densidad de población.

Cuando se quiere considerar el costo de oportunidad del suelo, se debe analizar no solo la valorización económica de éste, sino que además el valor ambiental que posee inserto en su entorno; es por esto que es relevante considerar el valor económico ambiental que tal posee para una comunidad específica, lo que puede significar analizar varios costos que no necesariamente son fáciles de identificar, como es la "percepción" de los habitantes.

Las consideraciones a tomar van desde el valor de uso del suelo, así como el valor de "no uso", el patrimonio que significan y la opinión pública. Para ello la valoración ambiental económica consiste en un conjunto de técnicas y métodos que permiten medir las expectativas de beneficios y costos derivados de alguna de las siguientes acciones:

Uso de un activo ambiental: se refiere al uso específico que se le asigna a cualquier activo ambiental, desde zonas para explotación comercial, a lugares protegidos como parques nacionales y reservas silvestres. El uso determina qué tan valioso es el activo.

Realización de una mejora ambiental: los costos incurridos en mejoras ambientales pueden ser un punto de referencia para el valor de un activo, es decir, aquellos que posean costos mayores en mejoras, tienden a valorarse más.

Generación de un daño ambiental: dependiendo de la magnitud del daño generado, así como los aspectos ambientales pertinentes, pueden significar un

---

[237] Eolic Partners S.A. 2006. Oliver Wendling y asociados Francesc Roig y Xavier Amargant

costo enorme en relación a la solución que este puede requerir, por ello la generación debe monitorearse.

Es así como se concluye que la elección de las variables queda restringida exclusivamente al criterio del inversionista, quien decidirá qué costo prefiere ahorrar, o qué costo desea mantener controlado.

Localización según costos de accesibilidad[238].

Existe un enfoque que plantea que el principal factor para localizar una planta son los costos de inversión, específicamente los costos de instalación que incluyen accesos, transporte, cimientos, entre otros[239]. "Wind Power", empresa Danesa de parques eólicos sostiene que el potencial energético es importante, pero que un porcentaje significativo de estos proyectos fracasa debido a lo complicado que es el acceso al emplazamiento final.

En un proyecto típico, los costos de instalación incluyen las fundaciones, la mano de obra y el costo de construcción de carreteras. Este último puede representar un incremento importante en la inversión, puesto que de no ser analizado correctamente puede llegar a ser muy elevado.

Este costo es variable, puesto depende exclusivamente de las condiciones del suelo, la disposición del terreno y la distancia que se desea cubrir. Lo importante es considerar que se han de transportar camiones que en promedio pesan 30 toneladas, por lo que es indispensable tener en consideración esta variable. Como se puede observar, el costo de accesibilidad puede desglosarse en varios costos, los que usualmente se incluyen en la inversión total del proyecto; ello no implica que no se pueda realizar una mejora en cuanto a la reducción de éstos.

---

[238] ***"Accesibilidad: facilidad con la que se puede alcanzar un cierto destino, desde otros puntos en el territorio (orígenes), por lo que sintetiza las oportunidades de contacto e interacción entre determinados orígenes y destinos"*** **Brian Goodall (1987).**

[239] Wind Power; "*Energy strategy 2025: well begun, but only half done", 2006.*

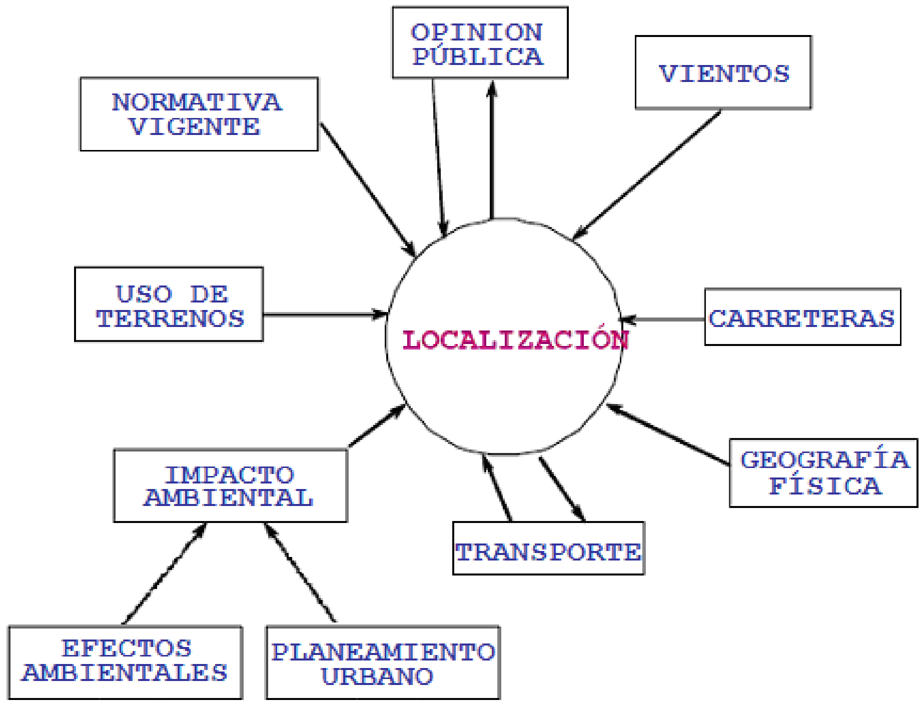
Al analizar la evolución de los costos de accesibilidad, primero hay que analizar cómo es que el término ha evolucionado en los últimos años. En un principio, la accesibilidad era la distancia que separaba a dos puntos distintos; esto daba a entender que como variable solo era una función de localización en el espacio, por lo que solo se consideraba como un indicador de distancia o de costo por viaje.

Posteriormente, se incorporó el enfoque de oportunidad que integraba la opción de las personas para participar de una actividad, considerando lo accesible que era ésta. Finalmente, se agregó al enfoque el valor que posee una zona determinada por poseer ciertas características de accesibilidad respecto de un origen, por lo que los costos no solo son aquellos que se incurren por viaje y transporte, sino que se agrega el costo oportunidad de la distancia recorrida.

Variables relevantes para la localización.

En general la macrolocalización de proyectos depende de factores que son conocidos. Estos son generales y aplicables a todo tipo de proyectos; sin embargo, los parques eólicos poseen ciertas variables que son distintas de un proyecto relacionado con sectores productivos. Es así como en el caso de los parques eólicos el análisis queda como se indica en la figura 2, que muestra solo los factores propios de un parque eólico, considerados ellos como los más relevantes:

Figura 31. Factores que definen la localización.




Fuente: Elaboración propia.

Lo siguiente es definir y explicar cómo se comportan estos factores y cómo es que influyen en la localización y determinar la relación que existe entre ellos, para construir un indicador final que reúna todos los aspectos señalados.

Vientos.

Para la industria eólica es muy importante tener la capacidad de describir la variación de las velocidades del viento. Los proyectistas de turbinas necesitan la información para optimizar el diseño de sus aerogeneradores, así como para minimizar los costos de generación. Los inversionistas necesitan la información para estimar sus ingresos por producción de electricidad. Los vientos que se deben considerar en el análisis son aquellos que no sobrepasan más allá de los 100 m de altura; estos son llamados “Vientos Superficiales”, dentro de los cuales se identifican las brisas marinas, vientos de montaña y otros.

Conocer cómo se comporta el viento es importante, puesto un aerogenerador obtiene su potencia de entrada convirtiendo la fuerza del viento en un par (fuerza de giro), actuando sobre las aspas del rotor. La cantidad de energía transferida al rotor por el viento depende de la densidad del aire, el área de barrido del rotor y la velocidad del viento. La energía cinética de un cuerpo en movimiento es proporcional a su masa; así, la energía cinética del viento depende de la densidad del aire, es decir, de su masa por unidad de volumen. En otras palabras, cuanto "más pesado" sea el aire más energía recibirá la turbina.

Un aerogenerador típico de 1.000 Kw. tiene un diámetro del rotor de 54 m., lo que supone un área del rotor de unos 2.300 $m^2$. El área del rotor determina cuánta energía del viento es capaz de capturar una turbina eólica. Dado que el área del rotor aumenta con el cuadrado del diámetro del rotor, una turbina que sea dos veces más grande recibirá 22= 2 x 2 = 4 veces más energía. La potencia del viento depende de 3 factores:

Área del rotor (A).

Densidad del aire (ρ).

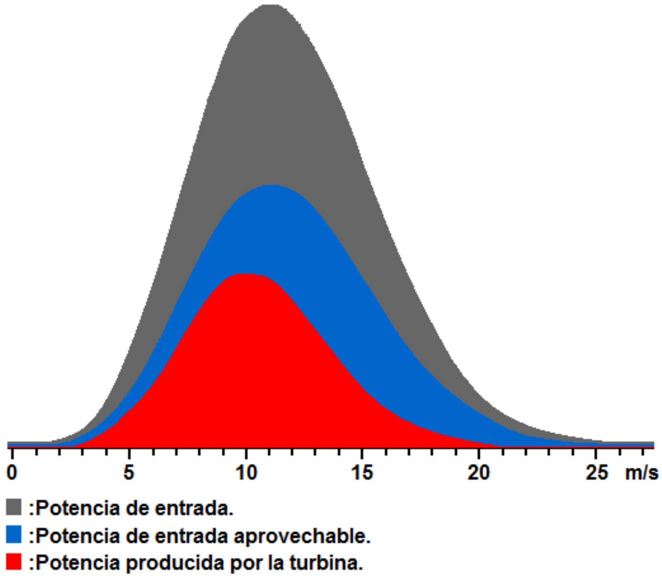
Velocidad del Viento (V).

Además, la expresión que expresa la potencia generada es:

$$P = \frac{1}{2}\rho A V^3 \qquad (1)$$

Respecto a la potencia que se puede transformar, el físico alemán Albert Betz formuló en 1919 la ley de Betz, la que demuestra que sólo puede convertirse menos del 16/27 (el 59 %) de la energía cinética en energía mecánica usando un aerogenerador. Esto lo publicó en su libro "Wind-Energie", en 1926. La conversión de energía puede graficarse en la siguiente figura:

Figura 32. Gráfico de Potencia según la ley de Betz.




Fuente: Windpower.

Geografía.

Se pueden identificar obstáculos que puede poseer el viento antes de que éste llegue a la turbina, como edificios, árboles, formaciones rocosas, entre otros; éstos pueden disminuir la velocidad del viento de forma significativa y a menudo crean turbulencias en torno a ellos.

La rugosidad también debe de ser tomada en cuenta, ya que en las capas más bajas de la atmósfera, las velocidades del viento se ven afectadas por la fricción con la superficie terrestre. En general, cuanto más pronunciada sea la rugosidad del terreno mayor será la ralentización que experimente el viento[240].

Los bosques y las grandes ciudades ralentizan mucho el viento, mientras que las pistas de hormigón de los aeropuertos lo ralentizan ligeramente. Las superficies de agua son incluso más lisas que las pistas de hormigón y, tendrán por tanto, menos influencia sobre el viento, mientras que la hierba alta y los arbustos ralentizan el viento de forma considerable.

---

[240] Helimax: *"Site prospecting"*, 2005.

Las superficies de mares y lagos se consideran muy lisas, por lo que la rugosidad de la superficie marina es muy baja (a velocidades de viento constantes). Con velocidades de viento crecientes, parte de la energía se emplea en producir oleaje, lo que implica un aumento de la rugosidad. Una vez se han formado las olas, la rugosidad decrece de nuevo. Por tanto, se tiene una superficie de rugosidad variable (lo mismo ocurre en zonas cubiertas con más o menos nieve). Sin embargo, si se generaliza, puede considerarse que la rugosidad de la superficie del agua es muy baja y que los obstáculos del viento son pocos.

Uso de terrenos y competencia.

La utilización de los suelos es a menudo un tema de discusión con respecto al desarrollo de plantas eólicas. La utilización de energía eólica para la generación eléctrica presenta nula incidencia sobre las características fisicoquímicas del suelo o su erosionabilidad, ya que no produce ningún contaminante que incida sobre este medio. Contrariamente a lo que ocurre con las energías convencionales, la generación de electricidad a partir del viento no origina productos secundarios peligrosos ni residuos contaminantes.

En grandes proyectos, las acciones que generan mayor impacto son las que se refieren a las obras viales, como vías de acceso, cunetas, edificaciones de control. Todas ellas causan alteraciones al suelo y a la cubierta vegetal y, en ocasiones, pequeñas modificaciones geomorfológicas por desmontes o aplanamientos. Pero en la mayoría de los casos de utilizan carreteras ya existentes.

Los parques eólicos no dejan de causar impactos que deben tenerse en cuenta para ser mitigados en la medida que sea posible. Uno de éstos es el deterioro del paisaje, provocando un impacto de tipo visual, ya que los emplazamientos con mayor fuerza del viento, donde suelen colocarse aerogeneradores, corresponden por lo general a entornos de baja densidad poblacional y, por tanto, con apreciados valores paisajísticos. Pero este es un impacto subjetivo, ya que dependerá de la apreciación de cada persona.

Opinión publica.

Una de las barreras más complejas para este tipo de proyecto es la opinión pública; ello se debe a que la aceptación de los proyectos depende mucho de la cultura, conocimientos respecto al proyecto, entre otros. Quizás el aspecto más importante a evaluar es la cultura que poseen las personas sobre lo que realmente es la energía eólica y qué saben sobre generadores eléctricos. Informes de otros países han mostrado que la ignorancia de las personas lleva a retrasos en la instalación e, incluso, en la puesta en marcha.

Considerar que la gente se preocupa del tamaño de las instalaciones, el ruido que esta pueden generar e incluso el movimiento que poseen ante vientos muy fuertes, causan repercusiones en el proyecto, puesto que la gente que se ve afectada por el solo hecho de una apreciación personal respecto al tema.

Relevancia del impacto ambiental.

Para este aspecto se debe cumplir con la legislación chilena, sobre todo aquello relacionado con el cuidado del medioambiente; para ello se debe considerar si acaso el proyecto completo o parcialmente tendrá que someterse al SEIA. La consideración de un SEIA está disponible en la publicación oficial del Ministerio Secretaría General de la Presidencia de la República de Chile, publicado el sábado 7 de Diciembre de 2002, en virtud del artículo 2° del Decreto Supremo N° 95/01, que modifica el reglamento del SEIA[241].

En este documento se identifican los siguientes artículos:

Articulo 3: Inciso B: “líneas de transmisión eléctricas de alto voltaje (sobre 23 kV) y subestaciones de líneas de transmisión eléctricas”.

Inciso C: “Centrales generadoras de energía mayores a 3 MWO”.

Inciso D: “Proyectos de desarrollo urbano en zonas no comprendidas en algunos planes a que alude a la letra H del articulo 10 de la ley”.

[241]República de Chile, *Reglamento del Sistema de Evaluación de Impacto Ambiental*, Ministerio Secretaría General de la Presidencia de la República, 2002.

Inciso H: “planes regionales de desarrollo urbano, planes ínter comunales, planes reguladores comunales y planes seccionales”.

Inciso P: “Ejecución de obras, programas o actividades en parques nacionales, monumentos naturales, reservas de zonas vírgenes, santuarios de la naturaleza, parques marinos, reservas marinas o en cualquiera otra área colocada bajo protección oficial, en los casos en que la legislación respectiva lo permita”.

Articulo 10: Inciso A “la duración o la magnitud en que se obstruye la visibilidad a zonas con valor paisajístico”.

En comparación con las fuentes de energía convencionales, los impactos ambientales de la energía eólica son locales y pueden ser monitoreados con facilidad. Además, no liberan gases u otras sustancias tóxicas, no contribuyen al efecto invernadero, al calentamiento global y no contaminan el aire, agua o suelo.

En proyectos grandes, las intervenciones causan una alteración del suelo y de la cubierta vegetal y, en ocasiones, tienen impacto sobre la fauna y las rutas migratorias, Otro impacto es el ruido que genera este tipo de parques.

Normativa vigente.

Actualmente el INN no posee una norma respecto a los estándares de una planta eólica, luego los únicos estándares existentes son internacionales; éstos son desarrollados por grupos de trabajo del Comité Técnico - 88 (TC-88) de la Comisión Internacional Electrotécnica (IEC[242]), organismo internacional reconocido para desarrollo de actividades estándares.

AWEA[243] es la organización industrial reconocida en EE.UU. para el desarrollo de estándares y mantiene contacto con la IEC para el desarrollo de estas actividades, involucrando profesionales de la industria en los subcomités del TC-88. EWEA[244] también reconoce esta norma, por lo que su implementación en Chile no es completamente descartable, sino que todo lo contrario, debiera

---

[242] IEC: International Electrotechnical Commission, 1992.
[243] AWEA: American Wind Energy Association.
[244] EWEA: European Wind Energy Association.

considerarse, puesto que la mayoría de las inversiones en energía provienen de países desarrollados como los de la unión europea o EE.UU.

Costos de la inversión.

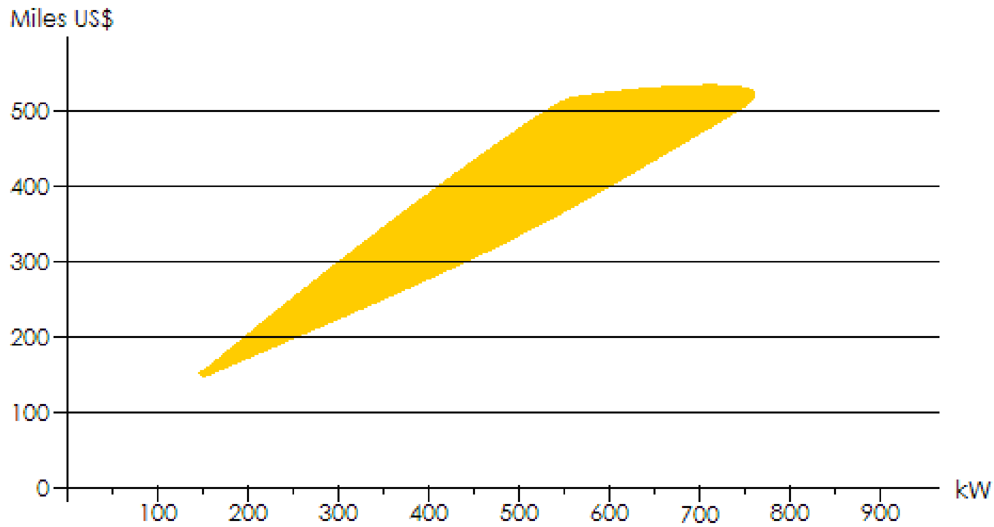
La inversión total puede resumirse en 3 grandes costos:

Costo de las turbinas:

El siguiente gráfico muestra la gama de precios de las turbinas de viento modernas. Como se puede apreciar, los precios varían para cada generador según su tamaño. Las razones son variadas; torres de diferentes alturas y diferentes diámetros de rotor. Un metro extra de torre puede costar aproximadamente US$ 1.500. Una máquina especial para vientos suaves con un diámetro de rotor relativamente grande será más cara que una gran máquina de viento con un pequeño diámetro de rotor[245].

[245] Windpower economics, 1998.

Figura 33. Precio Banana de aerogeneradores.




Fuente: Windpower, 1998.

Costo de instalación:

Los costos de instalación incluyen las fundaciones, normalmente en hormigón armado, la construcción de carreteras de ser necesario (para transportar la turbina y las secciones de la torre hasta el lugar de la construcción), un transformador, conexión telefónica para el control remoto y vigilancia de la turbina y los costos de conectividad desde la turbina hasta la línea de alta tensión[246]. Estos costos dependen de las condiciones del suelo, es decir, de cuán barato y fácil sea construir una carretera capaz de soportar camiones de 30 toneladas. Otros factores variables son la distancia a la carretera regular más cercana, los costos de llevar una grúa móvil hasta el sitio y la distancia a una línea de alta tensión capaz de manejar la producción de energía máxima de la turbina.

Otros costos:

[246] Windpower economics, 1998.

Se deben considerar los costos extras de este tipo de proyectos, tales como: los permisos necesarios para edificar, costo del terreno, re-localizaciones necesarias, entre otros. Estos costos son de significativamente menores a los de instalación y de turbina, por lo que no afectan en mucho la inversión inicial para este tipo de proyectos.

Variables seleccionadas.

Basándose en las metodologías convencionales y las variables analizadas anteriormente, es posible determinar cuáles son las consideraciones importantes al momento de determinar la macrolocalización de un parque eólico. Estas pueden resumirse en:

Velocidad media del viento: considera la velocidad del viento, la que se ve afectada por el tipo de terreno, la rugosidad y altura donde se realiza la medición.

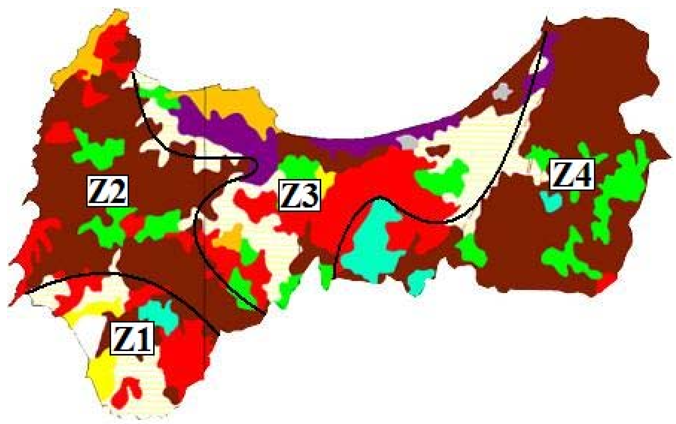
Accesibilidad de la zona: en la metodología propuesta la accesibilidad está compuesta por la cercanía a puertos de la región, tipos de carpeta de carreteras existentes en las zonas de análisis y la distribución de la red vial.

Costo oportunidad del suelo: se puede considerar tanto el valor propio del terreno, así como las restricciones que posee cada zona respecto de este tipo de proyectos.

A nivel mundial uno de los mayores problemas de la prospección eólica es que no considera en general todos estos aspectos, por lo que muchos proyectos de gran magnitud enfrentan desafíos posteriores relacionados con la biodiversidad, accesibilidad, impacto ambiental, entre otros. Al considerar estas tres variables, se busca lograr minimizar el efecto negativo que los parques eólicos pueden tener tanto a nivel visual, ambiental y económico sobre una región determinada.

Otra consideración del modelo es la subdivisión de las comunas de la región por zonas; estas zonas representan un uso de suelo específico para cada comuna. Para poder identificar este uso, se puede recurrir a análisis previos sobre uso de suelo. Para simplificar el análisis y, debido a que considerar el uso específico de cada lugar podría generar complicaciones, se dividieron las comunas en zonas de uso, lo que implicó generalizar el uso específico de un sector en aquel que se puede observar como “el uso más común”. Para entender mejor este análisis, se utiliza la comuna de Arauco a modo de ejemplo.

Figura 34. Uso de suelos para la comuna de Arauco.




Fuente: Catastro y evaluación de los recursos vegetacionales nativos, Octava Región del Bíobio.

Como se puede apreciar en la figura 5, la comuna se ha subdividido en 4 zonas. Cada zona representa un uso común del suelo o la tendencia con que se trabaja en dicha zona. Luego, para cada zona y por comuna, se buscó el valor económico del terreno; una buena aproximación se puede obtener observando el comportamiento del valor en el mercado, por ello, para determinar el valor para cada comuna se recolectaron datos publicados en diarios, revistas e Internet respecto del valor del suelo en cada comuna de la región.

Cada variable debe analizarse para la región que se desea trabajar; en este caso se analizarán las variables según las características de la región del Bíobio. Esto debido a que en general es una región desarrollada en su red vial y posee una serie de puertos importantes.

El modelo final recurre a tres indicadores para evaluar la macrolocalización, que se explican a continuación:

$F_i$: Accesibilidad de la región, mediante la influencia de las variables, tipo de camino, la cercanía de puertos y el desarrollo de la red vial se estima un valor numérico que indica que tan accesible es la zona, mientras mayor es este valor, la accesibilidad es peor, por el contrario, mientras menor es el valor, la accesibilidad es mejor. Se interpreta como la accesibilidad de la comuna "i".

$V_{zi}$: Mediante un mapa eólico, confeccionable o utilizando los realizados por organizaciones dedicadas al tema. Se identifica la velocidad promedio de cada zona por comuna; esta representa el régimen general que presenta la zona en un período de tiempo específico. Se interpreta como el viento promedio en la zona "z" de la comuna "i".

$P_{zi}$: Estimando el costo de oportunidad del suelo y cómo es que algunos activos naturales pueden afectar éste; se puede calcular las variaciones en el costo oportunidad del $m^2$ de terreno. Se interpreta como el costo de la zona "z" en la comuna "i".

Algunos datos de las características generales de la región del Bíobio son:

La máxima variabilidad del viento, se presenta en dirección NE - SW, coincidente con los vientos predominantes del área, representando alrededor del 70% de la varianza total del viento en cada localidad.

Los vientos son intensos y con alta variabilidad.

El comportamiento del viento en la región se encuentra altamente modulado por el ciclo anual, en asociación a la influencia del Anticiclón Subtropical del Pacífico Sur Oriental.

Enérgicas fluctuaciones del viento - con períodos cercanos a los cinco días - están presentes en el área, evidenciando la presencia de “bajas costeras”[247].

Respecto a cómo la geografía afecta los regimenes de viento y puede afectar al modelo, se puede decir que:

La cordillera de la costa del norte del río Itata se encuentra adosada al litoral y esta constituida por lomajes que rara vez superan los 400 m de altitud. Esta característica permite una acción mas extendida de las brisas costeras hacia el valle central, aún existiendo efectos locales producidos por algunas elevaciones[248].

Al sur del Itata adquiere nuevamente altura, para descender hacia el río Bíobio y separarse del borde litoral. Esto genera en la zona comprendida entre el río Itata y el Bíobio un corredor donde el viento se ve orientado por la geografía, lo que altera la dirección del viento y en algunos casos su velocidad.

Al sur del río Bíobio la cordillera de Nahuelbuta, que alcanza altitudes de 1.000 m se interpone fuertemente a la ventilación al interior de la región, pero el amplio litoral de la provincia de Arauco[249] permite grandes influencias de las brisas marinas en ésta.

Metodología propuesta.

Las variables se sintetizaron en tres indicadores: $F_i$, $P_{zi}$ y $V_{zi}$. En esta sección se busca la relación que poseen y cómo es que se puede construir una herramienta que incluya a éstas, para así determinar una localización que posea (en el mejor de los casos) el mínimo efecto sobre el entorno. Si bien el modelo puede ser sencillo, es un punto de vista diferente a cómo actualmente se evalúan la localización de parques. Recordando la definición de los indicadores:

---

[247] SHOA: Servicio Hidrográfico y Oceanográfico de la Armada.
[248] “Atlas Agroclimático de Chile, Regiones IV a IX.” CIREN-CORFO. Marzo 1990.
[249] 10 a 40 km de ancho.

$P_{zi}$: valor por uso de suelo de la zona “z” en la comuna “i”, dicho valor está influenciado por el uso cercano a dicha comuna y es mayor en aquellas donde el valor del suelo es muy alto debido a la cercanía a actividades turísticas o zonas de protección del estado.

$F_i$: accesibilidad de la comuna “i” este valor aumenta a medida que la comuna posee una peor accesibilidad respecto de las otras; el valor incluye variables como la distribución de la red vial y el tipo de carpeta que predomina en la zona.

$V_{zi}$: velocidad del viento medio que se puede encontrar en zona “z” de la comuna “i”; este factor varía en el tiempo por lo que es posible realizar mediciones de éste de forma mensual o semanal.

Se define $C_{zi}$ como el indicador correspondiente a la zona “z” de la comuna “i”. Como ya sabemos este indicador esta en función de los tres antes señalados, por lo que:

$$C_{zi} = f(F_i, V_{zi}, P_{zi}) \qquad (2)$$

Si se analiza el comportamiento de $F_i$, se sabe que este aumenta en relación de la accesibilidad de la zona de análisis y que su valor numérico es mayor mientras la situación de la comuna en cuanto a accesibilidad es peor con respecto a parque eólicos.

$$C_{zi} = \alpha * F_i * f(V_{zi}, P_{zi}) \qquad (3)$$

Donde α es la relación que posee la variable accesibilidad respecto de $C_{zi}$, con esto ya tenemos una interpretación del indicador $C_{zi}$, el que aumentará en la medida que peores son las condiciones de la zona analizada.

Luego $V_i$ es la velocidad del viento correspondiente a la zona. Se sabe que aquellas zonas con más alto valor son preferibles respecto del resto; con ello el efecto esperado en el indicador es que a mayor valor del viento el valor de $C_{zi}$ disminuya, por lo que la relación con la velocidad es inversamente proporcional. Esto queda expresado como:

$$C_{zi} = \alpha * F_i * \left(\alpha^{-1} * V_{zi}\right) * f(P_{zi}) \qquad (4)$$

Finalmente el precio $P_{zi}$ aumenta en aquellas zonas donde el valor económico es muy alto o que, por efectos de uso alternativo, éste aumenta debido a las restricciones. Con esto se puede establecer que a mayor precio del terreno el valor de indicador $C_{zi}$ aumenta, lo que lleva a que su relación sea:

$$C_{zi} = \left(\alpha * F_i\right) * \left(\alpha^{-1} * V_{zi}\right) * \left(\alpha * P_{zi}\right) \qquad (5)$$

Como α representa la relación entre las variables y $C_{zi}$, se puede decir que $C_{zi}$ está definida como:

$$C_{zi} = \frac{F_i * P_{zi}}{V_{zi}} \qquad (6)$$

Este modelo recopila ciertas consideraciones que hacen que sea preferible utilizar el producto de las variables en vez de una suma ponderada. Si se consideran las unidades que componen a $C_{zi}$, se puede identificar que:

$$C_{zi} = \frac{F_i(km) * P_{zi}\left(\frac{\$}{m^2}\right)}{V_{zi}\left(\frac{m}{s}\right)} \qquad (7)$$

Es posible observar una expresión para medir el valor de localización de una región, puesto que se obtiene el precio por $m^2$ de viento en función de la distancia. Si bien no es común encontrar esta unidad, puede interpretarse como el precio del $m^2$ de viento ubicado a cierta cantidad de kilómetros respecto de un puerto. Entonces, aquellas comunas con un $C_{zi}$ de valor mayor, tenderán a mostrar un mayor valor del suelo en función del $m^2$ de viento. Para efectos de escritura, esta medida se establece como “unidad de $C_{zi}$”. El valor de $C_{zi}$ es menor a medida que la zona analizada posee mejores condiciones para instalar un parque eólico.

Si se confecciona la lista de los diez mejores lugares para construir, se obtiene que ellos son:

Tabla 5. Ranking de los diez mejores valores para el indicador $C_{zi}$.

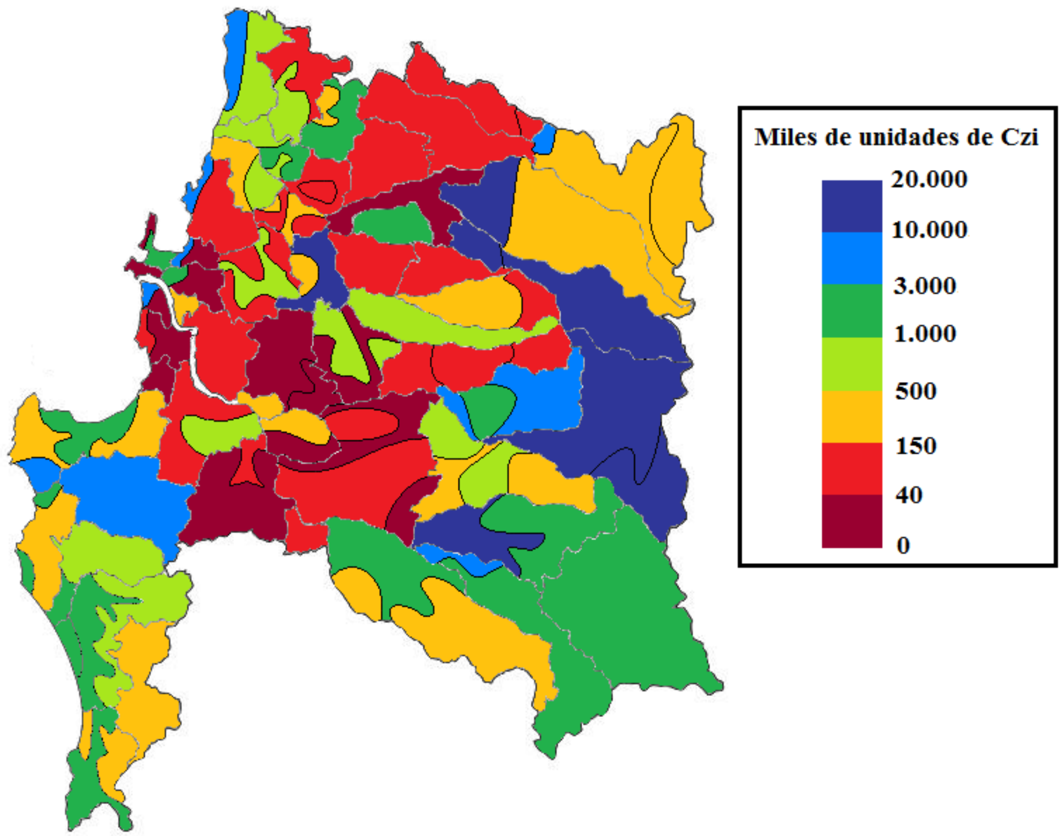
| Comuna | Zona | Czi |
|---|---|---|
| Coronel | Z2 | 710,13 |
| Yumbel | Z2 | 6.280,48 |
| Lota | Z1 | 6.627,92 |
| Talcahuano | Z1 | 7.101,34 |
| Concepción | Z2 | 9.468,46 |
| Chillán | Z1 | 13.217,84 |
| Los Ángeles | Z4 | 16.114,29 |
| Laja | Z1 | 17.028,57 |
| Los Ángeles | Z2 | 17.579,22 |
| San Pedro | Z2 | 21.303,88 |

Fuente: Elaboración propia.

El interior de Coronel es una de las mejores zonas para construir parques eólicos; esto se debe a los buenos vientos reinantes, una red vial desarrollada, la cercanía al puerto del mismo nombre y el costo de oportunidad que presenta esta zona.

Entonces, calculando el valor de $C_{zi}$ para cada zona definida, es posible utilizarlos para crear un patrón de colores al igual que en un mapa eólico. El mapa para la Región del Bíobio queda como el que se puede apreciar en la figura 6.

Figura 35. Mapa de resultados mediante metodología por unidades $C_{zi}$.



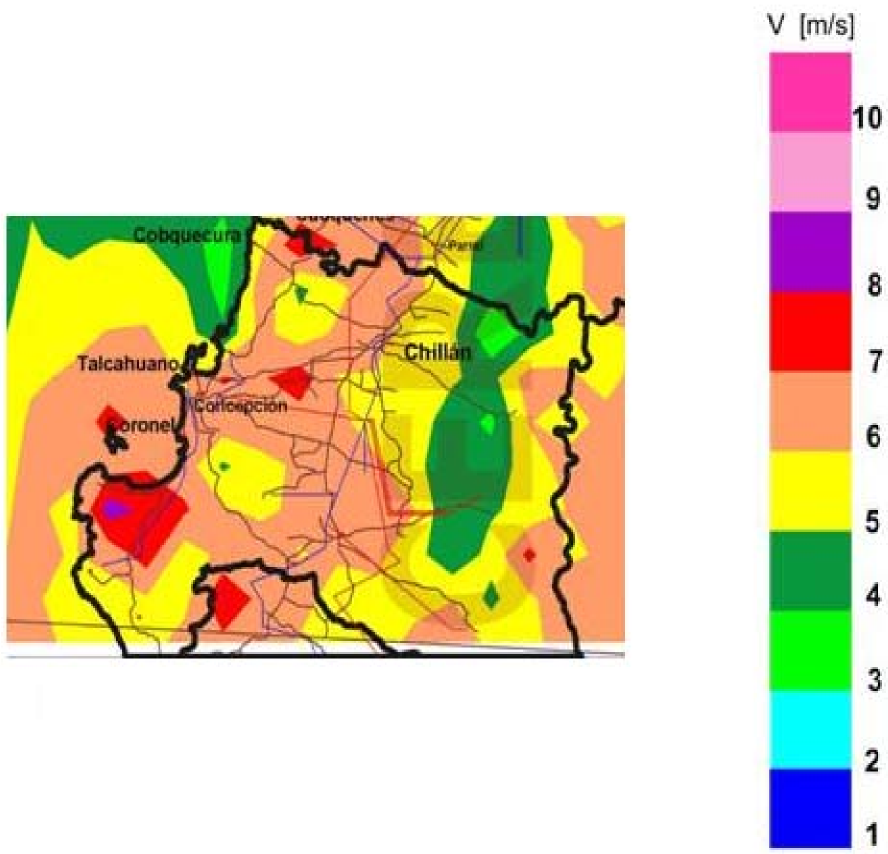

Fuente: Elaboración propia.

Existen zonas que llaman la atención, por ejemplo las correspondientes a Lota, Laja y Los Ángeles, ya que en primera instancia no pertenecen al grupo de zonas con vientos superiores. Se identifica una zona de posible desarrollo importante en el centro de la región, así como en la costa central de esta misma; por otro lado, en la alta cordillera aun cuando existen vientos favorables, tanto el costo de oportunidad y la accesibilidad juegan en contra de la instalación, por lo que son zonas poco atractivas para instalar parques eólicos.

Los resultados obtenidos son positivos respecto del objetivo planteado, puesto que el modelo logra estandarizar las comunas de la región y al mismo tiempo identificar zonas que con metodologías comunes no se hubieran señalizados como lugares potenciales de desarrollo de proyectos eólicos. Como se puede observar en la figura 6, existen zonas que mediante metodologías convencionales, no se habrían considerado. Para comprobarlo, se puede comparar el mapa eólico de la región con dicha figura.

Un ejemplo claro de lo anterior es la comuna de Arauco; en el mapa eólico los vientos que ésta posee son ideales para un parque eólico de alta potencia (ver figura 7), pero el mapa del indicador $C_{zi}$ indica lo contrario. Si se analiza con mayor detalle esta comuna - recordando las variables que se utilizan para el cálculo de $C_{zi}$ - posee en algunas de sus zonas humedales importantes, los que hacen que la construcción de cualquier proyecto energético deba ser analizada con mayor detalle.

Figura 36. Mapa eólico de la región del Bíobio.




Fuente: CERE-UMAG

Consideraciones al modelo desarrollado.

Este modelo presenta fortalezas y debilidades. Analizándolas se puede señalar que:

Fortalezas del indicador $C_{zi}$.

Al contrario del método cualitativo por puntos, no utiliza rangos para definir el valor de las variables, lo que permite detectar diferencias aún cuando los valores difieran en pocas unidades.

Considerar las relaciones que poseen las variables, ya sea directa o inversamente proporcional a $C_{zi}$; considera el efecto directo de una sobre otro.

Como se utilizan indicadores que se pueden mejorar, la precisión aumenta considerablemente a medida que cada uno de los factores mejora.

Al contrario de otros métodos convencionales de macrolocalización, el modelo considera el efecto completo de cada unidad que por factor puede poseer respecto de los demás; lo anterior puesto se utilizan los valores exactos y no una valoración por rango.

Debilidades del indicador $C_{zi}$.

La interpretación del indicador final, en inicios, puede resultar confusa, debido a que la unidad de medida en general no es regularmente usada y al mismo tiempo requiere de interpretación adecuada.

Como se trata de un modelo diferente a los que normalmente se utilizan, requiere una validación extensa de los resultados; para ello es necesario comprobar, de alguna forma, si efectivamente los sitios seleccionados mediante esta metodología poseen ventajas respecto de otros.

El modelo se comporta de forma aleatoria frente a ciertas situaciones especiales; esto se debe a que trabaja con valores generales para las áreas seleccionadas.

Conclusiones y Recomendaciones.

A nivel mundial, la selección de sitios para la instalación de los parques eólicos se ejecuta mediante tres modelos:

Costos de accesibilidad.

Potencial eólico del lugar.

Costo oportunidad de los suelos.

En Chile ellos no se usan, más bien se selecciona previamente un sitio y luego se evalúa su potencial eólico para desarrollar un proyecto. Esta selección no considera los costos de accesibilidad, ni los asociados a imagen pública.

En el costo total de un parque eólico el valor de los equipos de generación es fijo, por tanto, los costos que se pueden disminuir son los relacionados con el sitio, su acceso, la construcción, tendido y conectividad a la red, por nombrar algunos. Estos costos se puede reducir utilizando una metodología diseñada con este objeto.

Las variables relevantes para la decisión sobre macrolocalización de parques eólicos son:

Vientos.

Geografía.

Uso de terrenos.

Opinión pública

Impacto ambiental

Normativa vigente

Las metodologías convencionales, así como la que se propone, deben utilizarse para la selección de parques de gran tamaño (sobre 200 MW), puesto que es en estos casos cuando los costos asociados son altos. Además, si se desea alcanzar un desarrollo energético mediante energía eólica importante, el tamaño de los parques deberá crecer, traduciéndose en turbinas más grandes, con mayores costos de transporte en el largo plazo.

El modelo propuesto sintetiza las variables en tres indicadores que representan en buena medida el comportamiento de ellas, siendo: velocidad media del viento, accesibilidad de la zona, costo oportunidad del suelo.

Los resultados obtenidos mediante la metodología propuesta son bastante alentadores, puesto al compararlos con metodologías convencionales resultan distintos e identifican opciones que, de otra forma, tal vez no se hubiesen estudiado.

La importancia del crecimiento energético en el país es indiscutible, por lo que diversificar la matriz energética debe considerarse como una prioridad, disminuyendo la dependencia no solo de recursos extranjeros, sino que además de los cada vez más escasos recursos “convencionales”, logrando así mayor estabilidad en el país; por ello, la diversificación debe acelerarse.

Recomendaciones.

Es de vital importancia para el país mejorar la medición de los vientos; los mapas actuales son de baja calidad informativa. Si se desea un buen posicionamiento a nivel energético, se requieren mayores estudios respecto a cómo la fuente de la energía eólica se comporta.

Los indicadores de accesibilidad son variados; la metodología utilizada plantea algunos y utiliza uno solo. Esto no es un impedimento para desarrollar el modelo con un indicador más avanzado, de hecho se recomienda utilizar uno mayormente elaborado, puesto mejoraría el nivel de resultados.

Es importante no solo desarrollar metodologías que mejoren el proceso de toma de decisión de proyectos energéticos, sino también la tecnología asociada a éstos.

Referencias.

Au D., Nora; “Apunte para asignatura Estudio Técnico de Proyecto v1.0” Universidad del Desarrollo 2004.

AMERICAN WIND ENERGY ASSOCIATION. Wind Energy Fact Sheets, [en línea] Publicaciones AWEA [fecha de consulta: 06 Junio 2008]. Disponible en:

<http://www.awea.org/pubs/factsheets.html>.

ÁLVAREZ, CLEMENTE. Energía eólica. Dirección técnica: Instituto para la diversificación y Ahorro de la Energía, Madrid, España.

Chapple, Paula. Parque Eólico Canela: El Nido del Viento. BIP. (1)58: 30-37. Enero 2008.

CIREN-CORFO, “Atlas Agroclimático de Chile, Regiones IV a IX.”. Marzo 1990.

DANISH WIND INDUSTRY ASSOCIATION. Annual report – march 2007 [en línea] Energy strategy 2025: well begun, but only half done [fecha de consulta: 06 Junio 2008]. Disponible en:

<http://www.windpower.org/media(1552,1033)/aarsberetning_-_annual_report_2006.pdf>.

EUROPEAN UNION POWER. Taking control of energy future, [en línea] Christian Kjaer. [Fecha de consulta: 06 Junio 2008]. Disponible en:

<http://www.ewea.org/fileadmin/ewea_documents/documents/publications/articles/Taking_control_EUP_22006.pdf>.

Field, Barry C. Cano, Leonardo, "Economía Ambiental: una introducción" McGraw-Hill. , Colombia. CO. Pag.xviii, 587 p. 1995

Garrocho, C. y J. Campos: "Un indicador de accesibilidad a unidades de servicios clave para ciudades mexicanas: fundamentos, diseño y aplicación". Economía, Sociedad y Territorio, vol. VI, núm. 22, 2006, 349-397.

GERMAN ENERGY AGENCY DENA. Dena Study, [en línea] Deutsche Energy Agentur [fecha de consulta: 08 Junio 2008]. Disponible en:

<http://www.offshore-wind.de/page/index.php?id=2605&L=1>.

LIBERTAD Y DESARROLLO. Incentivos de energías renovables no convencionales. Libertad y desarrollo. (1)175: 2-5. Abril 2007.

LIBERTAD Y DESARROLLO. Suministro de gas natural y crisis energética. Libertad y desarrollo. (1)175: 6-9. Junio 2007.

Makrí, Maria-Christina & Folkesson, Carolin, "Accessibility Measures for Analyses of Land Use and Travelling with Geographical Information Systems", 2006.

Messer S., Gisela, "Evaluación de un plan de gestión para el humedal Los Batros, San Pedro de la Paz.", 2008.

Muñoz M., Ricardo, Garreaud S., René, Gallardo K., Laura, Cabello B., Andrés, y Rosenbluth, Benjamín. Mejoría del conocimiento del recurso eólico en el norte y centro del país. [en línea]: Comisión Nacional De Energía, Chile, fuentes energéticas. 2003 [fecha de consulta: 20 Abril 2008]. Disponible en:

<http://www.cne.cl/archivos_bajar/InformeFinalEolo2003.pdf>.

POBLETE SOTOMAYOR, Mirella. Medio Ambiente Y Calidad De Vida [en línea]: Biblioteca Del Congreso Nacional de Chile, Departamento de Estudios, Extensión Y Publicaciones. 2007 [fecha de consulta: 2 Abril 2008]. Disponible en:

<http://www.bcn.cl/bibliodigital/pbcn/medio/estudios_pdf_medio/%20Medio%20Ambiente%20y%20Calidad%20de%20Vida%20Nro%2019%20.pdf>.

PONCE ARQUEROS, Patricio. Energía Eólica: El futuro de Chile? [en línea]: Plataforma Urbana. 2007 [fecha de consulta: 3 Abril 2008]. Disponible en:

<http://www.plataformaurbana.cl/archive/2007/12/13/energia-eolica-el-futuro-de-chile/>.

República DE CHILE. Comisión Nacional De Energía, Chile. Guía para Evaluación Ambiental, Energías Renovables no Convencionales, Proyectos

Eólicos [en línea]: Comisión Nacional De Energía, Chile, fuentes energéticas. 2006 [fecha de consulta: 15 Abril 2008]. Disponible en:

<http://www.cne.cl/fuentes_energeticas/GUIA_EOLICA.pdf>.

República DE CHILE. Comisión Nacional De Energía, Chile. Prospección eólica en zonas de las regiones de Atacama, de Coquimbo y del Maule. [en línea]: Comisión Nacional De Energía, Chile, fuentes energéticas. 2007 [fecha de consulta: 20 Abril 2008]. Disponible en:

<http://www.cne.cl/archivos_bajar/informe.pdf>.

REPÚBLICA DE CHILE, Reglamento del Sistema de Evaluación de Impacto Ambiental, Ministerio Secretaría General de la Presidencia de la República (07 diciembre 2002, Santiago, Chile). Titulo I Disposiciones Generales.

ROIG, FRANCESC; WENDLING, OLIVER & AMARGANT, XAVIER. Parámetros Medioambientales de un Parque Eólico y Opinión Pública. [en línea]:2006 Eolic Partners, S.A. [fecha de consulta: 06 Junio 2008]. Disponible en:

<http://www.conama.es>.

SECRETARÍA REGIONAL MINISTERIAL DE VIVIENDA Y URBANISMO, Región del Bíobio, junto con URBE Arquitectos, “Memoria explicativa plan regional de desarrollo urbano VIII región del Bíobio”.

UNIVERSIDAD DE CHILE. Departamento de Geofísica, Facultad de Ciencias Físicas Y Matemáticas. Evaluación del potencial eólico nacional, Proyecto EOLO. [en línea]: 2003 [fecha de consulta: 20 Abril 2008]. Disponible en:

<http://www.dgf.uchile.cl/eolo/>.

UNIVERSIDAD DE MAGALLANES. Centro de Estudio de los Recursos Energéticos. Mejoría del conocimiento y administración de la información eólica en chile. [en línea]: Comisión Nacional De Energía, Chile, fuentes energéticas. 2005 [fecha de consulta: 20 Abril 2008]. Disponible en:

<http://www.cne.cl/archivos_bajar/INFORME_FINAL_CERE_para_CNE_2005_after_DMC2.pdf>.

Otras fuentes.

http://energiasrenovablesbiobio.com/general.php?plantilla=16&sec=6&sub=2

http://www.ceo.cl/609/article-65443.html#h2_2

http://www.e-seia.cl/

http://www.energiasrenovables.ciemat.es/

http://www.energiasrenovables.ciemat.es/?pid=2000&id_seccion=1

http://www.helimax.com/

http://www.endesa.cl/canela/

http://www.shoa.cl

http://www.conadi.cl/areasdesarrolloindigena.html.

# 67. Location of a Wind Energy Plant on the Coast of Ecuador

**Diego Maldonado, Daniel De Jerónimo**

Universidad San Francisco de Quito

Diego de Robles S/N y Pampite. Quito, Ecuador

Phone: (593) 2 280 7712, Fax: (593) 2 289 0070

diego_maldonado@hotmail.com

danieldjeronimo@gmail.com

Key Words: Facility Location, Renewable Energies, Wind Plant

Abstract: The demographic growth on Ecuador's coastal region represents a significant increase on energy demand which must be satisfied efficiently. While having a new set of potential customers, two important issues refer to where to locate an energy plant in order to serve them, and how to organize the productive departments of the energy plant so that its resources can be effectively utilized. To improve the chances of establishing a successful energy generation plant, which is the main focus for many entrepreneurs, this article proposes that the location and the layout of the new facility should be optimized. For this purpose, mathematical techniques should be applied to set the location of a facility capable of generating energy based on renewable resources while becoming an attractive project for investors. In particular, this article explains a process to select the most convenient location site for the construction and design of a wind energy plant on Ecuador's coastal region.

At the beginning of this article, there is a brief literature review on renewable energies, particularly the wind energy and its relevance in energy markets around the world. Next, we focus on the development of a mathematical procedure in order to find an optimal location site for the construction of a wind plant facility in Ecuador's coastal region. In order to accomplish this, a research is performed on some characteristics of the energy market located in the area where the wind plant site can be optimally located. This information and production and design parameters are used as input for the mathematical model. Then, the results are obtained using a heuristic method. At the end of this article, a preliminary layout of the wind plant is presented, which was obtained by means of a detailed qualitative analysis using Systematic Layout Planning (SLP). Finally, it is expected that the models presented in this article will provide useful information and knowledge to help put in practice a wind energy application in Ecuador in the near future.

## 1.- Introduction

Given that the development of societies worldwide depends highly on the consumption of energy, the Ecuadorian energy market should promote new energy generation projects in the short term. Nowadays, a strategy adopted by government institutions and private parties, takes advantage of environmentally-responsible renewable energy sources, such as wind power. Generally, the energy obtained from these resources is almost inexhaustible and environmentally friendly. In particular, the use of wind resources in Ecuador can contribute to satisfy the growing energy demand and also to become part of the development of future generations.

By means of creating a wind energy plant, one can discover environmental, social and economic benefits. Mainly, it would increase the energy production capacity in Ecuador which is useful for its population. Also, while producing this renewable energy, the Ecuadorian energy market diminishes its dependency on fossil fuels. In consequence, Ecuador can experience substantial savings on $CO_2$ emissions, providing benefits not only to the country, but also to the Latin-American region.

Certainly, the Ecuadorian energy market can take advantage of the benefits from wind power, by implementing a wind energy plant. So, this study proposes a plan to locate and design a wind energy plant using mathematical tools and techniques that assure the best location and distribution possible.

As the reader can verify, on section 2, there is a brief explanation of wind power and how it is used to generate energy. Next, a mathematical model to locate a wind energy plant in Ecuador is presented on section 3, and a layout design for this facility is shown on section 4. There are also conclusions and recommendations from this study on section 5.

## 2.- Wind Power

A renewable energy, such as wind power, is based in a primary source of energy, which is produced continuously (Merino 2, 2006). Its most important application relates to energy generation, which production rate grows significantly every year. This is due in part on the adoption of new technologies, but mostly because there are political and environmental international agreements that should be met (Escudero 348, 2004).

Energy is obtained from wind when its power is transformed into mechanical energy using a wind turbine or aerogenerator ("Energía Limpia"19, 2007). This machine is installed in a zone with appropriate weather conditions that favor the presence of winds. Moreover, to produce large quantities of wind energy, it is often utilized a set of aerogenerators, which creates a "wind farm". This type of facility often requires lower maintenance costs compared to other energy generating plants.

Wind power is developing most rapidly worldwide. Europe is the leader in generation of wind energy. Moreover, most of the existing European wind farm sites are located in Germany and Spain. On the other hand, Latin-American countries are yet to generate vast amounts of wind energy. Traditionally, Latin-American countries depend on water resources and also on the consumption of fuels to generate its energy. In case of Ecuador, there exists one wind power generating facility currently operating in Galapagos Islands, which preserves the fragile ecology of the islands.

3.- Location of the Wind Energy Plant

As wind power has several potential benefits, it is an attractive option to start a plan in which a wind energy plant would be built. The purpose of this industrial facility is to provide energy to the Ecuadorian population. For this facility to be successful, its location and its design should be planned carefully. Prior to creating the design of the wind energy plant, Fernández recommends planning its location appropriately in order to get as much market share as possible (2, 2005).

To locate the construction site of a wind plant facility in Ecuador's coastal region, it is useful to identify constrains that limit the facility generation capacity, as suitable wind generation sites are often limited. One of the main constrains refers to wind velocity, as the generation of energy increases proportionally as the kinetic energy from the wind grows (Alarcón, 2008).

Also, it is important to notice that the characteristics of the wind flow are subject to meteorological conditions depending on the location. For instance, Escudero states that "wind resources in territories that have an absence of mountains show uniform speed and direction characteristics throughout large extensions of land" (179, 2004). In addition, Mosquera affirms that the production of energy is superior near to the coast line due to the presence of fast and steady winds (12, 2006). In the case of Ecuador, its coastal region, that presents extensive plain terrains, can provide steady wind resources to produce energy in a wind plant.

After this initial determination, it is necessary to limit the area within Ecuador's coastal region in which the wind farm can be located. Again, the wind velocity factor can be used as a measure to set the best territory. Examining samples of wind velocities on six potential locations for the wind farm, it is determined that the province of Manabí has the greatest average of wind velocity. This significantly improves the chances of generating larger amounts of energy choosing appropriate wind turbines for the facility.

Once the territory for the location of the wind farm is delimited (in this case, the province of Manabí), the next step is to identify costumers that would receive the energy service from the wind farm. Taking Manabí's nineteen counties, each one of their capitals can represent the location of a group of potential customers with their own energy needs.

The next activity is to develop a mathematical model for a location problem. According to Villegas, there are three components that must be determined in this mathematical model (1, 2005):

*Facilities*: denotes the set of objects to be located to provide services.

*Locations*: refer to the set of possible sites to locate the facilities

*Customers*: those facility users that demand services.

In this practical application, the facility will provide its services to any customer in the province of Manabí. Notice that this study refers to the location of one wind energy plant and decides where the facility should be located depending on the customers needs and constrains applied.

The *p*-median problem is a useful tool to model a facility location problem. In the *p*-median problem, the geometric median acts as an estimator of the optimal location (Martínez 2, 2007). The main characteristics of this problem are the following:

The *p* parameter denotes the number of facilities that provide a similar type of service.

The relation between a facility and the location of a particular customer is given by a distance function.

Customers demand the service provided by any facility in the set *p*, and look for the closer service to their respective location.

The mathematical formulation for the *p*-median problem includes the following parameters (Fernández 4, 2005):

| | | |
|---|---|---|
| $X$ | Facility location | $X = (x, y)$ |
| $C$ | Set of customers | $C = \{c_1, \ldots c_i \ldots, c_m\}$ |
| $m$ | Number of customers | |
| $P$ | Customer Location Set | $P = \{P_1, \ldots P_i \ldots, P_m\}$ |
| $P_i$ | Location of customer $i$ | $P_i = (a_i, b_i)$ para $i = 1, \ldots, m$ |
| $w_i$ | Weight assigned to location $P_i$ | |
| $d(X,P_i)$ | Distance between location $P_i$ and $X$ | |
| $f(X)$ | Non-negative function | |

When $p$ equals to one for this $p$-median problem, it means that only one facility location is required. Therefore, the objective function focuses on finding the optimal location for the facility that minimizes the weighed sum of distances, represented by the following function:

$$f(X) = \sum_{i=1}^{m} w_i d(X, P_i) \qquad (1)$$

In this case, to solve the $p$-median problem, the Euclidean distance is used because this problem takes place on rural and open areas in Ecuador's coastal region. This norm measures distances between two points $P_1 = (x_1, y_1)$ and $P_2 = (x_2, y_2)$, as follows (Loria 2, 2007):

$$d(P_1, P_2) = \left(|x_1 - x_2|^2 + |y_1 - y_2|^2\right)^{1/2} \qquad (2)$$

In order to determine the distances between customers, it is required to obtain two-dimensional geographic coordinates for each customer location. While the coordinates of the wind energy plant remain unknown, it is identified that this facility will be surrounded by the customer's locations.

It is important to include the population as customers in the mathematical model. However, the number of customers can be reduced in order to simplify the model. Therefore, for this problem, the entire population from each county can be modeled as if it would be located on its capital, which gives 19 particular locations for the model, that is $m$ = 19. Then, approximate geographic locations for those customers can be obtained by using a geographic map.

Another component required by this mathematical model refers to the weights assigned to each customer. As the $p$-median problem identifies the optimal location that minimizes the weighted sum of distances between customers and the facility, it is important to set appropriate weights for the model to be valid. Having that into consideration, six factors were taken into account in this study:

*Wind velocity*: one of the main components of a wind energy plant is a wind turbine called aerogenerator. This component generates energy depending on the amount of kinetic energy that captures from the wind. For this reason the wind energy plant must be located in a place rich on winds.

In the province of Manabí, a study of wind velocities using measurements taken at three major airports was conducted by *Corporación para la Investigación Energética*. These measurements were used as an input to construct an eolic map. Then, for any specific location in Manabí, the wind velocity average can be obtained.

*Population with energy needs*: as of now, there are still populations in the province of Manabí that do not have energy service, so that new projects on energy generation can be developed and executed in order to meet the requirements and needs of those populations. In this case, the wind energy plant should be located near to their respective locations. Then, it is necessary to quantify the number of people that is in need of energy service.

*Distance to Ecuadorian energy systems*: due to energy transportation costs that can significantly increase with the distance between the plant and an energy distribution site, it is better to locate the wind energy plant close to an energy station available in Manabí.

*Distance to major roads*: during the implementation phase of this project, it is necessary to take into account that components and materials must be carried to the plant site using heavy-duty trucks. With this idea, it is necessary to have roads available. Otherwise the roads must be open first. Then, it is required to establish a measure from possible sites of the wind energy plant to the nearest roads.

*Rural population*: an extra income can receive those energy plants that produce and serve to rural populations. This fact is included on the Ecuadorian regulations for the energy market, which attempts to expand and improve its service. For the location of a wind energy plant, it is desirable to be located close to major rural areas and get the extra income at the execution phase of this project.

*Population inconformity*: as an important issue to consider, the wind energy plant might be located outside urban areas to have the least possible impact on the population. But still, the more people living in a county, the more problems the project can get in the future.

These factors must be considered as weights and included into the model in order to find the optimal location for the wind energy plant. After conducting a research on some characteristics of the energy market located in Manabí, the set of weights $W = \{w_1, \ldots w_i \ldots, w_m\}$ is determined. Then, this information is used as an input for the mathematical model.

Once the mathematical model is set, the next task is to find a solution to the *p*-median problem. For this study, a solution to the *p*-median problem is obtained using the Weiszfeld algorithm (1973). This algorithm is a heuristic method which generates iterations that provides approximate solutions close to the optimal solution. The main characteristics of Weiszfeld algorithm are the following (Cánovas 1, 1999):

There are *m* different points (vortex), each one of them located at a specific point from the set $P = (P_1, \ldots, P_m)$, defined in $\Re^2$ space.

There are *m* weights, represented by $w_i > 0$, $i = 1, \ldots, m$

There are *m* distances $d(X,P_i)$, from each vortex to the point that represents the facility.

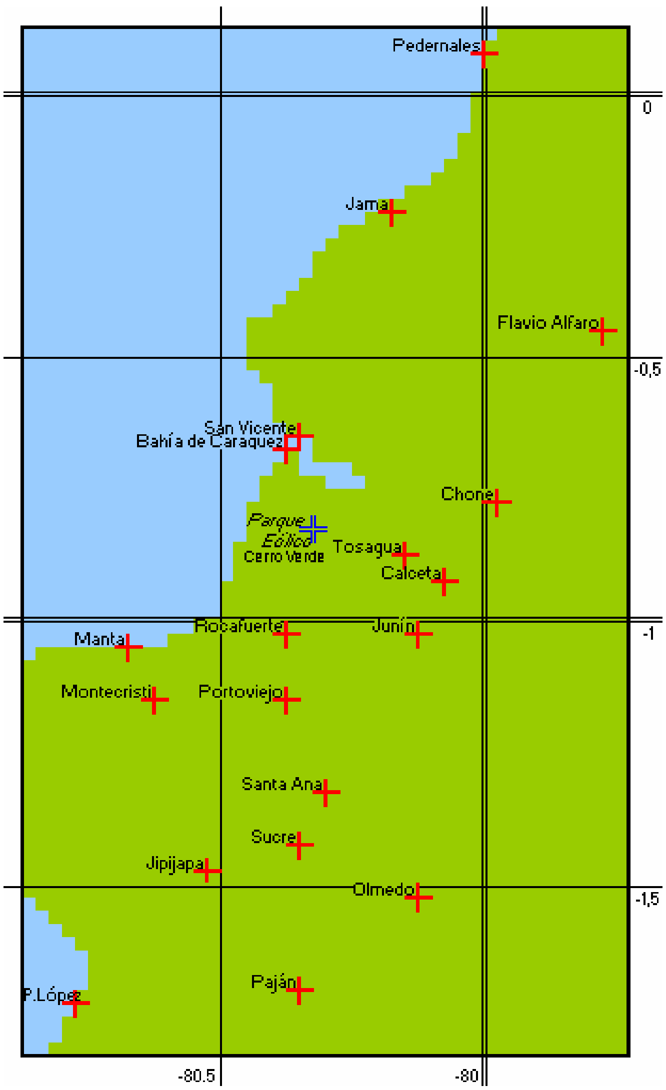
There is one point $X \in \Re^2$ that minimizes the weighted sum of distances *d*.

Using the Weiszfeld algorithm, solutions are found for each iteration, until the solution finally reaches a steady state. For this application, the solution has a pair of coordinates

($x$ = -80,3188; $y$ = -0.8473). After that, it is determined that the location belongs to the site “Cerro Verde”, using the geographic map shown in Figure 1.

One step further on the application of this location problem would be a physical verification of the optimal location. It is important to perform that in order to determine if geographic conditions allow the construction of the wind energy plant. There should not exist significant obstacles, such as houses, trees, towers, etc., that interfere with the normal path of winds. Otherwise, a near location could be utilized instead.

Figure 37. Geographic location of the Wind Energy Plant.




* Own Generation.

4.- Layout of the Wind Energy Plant

As part of the location and design of the wind energy plant in Ecuador, this study analyzes how to distribute the main facility components within the location terrain, those are: wind turbines and other electrical equipment.

There are many techniques that are used to generate a layout. One of them creates a block distribution, which presents positions and sizes of each department, based on the production process. By using Systematic Layout Planning (SLP), the departments can be distributed properly (Tompkins 306, 2006).

At the initial step, SLP requires to analyze the operation flow. In this case, the operational process starts at the wind turbines, which transforms the kinetic energy from the wind into mechanical energy and then electrical energy. After that, the electrical energy is conducted via cable until it reaches a control building where the electrical energy is processed and transported outside the wind energy plant. For this reason, this facility should have a product-oriented layout in order to accomplish a large-scale energy production. Also, this configuration allows the components to be ordered according to its productive activities (Vaneskahian 3, 2005).

There should be a close relation between wind turbines and the energy control building, because the latter depends on the performance of the aerogenerators. Also, it is important to notice that there should be a specific distance between wind turbines as a productive constrain. Escudero states that “there should be a minimum distance of 2.5 times the diameter between each aerogenerator tower to avoid turbulence” (228, 2004). In this case, the problem focuses on determining the location of the control building inside the wind energy plant.

At this point, the location of the control building would depend on the number of wind turbines intended to install in the wind energy plant. For example, if there are five wind turbines, it is possible to allocate the control building near to the middle tower.

There are also some practical guidelines to position the wind turbines, so that the energy generation is optimized:

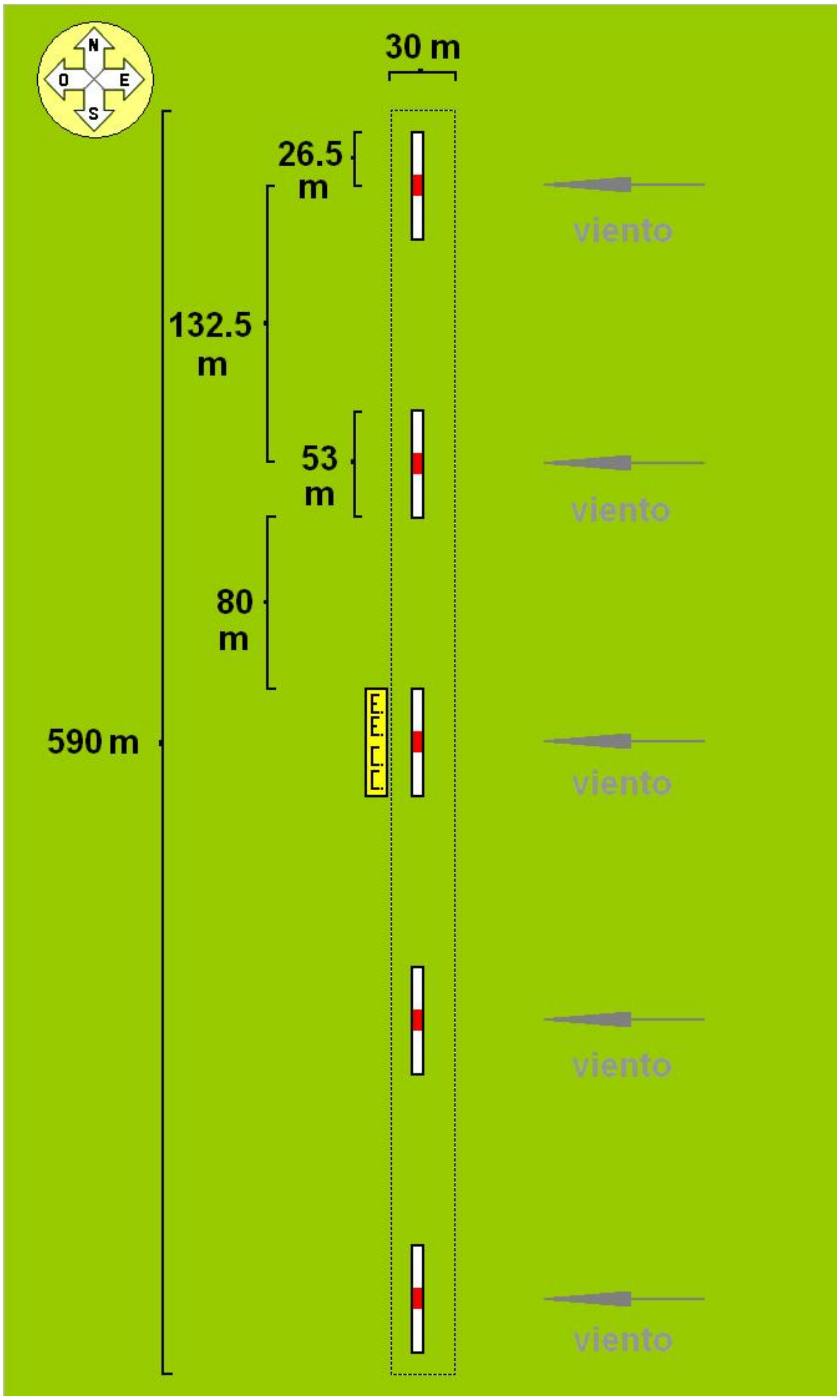
Mosquera recommends positioning the aerogenerators in rows, which is the most common configuration for wind plants (7, 2006)

Escudero states that “the most efficient production of energy is achieved when the aerogenerators are positioned perpendicular from the direction of the wind” (227, 2004).

As winds at the site “Cerro Verde” in Sucre County cross from east to west, then helices from wind turbines should be oriented from south to north.

Finally, Figure 2 shows a preliminary layout for the wind energy plant that contains five aerogenerators which includes a 53-meter-long helix. This can provide a realistic idea about the dimensions of the plant.

Figure 38. Wind Energy Plant Layout.




* Own Generation.

5.- Conclusions and Recommendations

Some conclusions of this study are the following:

In Ecuador, the wind power should generate special interest on future plans to take place at the energy generation market, especially in rural areas that do not have energy service available.

One of the advantages of joining many wind turbines in only one facility is that it increases the utilization of energetic resources and also decreases some environmental impacts.

Both location and design factors are important for the wind plant to be successful.

Once that the mathematical model generates a result, it is necessary to validate that the optimal location site would be a practical place to build the plant.

An important factor used to perform a layout analysis is the distance between aerogenerators. There should not be interference between wind turbines that could reduce the production capacity overall.

It is expected that the experiences provided in this study will help other energy projects in different regions in Latin America. Therefore, we would encourage public and private institutions to promote projects that support wind power not only in Ecuador, but also in Latin America. Given the economic situation in Latin America, it is required to perform an economic analysis prior to building the wind energy plant.

6.- References

Alarcón, Pedro. Entrevista Personal. 25 Abr. 2008.

Cánovas, Lázaro, Roberto Cañavate y Alfredo Marín. "On the Convergence of the Weiszfeld Algorithm". Mathematical Programming. Dic. 2001: 1. Universidad de Murcia. (May. 2008).

<http://www.springerlink.com/content/8g100u5p20dt9xww>

"Energía Limpia y Renovable". Revista Sector Industrial. 19 Abr. 2007: 3, 19.

Escudero, José María. Manual de Energía Eólica. Madrid: Ediciones Mundi-Prensa, 2004.

Fernández, José, et al. "Localización Competitiva en el Plano con Decisiones de Diseño". Análisis y Aplicaciones de Decisiones sobre Localización de Servicios. Jul. 2005: 2-4. Universitat Politécnica de Catalunya (Jul. 2008).

<http://www-eio.upc.es/personal/homepages/elena/Tutoriales/Murcia-Localizacion-Diseno.pdf>

Loria, Jimer. "Método para la Distancia Euclideana". Ago. 2007: 2-6. Instituto Tecnológico Superior de Calkini. (Jul. 2008).

<http://www.itescam.edu.mx/principal/sylabus/fpdb/recursos/r5096.DOC>

Martínez, F. Javier y José Moreno. "Optimización por Enjambre para la p-Mediana Continua y Discreta". Estudio Comparativo de Diferentes Estrategias Metaheurísticas. Feb. 2007: 2-3. Universidad de La Laguna. (May. 2008).

<http://webpages.ull.es/users/jamoreno/www/talks/MAEB07PSO.pdf>

Merino, Luís. "Energías Renovables". Energías Renovables para Todos. 19 Nov. 2006. Fundación de Energía de la Comunidad de Madrid. (Jul. 2008).

<http://www.energias-renovables.com/Productos/pdf/cuaderno_GENERAL.pdf>

Mosquera, Pepa. "Energía Eólica". Energías Renovables para Todos. 18 Nov. 2006. Ed. Fundación de Energía de la Comunidad de Madrid. (Jul. 2008).

<http://www.energias-renovables.com/Productos/pdf/cuaderno_EOLICA.pdf>

Tompkins, James, et al. Planeación de Instalaciones. 3ra ed. México: Thomson, 2006.

Vaneskahian, Alfredo. “Layout”. May. 2005: 3. Universidad de la República. (Jul. 2008).

<http://www.ccee.edu.uy/ensenian/catadprod/material/layout2005.pdf>

Villegas, Juan. “Algoritmos Evolutivos para la Solución de Problemas de Localización Multi-objetivo sin Restricciones de Capacidad”. Abr. 2005: 1. Escuela Latinoamericana de Verano en Investigación de Operaciones. (Jul. 2008).

<http://elavio2005.uniandes.edu.co/ResumenesParticipantes/Martes/VillegasJuaan_R.pdf>

# 68. Influence of the cost of long-term rationing on the optimal dispatch policy of the resources of the Uruguayan

**Alvaro Brandino, Marisa León, Sergio Pérez, Ruben Chaer**

# hydro-electrical system.

Influencia del costo de racionamiento de largo plazo en la política de despacho de los recursos del sistema hidro-eléctrico del Uruguay.

Facultad de Ingeniería , Unidad Reguladora de Servicios de Energía y Agua y Administración del Mercado Eléctrico del Uruguay.

Yacó 1478, C.P. 11400 Montevideo-Uruguay. Tel.:(+598)2.6135833

email: rchaer@fing.edu.uy

Keywords: Energy Rationing Cost

Abstract: Determining the cost of long-term rationing, also known as the cost of failure, involves the realization of complex procedures for determining the cost to the economy of a country that happens due to the failure in the supply of a given amount of energy. The determination of this cost generally comes from surveys done to representative sectors of the economy for determining the cost that would represent the lack of energy, and based on input output matrices evaluate at the same time the cost on the rest of the economic links in the economic chains of the country. In practice, the result is a value of the cost, that of course is an estimate, and therefore the value should be considered as a range of possible values.

This paper attempts to see the problem from the perspective of the operator of the system, and measure how the value that is assigned to the cost of failure affects the operation of the system. The resulting operations for different values of the cost of failure are shown, beginning with a value that is surely lower than the actual one, and raising it to values that are possibly higher than the actual

ones. The sensitivity of the power fails, the cost of thermal generation and the curves of risk of rationing are shown. The result shows  how the sensitivity decreases notoriously for values over 900USD/MWh indicating that for the case studied there are no operation options that can be made to avoid rationing even if wegive values over that value. The results can be used to measure the influence on the actual operation on the precision with which the cost of failure is determined . Also, in order to measure up to what point raise the cost of failure leads to make choices of operation (taking care of the water from lakes for example) to avoid future rationing, and from what value there is no longer operational decisions that can be taken.

## INTRODUCCIÓN

El Costo de Racionamiento de Largo Plazo (CRLP) de un sistema está asociado a los costos que tiene para la economía del país el no poder suministrar toda la energía demandada por el sistema. La metodología de determinación del CRLP es compleja [1] e incluye entre otros, la realización de encuestas a diferentes sectores de la economía para determinar los costos que tendrían ante la falta de suministro de energía; así como la identificación y cuantificación de las matrices insumo producto de las diferentes cadenas productivas para evaluar en forma adecuada los impactos en cadena asociados a un racionamiento. No es intención de este estudio determinar el CRLP sino simplemente evaluar la sensibilidad de los principales indicadores de la gestión del sistema a dicho costo.

Dada la volatilidad del precio del petróleo durante el primer semestre del 2008 y dado lo complejo que puede ser determinar los CRLP es casi inevitable tener que operar el sistema con valores de CRLP que pueden no estar ajustados y por lo tanto es interesante conocer la sensibilidad de la gestión del sistema a dichos valores.

En la actualidad los valores de CRLP están fijados en el sistema Uruguayo por Decreto del Poder Ejecutivo en 250 USD/MWh para el primer 5% (respecto de la demanda) de racionamiento, 400 USD/MWh para el siguiente 7.5% de racionamiento, 1200 USD/MWh para el siguiente 7.5 y 2000 USD/MWh para el 80% restante.

Para realizar los cálculos se utilizó el programa SimSEE [2] desarrollado en el Instituto de Ingeniería Eléctrica del Uruguay en el marco de un Proyecto de Desarrollo Tecnológico con financiación del Banco Interamericano de Desarrollo. Esta herramienta utiliza una optimización dinámica estocástica para valorizar el agua de los embalses.

## EL SISTEMA URUGUAYO

El sistema uruguayo consta de cuatro embalses. El más grande de los embalses tiene capacidad de almacenamiento de aproximadamente 90 días (de generación a pleno). El resto de los embalses tienen constantes de tiempo inferiores a la semana, pero sin embargo por la capacidad de potencia instalada resultan relevantes para el sistema uruguayo. La demanda de energía del sistema Uruguayo es entre 22 y 25 GWh por día hábil para el año 2008, con un pico de aproximadamente 1500 MW. La potencia instalada de origen térmico es aproximadamente de 700 MW. La potencia instalada de origen hidráulico es 1200 MW. La interconexión entre Uruguay y Argentina permite un intercambio máximo de aproximadamente 2000 MW en ambos sentidos y la interconexión entre Uruguay y Brasil aproximadamente 70 MW en el sentido de Brasil a Uruguay y 50 MW en el sentido contrario.

El parque térmico está formado por un grupo de unidades del tipo turbo-vapor alimentadas a fuel-oil pesado capaces de generar 243 MW en “Central Batlle” (CB) a un costo de 130 USD/MWh, 300 MW de turbinas a gasoil de buen rendimiento en “Punta Del Tigre” (PTI), con un costo variable de 187 USD/MWh, 200 MW de turbinas de gasoil de menor rendimiento ubicadas en la “Central Térmica de Respaldo” (CTR) con costo variable de 237 USD/MWh. El sistema prevee la incorporación de proyectos de generación distribuida que totalizan del orden de 30 MW y 20 MW de una turbina a gasoil de muy bajo rendimiento.

Con los valores del precio del petróleo del primer semestre del 2008, de aproximadamente 220 MW, la oferta térmica quedó con un costo variable de generación algo superior a los 250 USD/MWh correspondientes al primer escalón de CRLP.

METODOLOGIA

Para el cálculo de las sensibilidades utilizamos el simulador SimSEE cargando el sistema uruguayo con su proyección a partir de noviembre del 2008. La optimización de los recursos se realizó con un paso de discretización temporal de 24 horas y un horizonte de dos años. Para los resultados se consideraron los valores acumulados del primer semestre de dicho horizonte.

La aleatoriedad tanto de las crónicas de aportes hidráulicos a las represas como del estado de disponible/indisponible de las unidades de generación, lleva a que los resultados sean presentados tanto en su valor esperado o promedio como para diferentes probabilidades de ser excedidos. Para la simulación estadística se utilizaron 100 realizaciones de los procesos estocásticos.

En SimSEE el racionamiento es simulado especificando para la demanda los escalones de racionamiento y sus precios. Cada escalón de racionamiento es simulado internamente como una central térmica sencilla con Costo Variable de Racionamiento (CVR) igual al fijado para el respectivo escalón en la demanda y potencia máxima igual a la resultante de la potencia demandada multiplicada por la profundidad del escalón. Se consideraron escalones de racionamiento equivalentes al 5%, 7.5%, 7.5% y 80% de la demanda. Para el caso base los CVR respectivamente son 450, 600, 1200 y 2000 USD/MWh respectivamente. Los casos considerados corresponden al caso base multiplicando los CVR por 0.7, 0.8, 0.9, 1.3, 1.6 y 2 que resulta en los valores que se muestran en la Tabla I.

TABLA I. CASOS CONSIDERADOS.

| | *5%* | *7.50%* | *7.50%* | *80%* |
|---|---|---|---|---|
| *caso* | CVR1 | CVR2 | CVR3 | CVR4 |
| *0.7* | 315 | 420 | 840 | 1400 |
| *0.8* | 360 | 480 | 960 | 1600 |
| *0.9* | 405 | 540 | 1080 | 1800 |
| *1.0* | 450 | 600 | 1200 | 2000 |
| *1.3* | 585 | 780 | 1560 | 2600 |
| *1.6* | 720 | 960 | 1920 | 3200 |

| | | | | |
|---|---|---|---|---|
| *2.0* | 900 | 1200 | 2400 | 4000 |

Para el cálculo de los ingresos al spot, se tuvo en consideración que el precio spot en Uruguay está topeado por decreto al valor máximo de 250 USD/MWh. El valor calculado es el que recibiría un generador de 1MW que estuviese todas las horas del semestre despachado.

LOS RESULTADOS

Las siguientes tablas resumen los resultados obtenidos para el semestre noviembre 2008 – abril 2009. La Tabla II presenta la generación hidráulica, la Tabla III el costo de operación consistente en el gasto de combustible más el gasto en importaciones de energía, la Tabla IV la energía racionada expresada en % de la demanda del período y la Tabla V resume los ingresos spot que recibiría un generador de 1MW que hubiese estado despachado todo el tiempo.

TABLA II. GENERACION HIDRAULICA [GWh].

| *Caso* | *Prom.* | *Pe10.0%* | *Pe30.0%* | *Pe70.0%* | *Pe90.0%* |
|---|---|---|---|---|---|
| *0.7* | 2424.5 | 3297.6 | 2780.3 | 2098.3 | 1744.9 |
| *0.8* | 2406.1 | 3286.7 | 2758.6 | 2085.5 | 1743.6 |
| *0.9* | 2389.3 | 3271.7 | 2735.3 | 2056.2 | 1735.6 |
| *1* | 2375.7 | 3260.7 | 2714.1 | 2039.3 | 1739.7 |
| *1.3* | 2344.4 | 3230.5 | 2663.7 | 2008.7 | 1700.9 |
| *1.6* | 2320.8 | 3216.0 | 2623.5 | 1980.5 | 1704.8 |
| *2* | 2299.5 | 3205.1 | 2574.8 | 1978.8 | 1706.6 |

TABLA III. COSTO COMBUSTIBLE+IMPORTACIONES [MUSD].

| *Caso* | *Prom.* | *Pe10.0%* | *Pe30.0%* | *Pe70.0%* | *Pe90.0%* |
|---|---|---|---|---|---|
| *0.7* | 269 | 382 | 328 | 212 | 140 |
| *0.8* | 274 | 385 | 334 | 216 | 142 |
| *0.9* | 278 | 388 | 338 | 220 | 145 |

| | | | | | |
|---|---|---|---|---|---|
| *1* | 281 | 391 | 341 | 223 | 150 |
| *1.3* | 288 | 399 | 348 | 233 | 160 |
| *1.6* | 293 | 399 | 351 | 242 | 166 |
| *2* | 297 | 399 | 355 | 252 | 172 |

TABLA IV. ENEGIA RACIONADA [% de la demanda].

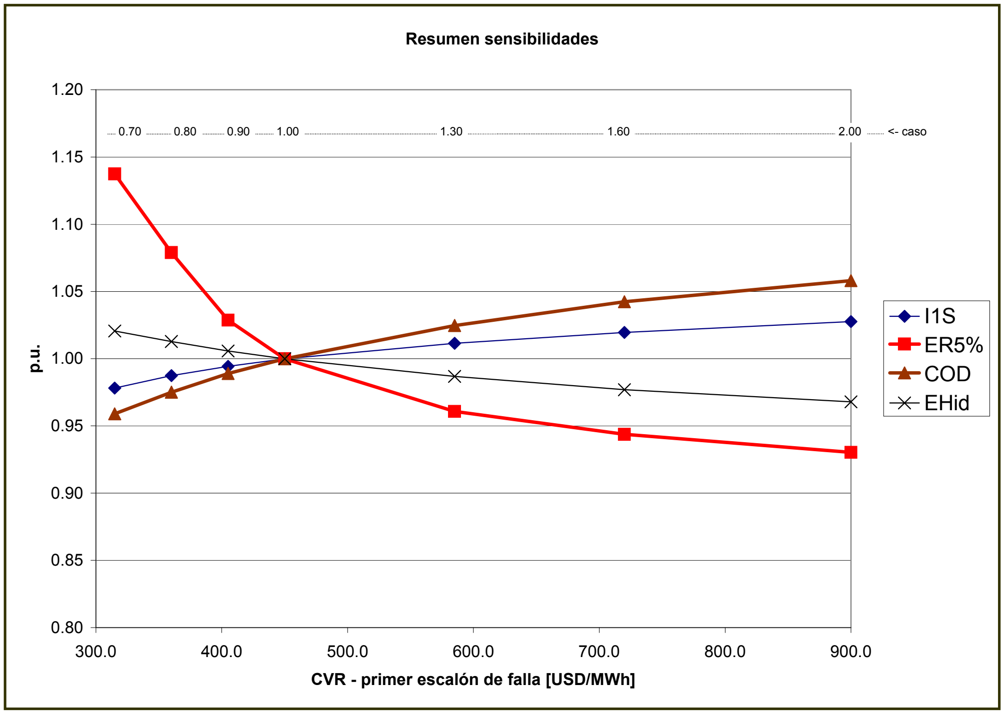
| *Caso* | *Prom.* | *Pe5.0%* | *Pe30.0%* | *Pe70.0%* | *Pe95.0%* |
|---|---|---|---|---|---|
| *0.7* | 4% | 22% | 3% | 0% | 0% |
| *0.8* | 4% | 21% | 2% | 0% | 0% |
| *0.9* | 3% | 20% | 2% | 0% | 0% |
| *1* | 3% | 19% | 2% | 0% | 0% |
| *1.3* | 3% | 19% | 1% | 0% | 0% |
| *1.6* | 3% | 18% | 1% | 0% | 0% |
| *2* | 3% | 18% | 1% | 0% | 0% |

TABLA V. INGRESOS 1MW AL SPOT [MUSD].

| *Caso* | *Prom.* | *Pe10.0%* | *Pe30.0%* | *Pe70.0%* | *Pe90.0%* |
|---|---|---|---|---|---|
| *0.7* | 0.79 | 0.99 | 0.88 | 0.71 | 0.63 |
| *0.8* | 0.80 | 1.00 | 0.89 | 0.72 | 0.63 |
| *0.9* | 0.81 | 1.00 | 0.89 | 0.73 | 0.63 |
| *1.0* | 0.81 | 1.00 | 0.90 | 0.73 | 0.64 |
| *1.3* | 0.82 | 1.00 | 0.91 | 0.74 | 0.64 |
| *1.6* | 0.83 | 1.00 | 0.92 | 0.76 | 0.64 |
| *2.0* | 0.83 | 1.01 | 0.93 | 0.76 | 0.65 |

La Figura 1 muestra un resumen del conjunto de las Tablas I a V mostrando las variaciones en p.u. de las diferentes magnitudes respecto del caso base. En todos los casos se consideró la columna “promedio” de las tablas salvo en el caso de la energía racionada en que se consideró la columna correspondiente a un probabilidad de excedencia de 5%.

Fig. 1. Resumen de sensibilidades en p.u.




En la Figura 1, se puede apreciar que la mayor sensibilidad la presenta la energía racionada con probabilidad de excedencia 5% (ER5% en la figura) teniendo sensibilidad negativa, seguida de los Costos Operativos Directos (COD, térmicos más importaciones) con sensibilidad positiva y aproximadamente con el mismo nivel de sensibilidad están la Energía generada Hidráulica (EHid) y los Ingresos de 1MW al Spot (I1S) con sensibilidades negativa y positiva respectivamente.

Al aumentar los CVR el optimizador ve que le resulta más costoso racionar e intenta disminuir la energía racionada (sensibilidad negativa de ER5%), para ello intenta mantener el nivel de los lagos más altos para disponer de la energía en los momentos que pueda usarla para disminuir el racionamiento generando por lo tanto menos con las hidráulicas (sensibilidad negativa de EHid). Como contrapartida debe generar más con las térmicas o importar más energía (sensibilidad positiva de COD). Al aumentar el costo de generación sube el costo marginal del sistema y por lo tanto el precio spot de ahí la sensibilidad positiva de I1S. La menor sensibilidad de I1S está asociada a que el precio spot está topeado a 250 USD/MWh.

Es importante observar en la Fig.1., que ER5% tiene pendiente superior para los casos de menor CVR que para los casos con mayor CVR. Este comportamiento de “saturación” indica que por más que se eleven los CVR llegará un momento que no es posible disminuir la energía de racionamiento con los recursos disponibles.

La Figura 2, muestra la valorización del agua de la principal represa del sistema uruguayo (Lago de Rincón del Bonete). La figura corresponde a la valorización realizada suponiendo una condición hidrológica media.

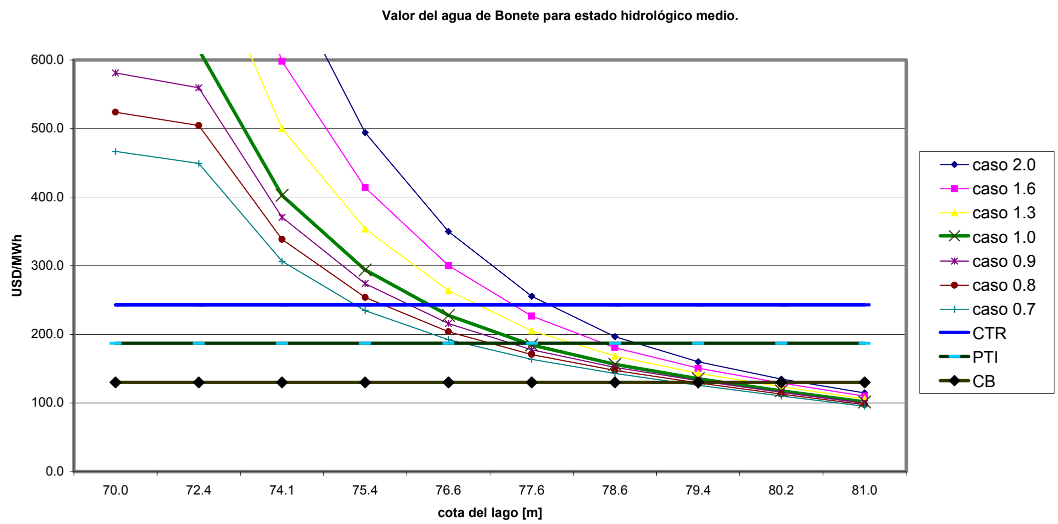



Fig. 2. Valor del agua de Bonete vs. Térmicas del sistema.

Las rectas horizontales de la Fig. 2. corresponden a los costos variables de generación de las principales centrales térmicas del sistema. La recta horizontal superior corresponde a los CV de la CTR y como se puede observar, para el caso 0.7 se despacha la CTR si la cota del lago baja de 75.4 m mientras que si consideramos el caso 2.0 la CTR será despachada si la cota del lago baja de 77.85 m. En definitiva, la Fig. 2. nos muestra en qué medida somos más conservadores en el uso del agua del lago al subir los CVR.

De la Fig. 2. se puede concluir que la política de uso del agua del lago de Rincón de Bonete tiene una sensibilidad importante a los CVR considerados. Esta sensibilidad parece demasiada cuando se compara con la sensibilidad mostrada por la generación hidráulica (EHid en la Fig. 1.), pero se debe tener en cuenta que la generación hidráulica está referida al conjunto de centrales hidráulicas del país y que en ese conjunto la central de la represa de Rincón de Bonete genera solamente el 20% de la demanda aproximadamente.

## CONCLUSIONES

Se mostró la importancia del Costo de Racionamiento de Largo Plazo en la determinación de la política de uso del agua del principal embalse del Uruguay. La sensibilidad de los costos directos de operación y de los ingresos al spot a los valores del CRLP son poco relevantes comparados con la sensibilidad de la energía de racionamiento, por lo que parece razonable que ante un desajuste de los CRLP por variaciones bruscas en los costos de los combustibles se busque compensar dicho desajuste considerando valores de CVR incrementados hasta que se disponga de los nuevos valores de CRLP. Cuánto incrementarlos dependerá de la reducción que se tenga de la energía de racionamiento (valorizada al valor incrementado) por dicho incremento vs. el aumento de los costos operativos directos.

## REFERENCIAS


[1] Luis Vargas, Costo de Racionamiento de Larga Duración en el Mercado Eléctrico. (http://iie.fing.edu.uy/epim2008/programa/luis%20vargas-costoracionamientolargaduracion.pdf).

[2] Sitio web del simulador SimSEE. (http://iie.fing.edu.uy/simsee).

# 69. Decision of the Monthly Seasonalization of Electricity Supply Contracts in Brazil based on the Optimization of the Omega Measurement (Ω)

**Mario Domingues Simões- Leonardo Lima Gomes- Luiz Eduardo Brandão**

IAG Business School - Pontifícia Universidade Católica do Rio de Janeiro

Rua Marquês de São Vicente, 225, Gávea, RJ

Phone: 55-21-21389301 ; Fax: 55-21-21389272

leonardolima@iag.puc-rio.br ; msimoes@alum.mit.edu ; brandao@iag.puc-rio.br

ABSTRACT: Electricity supply contracts, in Brazil, are governed and implemented in the Electrical Energy Commerce Chamber (Câmara de Comercialização de Energia Elétrica - CCEE), and display certain flexibilities, among which there is the possibility of seasonalizing the contracted energy supply, as long as the total delivered during the contract is equal to that contracted. The alternative for an energy supplier is to sell the energy in the spot market, which may be or not a lucrative alternative, depending on then current spot prices as compared to that contracted. In this work, it is made a brief description of the behavior of the contract and its possible seasonalization, as well as a description and considerations about the omega performance indicator chosen. In the end, it is made a proposal about how to define the best energy supply profile, for the twelve months of the contract time span, based on an optimization of the omega measurement. The omega measurement indicates the ratio between the gains and the losses portions of a results probability distribution, relative to a target result defined. In the implementation of the proposed solution, such factors as the method for the calculation of the omega indicator and the generation of an initial optimization guess are taken into account. The results obtained clearly show the inverse proportionality between the level of gain desired and the amount of risk that must be born. Besides, it can also be observed a very high initial growth of the VaR incurred, but with an assymptotic stabilization tendency, for the various levels of gain targets.

Keywords: decision analysis; omega measurement; electricity

Introdução

O setor elétrico brasileiro (SEB) passou por grandes mudanças nos últimos anos, destacando-se a reformulação do setor que foi iniciada a partir do segundo semestre de 1997, quando foram efetuadas as primeiras privatizações no setor. Até aquele ponto a situação era, basicamente, traduzida em um monopólio estatal administrado por empresas federais e estaduais. A partir daquele momento as privatizações foram iniciadas, ao mesmo tempo levando a uma grande reestruturação do setor.

As mudanças então iniciadas foram baseadas no chamado Projeto de Reestruturação do Setor (Projeto RE-SEB), coordenado pelo Ministério de Minas e Energia, apresentando como principais características:

a desverticalização da produção, transmissão, distribuição e comercialização de energia elétrica;

os segmentos de produção e comercialização passaram a desfrutar de liberdade para competir, com preços contratados definidos pelo mercado;

geradores e comercializadores foram permitidos ter livre acesso às redes de transmissão e distribuição;

foi criado o Mercado Atacadista de Energia (MAE), atualmente rebatizado de Câmara de Comercialização de Energia Elétrica (CCEE), como sendo um ambiente de contabilização e liquidação da energia elétrica negociada.

Em seguida, o formato de negociação de energia foi aprimorado. Os ambientes de negociação de energia elétrica foram estabelecidos no decreto nº 5.163 de 30 de Julho de 2004, sendo regulamentados na forma do Ambiente de Contratação Livre (ACL) e Ambiente de Contratação Regulada (ACR).

O ACL é definido como o segmento do mercado no qual se realizam as operações de compra e venda de energia elétrica, objeto de contratos bilaterais livremente negociados. Já o ACR é o ambiente que envolve as contratações de energia com as distribuidoras por meio de processos regulados.

Empresas de geração podem vender energia tanto no ACR como no ACL a depender da estratégia adotada. No caso específico das hidrelétricas, essas possuem uma capacidade máxima de contratação de energia denominada energia assegurada.

A energia assegurada pode ser definida como a energia que uma hidrelétrica consegue disponibilizar ao sistema em uma situação hidrológica crítica, dado um nível de confiabilidade de 95%. Por exemplo, uma hidrelétrica pode ter 450 MWmed de capacidade instalada, mas apenas 200 MWmed de energia assegurada dada uma situação hidrológica desfavorável. Assim, esta hidrelétrica só poderá realizar contratos de venda totalizando até 200 MWmed. O conceito de MWmed será detalhadamente explicado na seção 2.1, adiante.

Devido ao consumo sazonal de energia no Brasil, foi estabelecida uma flexibilidade para as hidrelétricas conhecida como sazonalização da energia assegurada sendo de particular interesse e objeto deste trabalho.

A sazonalização permite que, a cada ano, o agente de geração hidrelétrica declare para o ano seguinte o quanto será a energia mensal fornecida, respeitando-se os limites inferior de zero e superior da capacidade instalada, e o total anual da energia assegurada.

Assim, considerando o exemplo anterior, a hidrelétrica que detém 200 MWmed de energia assegurada pode escolher uma sazonalidade a partir da qual possui 400 MWmed no mês de janeiro e 0 MWmed no mês de Dezembro, mantendo-se em 200 MWmed a energia assegurada nos outros meses. A média anual permaneceu em 200 MWmed e o limite superior da capacidade instalada não foi violado (450 MWmed).

Dessa forma, é possível haver fornecimentos de energia acima ou abaixo da média especificada, durante o período contratado, desde que o total fornecido no período obedeça ao contrato firmado.

Quando isso acontece, sendo a energia assegurada mensal maior ou menor do que a energia contratada, as diferenças contabilizadas a maior ou a menor são liquidadas de acordo com os preços de curto prazo (Preço de Liquidação das Diferenças - PLD), que podem ser maiores ou menores do que o preço fixo contratual.

A análise da decisão sobre o perfil de sazonalização é uma questão prática com a qual os agentes de geração hidrelétrica se deparam anualmente, sendo uma das principais decisões comerciais de um gerador.

Ressalta-se que as empresas de geração que realizam a sazonalização como uma operação descasada têm uma preocupação muito grande em controlar o risco e, conseqüentemente, o tamanho deste descasamento. É comum que estas empresas utilizem o *Value at Risk* (VaR) para controlar a exposição ao risco de mercado. Na seção 3.1 é apresentada a definição cuidadosa de VaR.

Assim, a questão de pesquisa que se pretende abordar no presente trabalho diz respeito à seguinte situação: *"Qual é a melhor forma de sazonalizar a energia assegurada maximizando o resultado da hidrelétrica e considerando-se restrições de valor em risco (VaR)"*?

No sentido de responder a esta questão, a maximização da medida ômega (Ω) foi escolhida como critério de seleção do perfil da sazonalização, a cada período contratual, dado um nível de VaR. A medida Ω foi escolhida porque consegue incorporar todos os momentos da distribuição, fornecendo uma completa descrição das características do risco-retorno, de tal modo que resulta em uma medida intuitivamente atrativa e facilmente computável.

No caso específico de trabalhos sobre comercialização de energia elétrica no Brasil, observam-se distribuições de preços extremamente afastadas da normalidade, o que torna o uso da medida Ω particularmente valioso.

Além de procurar responder a uma pergunta associada a um problema real, este artigo contribui com a utilização de uma técnica recente de otimização de carteira que é a maximização da medida Ω com restrição de VaR. Adicionalmente, apresenta variáveis e especificidades do SEB pouco exploradas em trabalhos científicos brasileiros.

Este trabalho está organizado da seguinte forma: a seguir será feita uma introdução ao mercado de energia elétrica no Brasil buscando apontar e explicar algumas características de fornecimento e operação deste mercado. A seguir, será feita uma revisão da literatura com uma explicação sobre a função ômega e suas particularidades. Após esta explicação, serão apresentadas a modelagem do problema, as soluções obtidas e, finalmente, serão enunciadas as conclusões e recomendações.

## O Mercado de Energia Elétrica no Brasil

### Formatação dos Contratos

No Brasil, a unidade básica negociada em contratos de energia elétrica é o megawatt-hora (MWh), com os preços negociados em reais por megawatt-hora (R$/MWh). Um contrato especifica as quantidades de energia elétrica a serem entregues durante determinados intervalos de tempo.

Seja um contrato com prazo de dois meses, para entrega em março e abril de determinado ano, que determina que o fornecedor entregue 74.400 MWh em março e 72.000 MWh em abril. Se o preço contratado for de 50 R$/MWh, o faturamento do fornecedor deverá ser de R$ 50 x 74.400 em março e de R$ 50 x 72.000 em abril.

Como os meses de março e abril têm, respectivamente, 744 e 720 horas, o valor médio de energia entregue será de 100 megawatts (MW). É bastante comum que a quantidade negociada seja expressa em MW, mais especificamente em MW médios (MWmed), indicando ser esta a média no período. A quantidade negociada, de 100 MWmed para março e abril, equivale a 100 (MW) x 744 (horas) MWh em março e 100 (MW) x720 (horas) MWh em abril.

O mercado brasileiro de energia elétrica está dividido em quatro sub-mercados, ainda que o sistema seja integrado em âmbito nacional. Dependendo da situação do armazenamento de água, da oferta e da demanda, cada sub-mercado pode apresentar preços bastante diferentes. Daí a importância da especificação do local da entrega em cada contrato.

No exemplo aqui apresentado, o contrato seria expresso com as seguintes características:

ponto de Entrega: Sub-mercado Sudeste/Centro-oeste;

duração: Março e Abril do ano tal;

quantidade: 100 MWmed;

preço: 50 R$/MWh.

A Sazonalização

Segundo a CCEE, *"Sazonalização é o processo de alocar mensalmente um montante anual de energia, seja de um contrato ou a energia assegurada de uma usina"*. Ou seja, trata-se de uma das principais flexibilidades automaticamente inseridas na capacidade de fornecimento de uma hidrelétrica, em um contrato.

A sazonalização da Energia Assegurada possui como limites a máxima capacidade instalada e zero. Assim, uma Pequena Central Hidrelétrica (PCH) de capacidade de geração de 20 MW, poderia ter uma quantidade de energia assegurada no âmbito da CCCE aferida em 10 MWmed, e poderia sazonalizar seu contrato de fornecimento de energia entre 0 e 20 MWmed, conforme sua expectativa das condições esperadas no período.

Supondo-se que a PCH do exemplo anterior tivesse contratado uniformemente toda a sua energia assegurada de 10 MWmed, no caso em que a energia sazonalizada mensal fosse abaixo dos 10 MWmed contratados, a diferença seria contabilizada como um débito contra este fornecedor, ao PLD do período. Ao contrário, seria um crédito nas mesmas condições.

Partindo-se da premissa de que a sazonalização levará a geradora a ter excedentes em alguns meses e déficits em outros, a simulação dos PLDs se torna uma informação bastante relevante na análise de decisão. A seguir, descreve-se como o PLD é formado a partir da operação ótima de um sistema hidrotérmico.

## Formação e Simulação dos PLDs

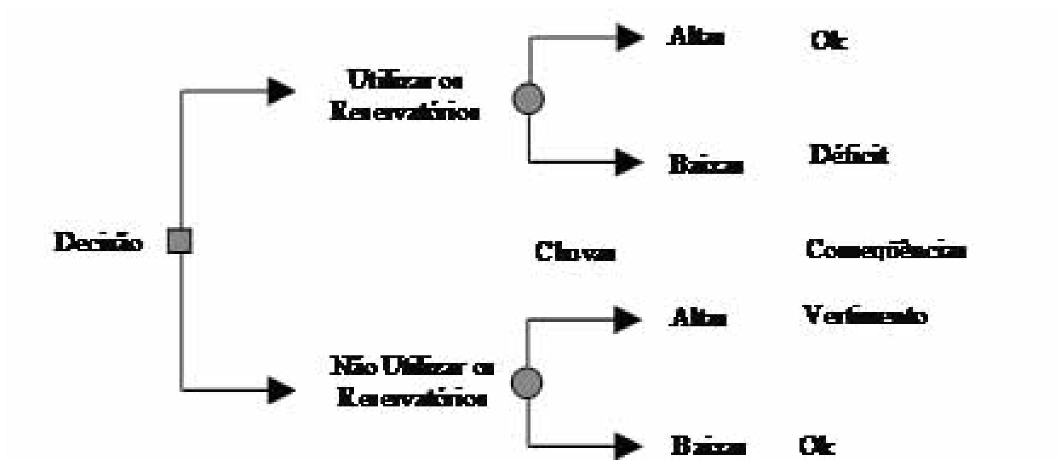
O PLD é utilizado para liquidar a compra e a venda de energia no mercado de curto prazo. A formação do preço da energia comercializada no mercado de curto prazo se faz pela utilização dos dados considerados pelo Operador Nacional do Sistema (ONS) para a otimização da operação.

O Brasil adotou um esquema de decisão de operação centralizado realizado por modelos acoplados de otimização, sendo um modelo de médio prazo acoplado a um de longo prazo, chamado Newave, cujo objetivo é minimizar o custo total de operação do sistema hidrotérmico ao longo de um horizonte de planejamento. Esses modelos utilizam o método de programação dinâmica dual estocástica descrita em Pereira e Pinto (1991). A fim de conceituar melhor a formação de preço no sistema hidrotérmico brasileiro, torna-se necessária uma abordagem sobre como é feita a operação sob uma ótica econômica. As seções a seguir apresentam essa abordagem.

## Operação de um Sistema Hidrotérmico

A característica mais evidente de um sistema com geração hidroelétrica é poder utilizar a energia “grátis” que está armazenada nos reservatórios para atender à demanda evitando, desta maneira, gastos de combustível com as unidades térmicas. Entretanto, a disponibilidade de energia hídrica está limitada pela capacidade de armazenamento nos reservatórios. Isto introduz uma dependência entre a decisão operativa de hoje e os custos operativos no futuro.

**Figura 39 – Uso Ótimo da Água (GOMES; LUIZ 2009)**




Em outras palavras, se utilizarmos hoje as reservas de energia hídrica, com o objetivo de minimizar os custos térmicos, e ocorre uma seca severa no futuro, pode haver um racionamento de custo elevado para a sociedade. Se, por outro lado, preservamos as reservas de energia hídrica, através de um uso mais intenso de geração térmica, e as afluências futuras são elevadas, pode ocorrer um vertimento nos reservatórios do sistema, o que representa um desperdício de energia e, conseqüentemente, um aumento no custo operacional. Esta situação está ilustrada na Figura 39.

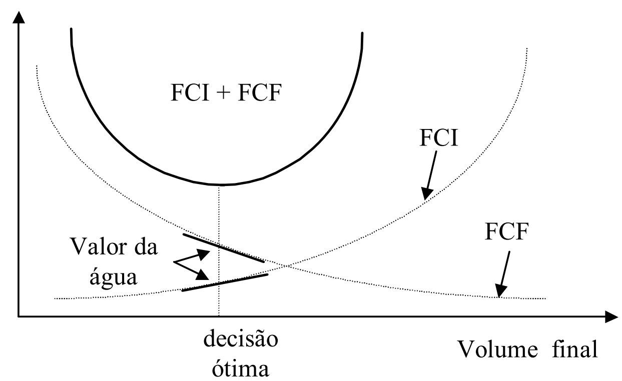
O operador de um sistema hidrotérmico deve comparar o benefício imediato do uso da água e o benefício futuro de seu armazenamento, conforme ilustrado na Figura 2.

A *função de custo imediato - FCI* - representa os custos de geração térmica no estágio *t*, ou seja, no estágio imediato, presente. Observa-se que o custo imediato aumenta à medida que diminui a energia hídrica disponível, isto é, quanto menor for a decisão de geração hídrica, maior será a de geração térmica.

Por sua vez, *a função de custo futuro - FCF* - está associada ao custo esperado de geração térmica e racionamento do final do estágio *t* (início de *t+1*) até o final do período de estudo. Esta função diminui à medida que aumenta o volume armazenado final, pois haverá mais energia hídrica disponível no futuro.

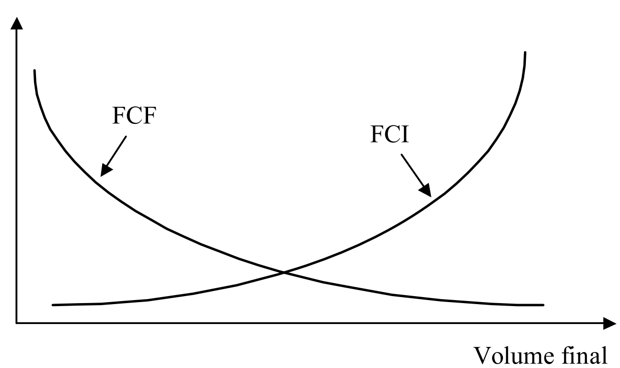
O uso ótimo da água armazenada corresponde ao ponto que minimiza a soma dos custos imediato e futuro. Como é mostrado na Figura 41, o ponto de mínimo custo global corresponde ao ponto onde os módulos das derivadas da FCI e da FCF com relação ao armazenamento de água se igualam. A derivada da FCI e da FCF no ponto ótimo também é conhecida como valor da água, pois

**Figura 41 – Uso Ótimo da Água (GOMES; LUIZ 2009)**




representa a taxa custo R$ (ou valor) por volume de água deixado no

**Figura 40 – Custo Imediato e Futuro (GOMES; LUIZ 2009)**




reservatório para formar o volume final.

Revisão da Literatura e a Medida Ômega (Ω)

Alguns Métodos de Escolha de Carteiras

O trabalho de Markowitz (1952) foi o precursor na análise de decisão em formação de carteiras, tendo ele utilizado a variância do retorno da carteira como medida de risco. Em seu trabalho, deseja-se obter uma carteira de risco mínimo, ou seja, de variância mínima, sujeita a restrições de uso do capital e de limite mínimo de retorno nesta carteira.

O risco sobre o retorno pode ser tratado como uma variável aleatória, sendo que apenas o segundo momento da distribuição de probabilidades do retorno é tomado como indicador para definir a maior ou menor exposição ao risco do ativo em pauta.

Adicionalmente ao trabalho desenvolvido por Markowitz, surgiram medidas e índices de desempenho utilizados para escolher carteiras. Os resultados formalizados pelos tradicionais trabalhos de Treynor (1965), Sharpe (1966) e Jensen (1968) contribuíram com alguns índices amplamente conhecidos e aceitos no mercado. A partir destes, a literatura cita inúmeros trabalhos que abordaram a análise de risco, enriquecendo de sobremaneira as alternativas para a mensuração de resultados.

O índice de Sharpe (IS), por exemplo, avalia o desempenho de uma carteira levando-se em conta a divisão entre o retorno esperado e o desvio padrão do retorno da carteira.

Na evolução dos critérios de escolha de carteiras e controle de risco, surgiu o *Value at Risk* (VaR), forma de quantificação desenvolvida pelo banco JP Morgan (1996). Esta é uma forma sistemática resultante do esforço de determinar, a cada período, qual o valor de perda dado um certo nível de significância estatística.

Assim, um $VaR_{95\%}$ traduz, em um número, que há 5% de probabilidade de que um valor maior do que o indicado seja perdido. Isto quer dizer que, dada a distribuição de valores que se acredita válida, por exemplo, a distribuição de retornos de determinada carteira, o VaR corresponderá ao valor associado a um percentil extremo definido daquela distribuição (normalmente 1% ou 5%).

A Medida Ômega

Muitas dificuldades são encontradas no momento de definir uma adequada medida de desempenho de um ativo ou de uma carteira. A maioria dos indicadores considera duas importantes simplificações: a média e a variância descrevem completamente a distribuição de retornos.

Estas simplificações são válidas se é assumida uma distribuição normal dos retornos ou valores, mas é geralmente aceito o fato empírico de que os retornos dos investimentos não possuem uma distribuição normal. Assim, além da média e variância, momentos de ordem superior são necessários para mais exatamente descrever a distribuição.

Apresentada por Keating e Shadwick (2002), a medida Ômega (Ω) consegue incorporar todos os momentos da distribuição. Ela fornece uma completa descrição das características do risco-retorno, de tal modo que resulta em uma medida intuitivamente atrativa, além de ser facilmente calculada, como será visto a seguir. Ao invés de estimar alguns momentos individuais, a medida Ω considera o impacto total da distribuição, o qual é certamente de interesse dos tomadores de decisão.

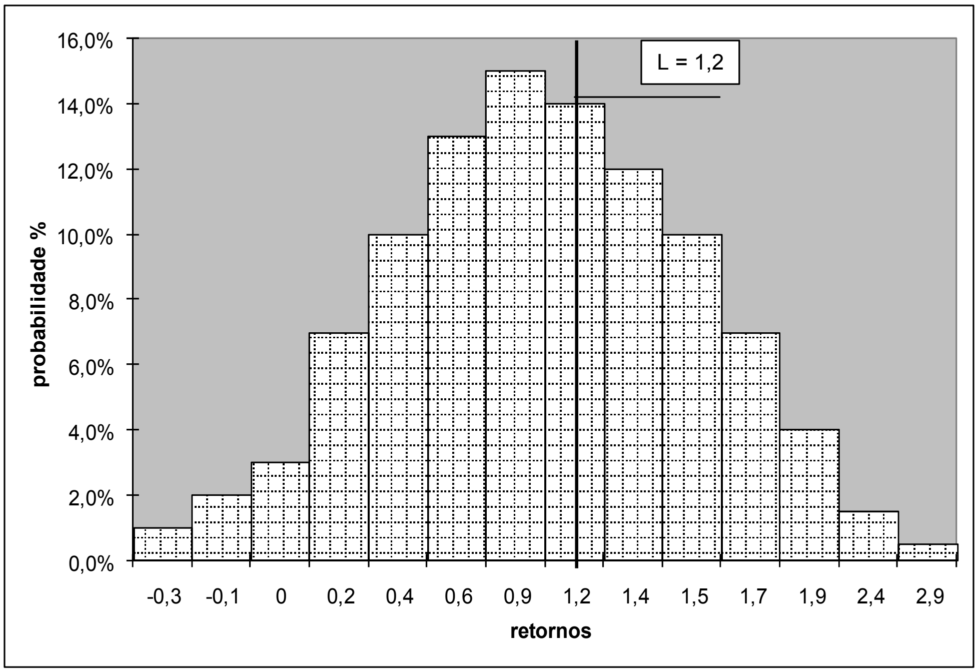
A medida Ω, por definição, leva em conta um nível de retorno ou valor chamado de “limite” (L), definido exogenamente, o qual é a fronteira entre o que se considera como ganho e como perda. Mesmo em distribuições normais, dependendo do valor do L, a medida Ω fornece informações adicionais que só a média e variância não conseguiriam. Isto levaria a obter diferentes resultados em otimização de carteiras, se comparado com a otimização clássica de Markowitz.

Cabe destacar que a definição de um limite (L), também interpretado como uma meta, possui alta aderência com a realidade das empresas e do mercado financeiro. Empresas e investidores estão habituados a definir metas, abaixo das quais se considera uma perda e acima das quais se considera um ganho.

A utilização da medida Ω é recente, tendo grande potencial de desenvolvimento e novas aplicações. Alguns trabalhos que empregaram este índice de performance podem ser citados. Kazemi, Schneeweis e Gupta (2003) discutem o uso da medida, trazendo como contribuição a demonstração de que a função Omega Ω(L) pode ser escrita como uma divisão de dois valores esperados, ganhos esperados e perdas esperadas. Ick e Nowak (2006) fazem uma proposta para otimizar uma carteira de ações utilizando a medida Ω. Castro (2008) utiliza a otimização da medida Ω na escolha de carteiras de projetos com opções reais. Ele aplica a metodologia desenvolvida a projetos do setor petrolífero brasileiro.

Definição e Cálculo da Medida Ômega

Com a finalidade de exemplificar o cálculo da medida Ω será considerada uma distribuição de retornos de um ativo apresentada na Figura 42. A meta (ou




limite) de retorno adotada foi de L =1,2.

Esta distribuição servirá para ilustrar o conceito da medida Ω e a forma de calcular o valor da função Ω para um determinado limite L, dada uma distribuição de retornos esperada para um ativo, seja ele um ativo único ou uma carteira ou coleção deles (CASTRO, 2008).

Assim, uma vez dada a distribuição e especificado o limite L, pode-se comparar a probabilidade de ganhos e perdas ponderados pelo seu valor. O ganho esperado de um retorno maior do que L é o valor esperado (condicional) dos retornos que excedem L ou $E(r|r \geq L)$; a perda esperada é obtida como $E(r|r<L)$.

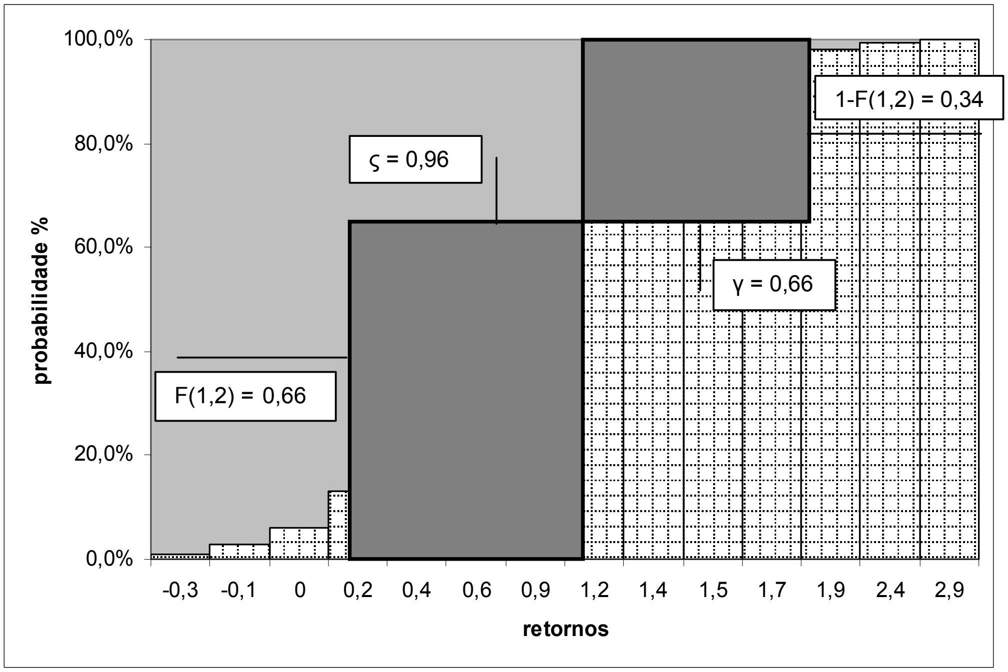
Desta forma, o ganho esperado e a perda esperada, no caso da distribuição da Figura 4, podem ser calculados como:

$\gamma = E(r|r \geq L) - L = E(r|r \geq 1{,}2) = (1{,}2+1{,}4+1{,}5+1{,}7+1{,}9+2{,}4+2{,}9)/7 - 1{,}2 = 0{,}66$

$\varsigma = E(r|r<L) - L = E(r|r<1{,}2) =(-0{,}3-0{,}1+0+0{,}2+0{,}4+0{,}6+0{,}9)/7 -1{,}2 = -0{,}96$

Visualmente tem-se uma situação como a que é mostrada na Figura 43. É importante notar que os valores médios esperados dos ganhos e perdas não são informativos por si só, mas devem ser ponderados pelas suas probabilidades.

**Figura 43 – Ilustração das Parcelas de Ganho e Perda**

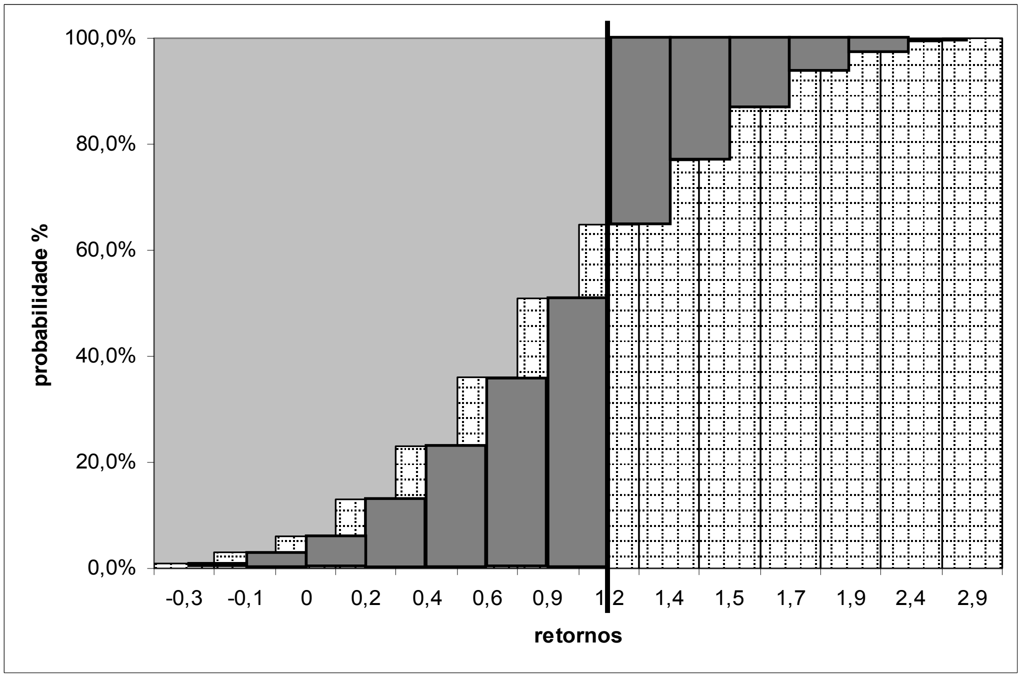



Assim, se F(r) for a função de distribuição cumulativa de probabilidades para os retornos, tem-se que a probabilidade de que um retorno seja menor do que o limite L é F(L), e a probabilidade de que um retorno seja maior do que o limite L é 1-F(L)

A medida Ômega pode ser definida, então, como $\Omega = [\gamma \times (1-F(L))] / [\varsigma \times F(L)]$, o que daria uma indicação da qualidade do retorno dos ativos em relação ao limite requerido L. Na Figura 43, apresenta-se a distribuição cumulativa de retornos para o ativo do exemplo. Pode-se observar o índice Ômega através de seus numerador e denominador, os retângulos superior direito e inferior esquerdo, respectivamente.

Conforme visualizado no gráfico da Figura 43, o valor de Ω pode ser determinado como sendo $\Omega = (0,66 \times 0,34) / (0,96 \times 0,66) = 0,354$. Entretanto, este cálculo de Ω apenas considera um valor para os ganhos, o ganho médio, assim como um único para as perdas. Aprimorando-se o cálculo, podem ser utilizados todos os valores disponíveis no intervalo, conforme ilustrado na Figura 44.

**Figura 44 – Ilustração das Parcelas Ganho e Perda com Todos os Valores**




Quando a distribuição de probabilidades deixa de ser discreta, isto é, quando ela realmente se torna uma função de densidade definida em todo o conjunto dos números reais, e os intervalos de valores de retornos tornam-se menores até o limite em que tendem a zero; a forma serrilhada da curva de distribuição cumulativa aproxima-se de uma linha contínua e o cálculo da função Ômega para uma certa distribuição de freqüência e dado um limite dos retornos requerido L, torna-se o valor Ω(L) e é o resultado da divisão da área superior pela inferior do gráfico, conforme mostrado na Figura 45.

A função Ômega, na forma de sua definição e calculada na sua forma contínua, pode ser definida de acordo com a equação:

$$\Omega(L) = \frac{I_2}{I_1} = \frac{\int_L^b [1 - F(x)]dx}{\int_a^L F(x)dx} \qquad (1)$$

onde: *F(x)* = função de distribuição cumulativa (FDC) dos retornos “x”

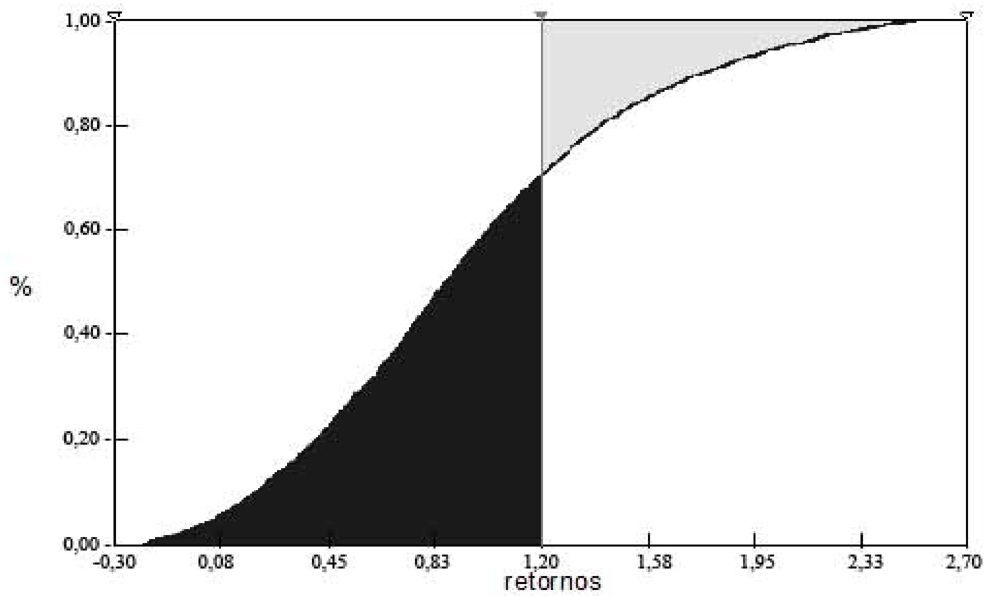
*L* = nível mínimo requerido dos retornos

*a* = menor retorno

*b* = maior retorno

A função Ω(L), assim definida, engloba todas as características da distribuição de retornos, pois considera toda a função de distribuição destes, incorporando todos os efeitos dos momentos de ordem superior que porventura possam ser relevantes. Mais detalhes sobre a definição e as propriedades da medida Ω podem ser encontrados em Kazemi, Schneeweis e Gupta (2003).

**Figura 45 – Ilustração das Parcelas Ganho e Perda com Todos os Valores**




Metodologia

Modelagem dos Resultados Considerando Sazonalização

A sazonalização da quantidade de energia assegurada versus a quantidade contratada uniforme, em contratos de fornecimento de energia elétrica, será decidida em função dos ganhos esperados da comercialização da energia de acordo com as condições contratuais *vis a vis* os resultados obtidos com sua venda, ou compra, no mercado livre ao PLD do momento.

Assim, em primeiro lugar, é necessário que sejam definidos os limites possíveis desta sazonalização. Em seguida, deve-se obter um conjunto de PLDs simulados, preços de liquidação para esta quantidade de energia, a cada momento.

Aqui será considerado o caso de uma PCH com energia assegurada de 10 MWmed, e um respectivo contrato de venda no mesmo montante e uniforme ao longo dos meses, em um ano. Esta PCH tem uma capacidade instalada de 20 MWmed. Assim, o limite mensal de sazonalização é de 100% para cima ou para baixo, isto é, com entrega de 0 a 20 MWmed, a cada mês.

O resultado de uma sazonalização da energia assegurada, para o caso desta PCH, será a diferença entre o valor da energia produzida e entregue nas condições de contrato, e o da energia comprada no mercado livre (no caso de entrega menor do que o valor contratado) ou da energia vendida naquele mercado (no caso de entrega maior do que o valor assegurado), para cada mês de liquidação.

Para cada uma destas situações, a única variável a ser considerada é o preço de liquidação das diferenças (PLD), uma vez que todos os demais fatores são constantes ou fixos, e iguais para quaisquer das alternativas.

Para cada mês considerado, a seguinte equação (2) traduz os resultados obtidos em relação ao contrato de venda de energia uniforme e a preço fixo:

$$\sum_{i=1}^{12} R_i = \sum_{i=1}^{12} (Ea_i - Ec) \times (h_i) \times (PLD_i - Pc) \times (1 - I) \qquad (2)$$

onde: $i$ = mês

$R$ = resultado apurado

$Ea$ = energia assegurada (MWmed)

$Ec$ = energia contratada (MWmed)

$h$ = número de horas no mês

$PLD$ = PLD médio mensal (R$/MWh)

$PC$ = preço contratado (R$/MWh)

$I$ = total de impostos e taxas

É importante notar que o resultado da equação (3) é o valor em R$, referente à soma mensal dos superávits ou déficits de uma determinada sazonalização durante o período de um ano, em relação a entrega (venda) “flat” pura e simples.

Estes cálculos podem ser baseados em séries simuladas dos PLDs para o período em questão. Ora, esta coleção de resultados calculados de acordo com a equação (2) produzirá uma distribuição de probabilidade de valores resultado. Por exemplo, para a simulação de 2000 séries de PLDs serão obtidas 2000 séries de valores mensais, chegando-se a 2000 valores de resultados anuais.

Cálculo e Simulação dos PLDs

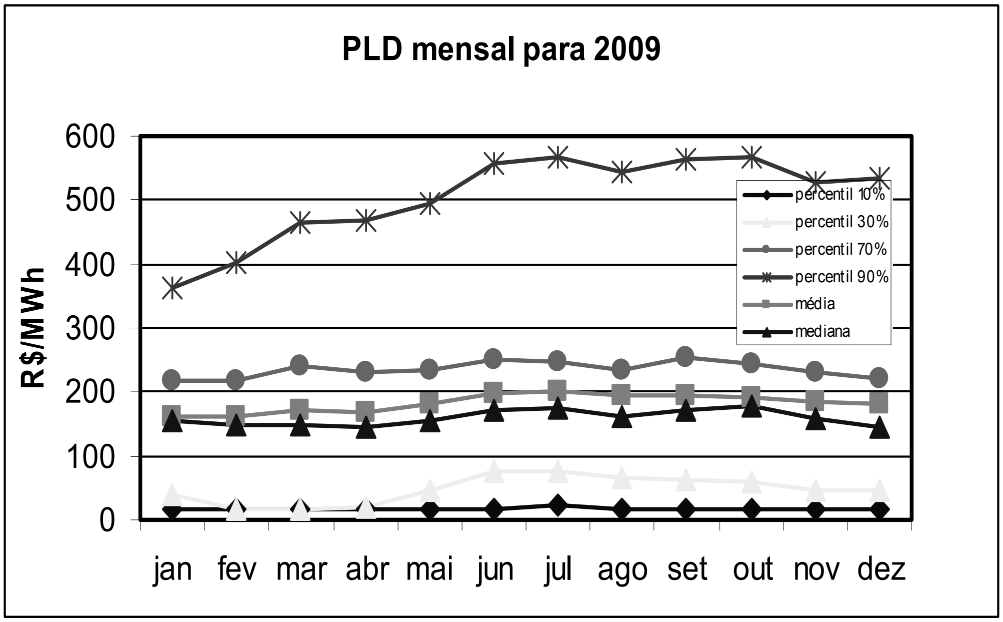
Embora de fundamental importância na consecussão do objetivo deste trabalho, os PLDs não foram um objeto deste mas obtidos através do procedimento da própria CCEE. A formação e simulação destes PLDs foi efetuada através do modelo Newave-versão 14, elaborado pelo Centro de Pesquisas de Energia Elétrica (CEPEL).

Como mencionado anteriormente, este modelo otimiza a estratégia de geração de longo prazo, de acordo com o conceito comentado anteriormente, simulando preços em base mensal. Cabe ressaltar, mais uma vez, que este é o próprio modelo utilizado na formação dos preços de curto prazo (PLD), publicados na CCEE.

Foram utilizados os dados de entrada empregados no programa mensal de operação de agosto/2008, coordenado pelo Operador Nacional do Sistema (ONS), sendo considerados um piso de preço de R$ 15,47/MWh e um teto de R$ 569,59/MWh, segundo o Despacho ANEEL Nº 002 de 04/01/2008.

As 2000 séries de preços obtidas formaram a distribuição estatística de preços prováveis para o período em que se deseja analisar e calcular a sazonalização ótima, que forneça um resultado máximo possível do total dos resultados a serem obtidos. A Figura 46 apresenta os percentis referentes às distribuições de probabilidade correspondentes aos PLDs simulados.

**Figura 8 – Percentis Referentes à Simulação de PLDs**




Os dados do contrato de venda e das condições de sazonalização considerados no exemplo desenvolvido são apresentados a seguir:

contrato de 10 MWmed mensais de energia assegurada;

capacidade máxima de geração de 20 MWmed;

sazonalização de entrega mensal de 0 a 20 MWmed;

preço contratado de venda de R$ 100/MWh;

impostos totais de 43,25% (IR, CSSL, PIS e COFINS).

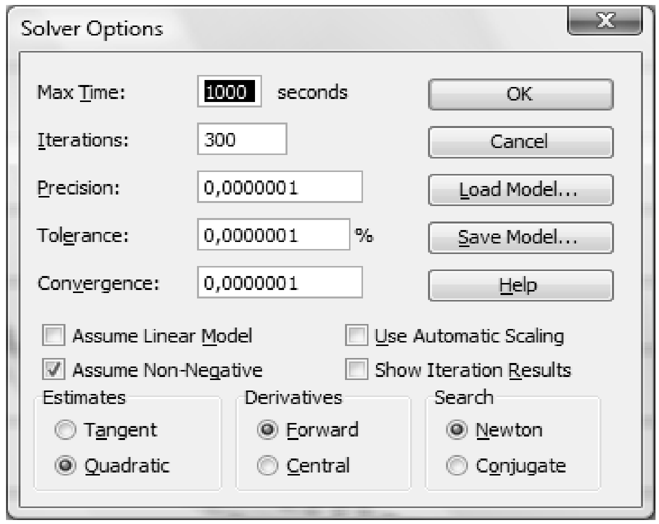
Estas características são bastante semelhantes à situação de uma PCH, conforme modelo adotado no Brasil, tornando este estudo bastante relevante a operadores deste tipo de usina.

Otimização e Convergência

Os cálculos foram efetuados em um computador do tipo PC usando-se uma planilha MS Office Excel, e com a ajuda dos programas *add-in* Solver e Solver Premium, integrados à própria planilha.

A configuração das opções de execução do *add-in* Solver, por todo o trabalho apresentado foi a seguinte, conforme **¡Error! No se encuentra el origen de la referencia.**. Houve uma grande preocupação com a qualidade dos resultados do ponto de vista numérico, isto é, qual a confiabilidade que se poderia ter em

**Figura 9 - Opções de execução do *add-in* Solver**




determinado ponto ótimo, do ponto de vista da convergência ser obtida de forma apropriada.

Já a escolha de um ponto de partida para cada corrida de otimização dos valores sazonalizados provou ter influência decisiva na convergência a um valor ótimo, evitando convergência a valores sub-ótimos regionais.

Para evitar estes problemas e poder ser mantida a mesma base de comparação, foi adotado a seguinte marcha para a escolha de um ponto de partida:

calcular ômega marginal mensal (+1 e -1 MW);

calcular diferença entre os valores marginas (sobra - falta);

escolher as 5 maiores diferenças e atribuir o dobro do valor contratado a elas;

escolher a sexta colocada e atribuir a diferença entre a soma das anteriores e o total anual do contrato;

atribuir zero aos demais seis meses.

Os cálculos efetuados de acordo com o procedimento supra geraram resultados fornecendo um perfil de distribuição sazonalizada inicial de 0 MW de janeiro a maio e em dezembro, e 20 MW de junho a outubro e 19,7 MW em novembro.

Resultados

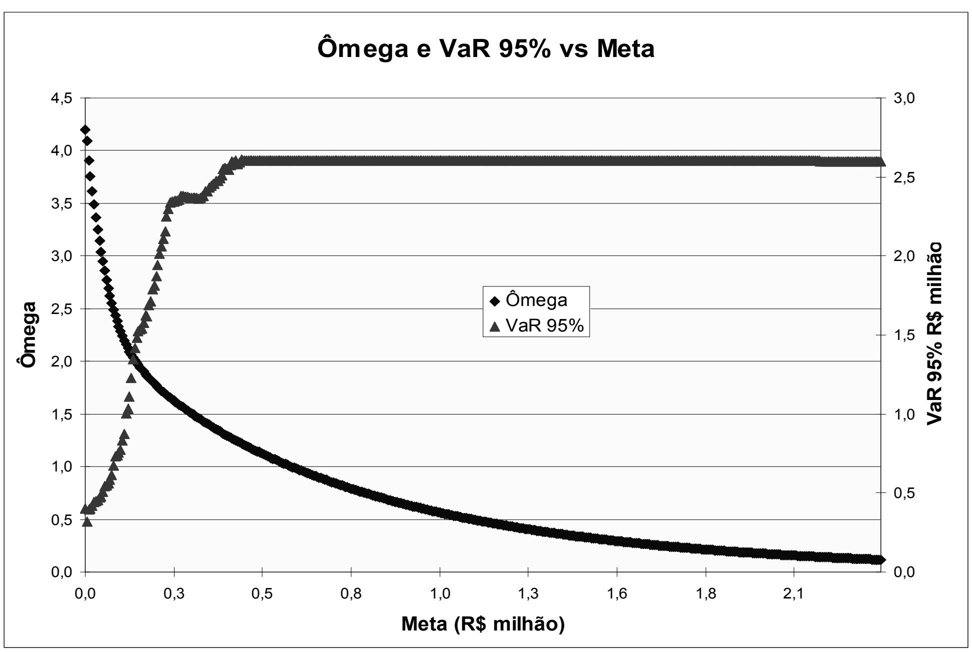
Foram realizadas várias análises de sensibilidade, analisando-se como a medida Ω varia com a mudança da meta pretendida e do $VaR_{95\%}$. Adicionalmente, estudou-se o comportamento da decisão de sazonalização propriamente dita variando-se a meta e o $VaR_{95\%}$.

Variação do Ω e do $VaR_{95\%}$ em Função da Meta

A fim de evidenciar o comportamento do Ω e do $VaR_{95\%}$ em função do limite L estabelecido, este foi variado desde zero até pouco mais de R$ 2,3 milhões, com o resultado sendo mostrado na **¡Error! No se encuentra el origen de la referencia.**.

Como pode ser observado, o valor de ômega cai rapidamente desde cerca de 4, tendendo a uma assíntota próxima de zero. Com uma sazonalização ótima podendo render algo em torno de R$ 600 mil / ano, há uma relação da ordem de 1:1, entre ganhos e perdas. A partir da **¡Error! No se encuentra el origen de la referencia.** também se pode observar que o $VaR_{95\%}$ sobe rapidamente, tendendo para um valor assintótico em torno de R$ 2,6 milhões.

**Figura 10 - Ω e VaR95% Variando-se a Meta (limite L)**



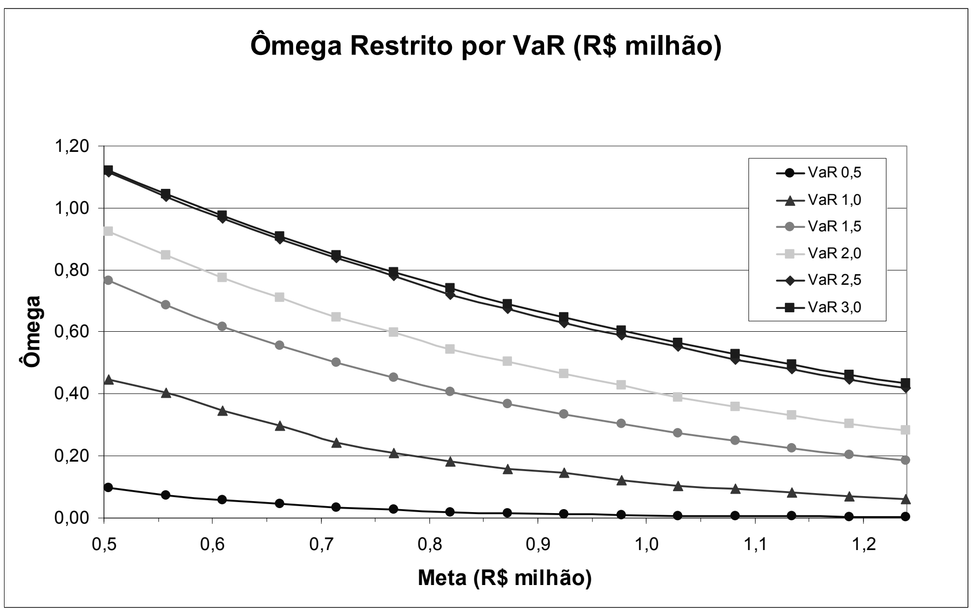
Variação do Ω Fixando o $VaR_{95\%}$

Os valores do limite L considerados variaram de R$ 0,5 milhão a pouco menos de R$ 1,3 milhão. Foram obtidas seis curvas de Ω, travando-se o $VaR_{95\%}$ de 0,5 a 3,0 milhões de R$ / ano, em adições de R$ 0,5 milhão.

As curvas apresentadas na **¡Error! No se encuentra el origen de la referencia.** mostram uma oscilação maior de valores ótimos para os níveis de $VaR_{95\%}$ mais restritivos, que correspondem a valores Ω mais baixos.

Também fica claro, e se pode facilmente observar, que as restrições mais intensas de $VaR_{95\%}$ implicam em valores de ômega extremamente pequenos. Isto denota que, se por um lado pretende-se minimizar riscos através da imposição de valores de VaR reduzidos, por outro lado, torna-se improvável alcançar metas um pouco mais audaciosas, uma vez que os níveis de Ω serão próximos a zero.

**Figura 11 – Ω com restrição de $VaR_{95\%}$**

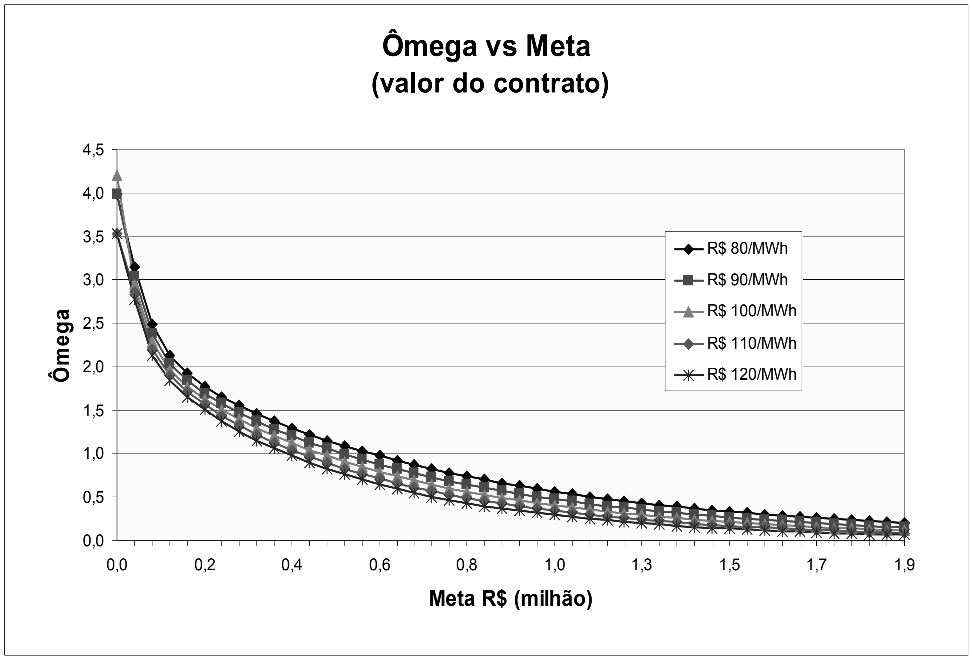



Sensibilidade de Ω e $VaR_{95\%}$ ao Preço Contratado

A **¡Error! No se encuentra el origen de la referencia.** mostra os resultados esperados para níveis de valor contratado com uma variação de 20% para mais ou para menos do valor de 100/MWh.

Valores mais baixos de preço de contrato de venda, e por conseguinte maiores diferenças possíveis entre os PLDs atingidos (para cima) e o valor base,

**Figura 12 – Ω *versus* Preços Contratuais**




favorecem ganhos com uma sazonalização ótima da entrega de energia.

Perfil de Entrega Sazonalizada

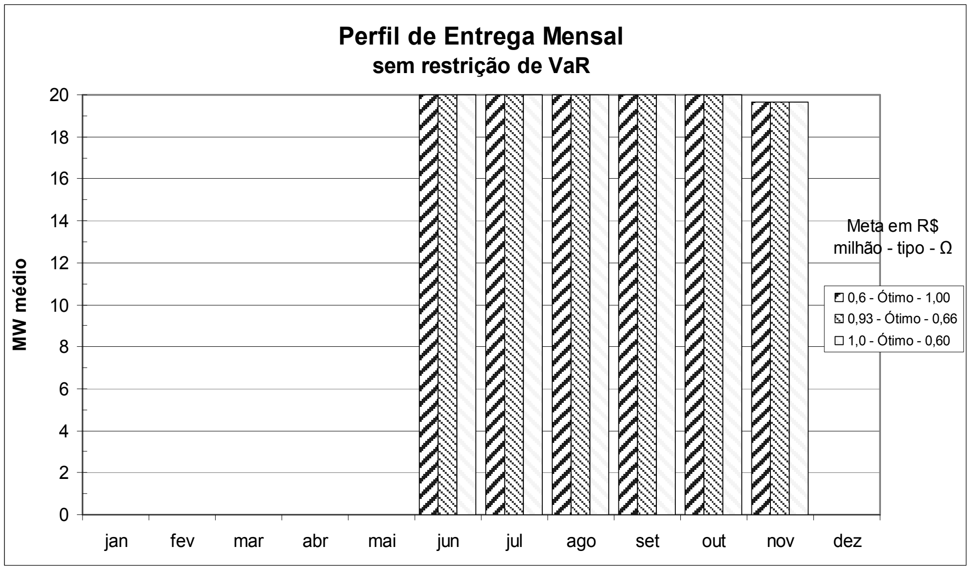
Tendo sido feitas as diversas avaliações mostradas anteriormente, resta saber qual o perfil ideal de entrega de energia em função dos parâmetros escolhidos, seja com restrição ou sem restrição de $VaR_{95\%}$.

Nas Figura 47 e Figura **48**, a seguir, pode ser visto o perfil de entrega mensal para diversos tipos de sazonalização da entrega mensal de energia.

A Figura 47 apresenta a sazonalização ótima adotando-se metas de 0,6, 0,93 e 1,0 milhão de R$ / ano; não há restrição de $VaR_{95\%}$ para estes casos. Observa-se que a decisão de sazonalização é praticamente a mesma para as três situações. Ou seja, concentrando-se toda a energia assegurada entre junho e novembro.

A Figura 48 apresenta a sazonalização ótima adotando-se metas de 0,6 e 1,0 milhão de R$ / ano. Existem três situações. Na primeira, não há restrição de

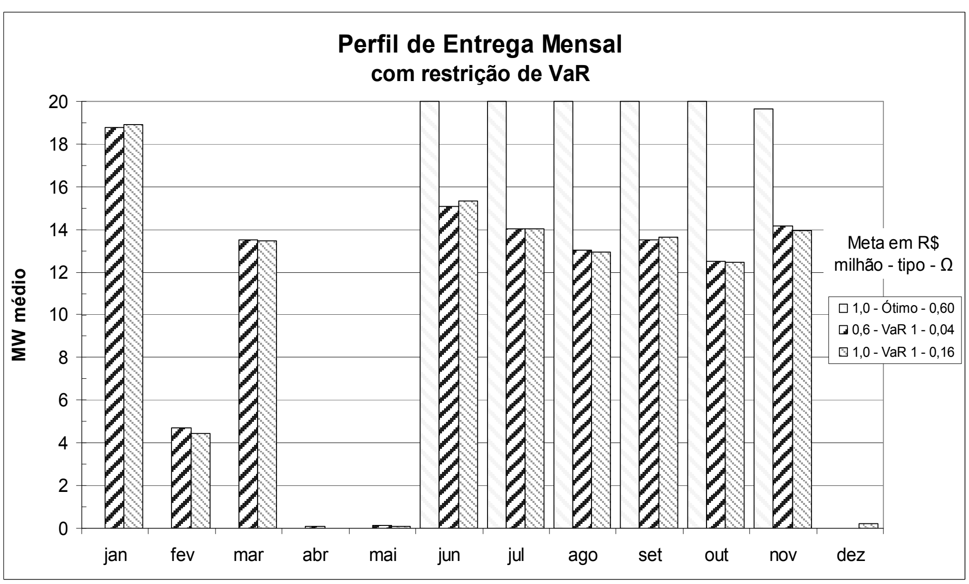
$VaR_{95\%}$; nas outras duas há restrição de $VaR_{95\%}$ de 1,0 milhão de R$ / ano, diferenciando-se as metas.




Pode-se visualisar que a decisão de sazonalização muda consideravelmente nas duas situações em que há restrição de $VaR_{95\%}$. Para estas duas situações, existem alocações significativas de energia também nos meses de janeiro a março. Percebe-se que a restrição de $VaR_{95\%}$ faz com que a decisão ótima fique mais próxima de uma alocação uniforme ao longo do ano, ou seja, menor alocação concentrada nos meses de junho a novembro.

Uma observação importante, em todos os casos, é que os valores calculados

**Figura 48 – Perfil Ótimo de Entrega com Restrição de $VaR_{95\%}$**



resultantes da otimização apresentam um precisão muito maior do que aquela utilizada na liquidação das diferenças de energia detectadas na CCEE, portanto, em alguns casos, sendo insignificantes do ponto de vista prático.

## Conclusões

Neste artigo encontrou-se a melhor forma de sazonalizar a energia assegurada de uma usina, maximizando o seu resultado e tendo-se considerado restrições de $VaR_{95\%}$.

No sentido de otimizar o resultado, foi escolhido como critério de seleção da sazonalização a maximização da medida ômega (Ω) para a distribuição esperada de resultados, dado um nível de $VaR_{95\%}$. A medida Ω foi escolhida porque consegue incorporar todos os momentos da distribuição, fornecendo uma completa descrição das características do risco-retorno.

Além de procurar responder a uma questão relacionada a um problema real, este trabalho apresenta a utilização prática de uma técnica recente de otimização de carteiras, que é a maximização da medida Ω, com restrição de VaR, para uma distribuição esperada de resultados. Adicionalmente, apresentou-se variáveis e especificidades do SEB pouco exploradas em trabalhos científicos brasileiros, mas que permitem aos agentes exercerem escolhas de flexibilidade nos contratos fornecimento de energia elétrica.

Os resultados mostraram que os valores da medida ômega (Ω) diminuem muito rapidamente com o aumento do limite L. Ou seja, se a meta de ganhos (o valor do limite "L") for ousada demais para o porte da operação, a relação entre ganho e perda fica muito prejudicada, do ponto de vista que a chance de um resultado, estando diretamente ligada à relação traduzida por Ω, fica muito pequena.

Por outro lado, a imposição (ou aceitação) de valores mais baixos para o preço do contrato de venda, permite que as escolhas de sazonalização sejam baseadas em possíveis maiores diferenças entre os PLDs atingidos (para cima) e o valor base contratual. Assim, com essas diferenças favorecendo ganhos com uma sazonalização ótima da entrega de energia, melhores resultados podem ficar potencialmente contidos em contratos que, talvez, sejam mais fáceis de serem negociados e implementados, na medida em que, por terem preço menor, aparecem mais vantajosos aos olhos do consumidor.

Uma situação peculiar é que a decisão de sazonalização muda substancialmente quando há restrição de VaR. Especificamente, a imposição deste tipo de restrição faz com que haja menos espaço de manobra para se exercer variações nos volumes de energia fornecidos, uma vez que também há que se avaliar o VaR envolvido em determinado perfil de entrega. Esta restrição faz com que a decisão ótima tenda a se deslocar no sentido de um maior espalhamento, ou seja, uma alocação mais uniforme da quantidade de energia entregue ao longo do ano.

Ao mesmo tempo, a imposição de uma restrição de VaR, na tentativa de limitar o risco incorrido na operação, na prática garante que o resultado pretendido não deverá ser atingido  uma vez que o valor de Ω alcançado, muito menor do que um, indica que as chances de resultados aquém da meta são muito maiores do que daqueles acima da meta

Isto ocorre porque, como foi mostrado, a decisão ótima concentra o maior volume de entrega em uma única parte do ano quando, por razões naturais de precipitação pluviométrica, os preços no mercado à vista tendem a ser mais altos.

Ora, ao se introduzir uma restrição referente à assunção de risco, a solução encontrada, para ficar com menores valores em risco, é forçada a situar-se numa forma mais afastada da concentração ótima sem restrições e com maior VaR, e mais espalhada durante o período anual.

Em uma situação extrema, se a restrição de VaR for igual a zero, ou seja, valor em risco, a solução seria manter a energia assegurada com os mesmos valores ao longo dos meses, sem qualquer afastamento do valor contratado, apresentando um valor de faturamento constante e bem definido, qual seja aquele contratual. Portanto, esta seria uma situação sem graus de liberdade para se realizar a sazonalização.

Como sugestões para trabalhos futuros, a mesma metodologia poderá ser empregada para analisar outras operações no mercado de energia elétrica, tais como: compras descasadas, vendas descasadas e compras sazonais (na safra) de energia produzida a partir do bagaço de cana.

Adicionalmente, a utilização da medida ômega (Ω) apresenta grande potencial em estudos de otimização de carteiras de ações e carteiras de projetos com opções reais, por considerar todos os momentos das distribuições de probabilidade dos resultados esperados, e manipula com facilidade as situações de projeções estatísticas de valores que produzem distribuições, independentemente do modelo utilizado para estas simulações.

Nos casos de contratos de fornecimento de energia elétrica sujeitos a flexibilidade de sazonalização da entrega, como descrito no caso presente, e que acontece no mercado brasileiro de energia elétrica, sugere-se que novos trabalhos sejam realizados explorando a possibilidade de preços contratuais reduzidos a um mínimo aceitável aliados a maiores volatilidades dos PLDs previstos.

Neste casos, o ganho perseguido pelo fornecedor seria obtido de forma mais acentuada através da exploração da flexibilidade contratual permitida pela sazonalização, e menos pela remuneração contratual em si.

Outra restrição importante do modelo apresentado, de aferição da qualidade da sazonalização, está na hipótese implícita de que a manipulação dos valores de entrega de energia contratada não alteram os níveis de preço do mercado à vista. Em outras palavras, o conjunto de geradoras que sazonalizarão a sua entrega de energia não pode ser tão grande ao ponto em que o somatório da quantidade de sua energia sazonalizada possa afetar a estabilidade de preços do mercado.

Para evitar e controlar este efeito, os métodos de previsão de preços devem ser bem aferidos e cuidadosamente monitorados, pois embora não sejam uma variável passível de controle pelo gerador, mas somente pelo operador do Sistema, eles afetam diretamente o valor que está sendo usado para otimização do perfil de entrega.

Assim, se a quantidade de energia sazonalizada leva a uma concentração tão grande de disponibilidade de energia no mercado à vista, que o perfil de preços desse mercado se altera, então a modelagem aqui empregada não mais seria possível. Essa situação enseja uma nova atitude e modelagem e, assim, espaço para vários outros trabalhos deste tipo.

Finalmente, ainda trabalhos posteriores poderiam buscar comparações das decisões realizadas a partir de medidas clássicas, como o índice de Sharpe, e com aquelas obtidas pelo uso da medida ômega (Ω). A avaliação de vantagens computacionais e de valor dos resultados seria de grande utilidade para os geradores de energia.

Referências Bibliográficas

CASTRO, J. G., “Otimização da Performance de um Portfólio de Ativos e Opções Reais utilizando a Medida Omega”, Tese de Doutorado, DEI, PUC - Rio, 2008.

GOMES, L. L.; LUIZ, I. G., “Valor Adicionado aos Consumidores Livres de Energia Elétrica no Brasil por Contratos Flexíveis: Uma Abordagem pela Teoria das Opções”, *Revista Eletrônica de Administração*, 2009, no prelo.

ICK, M.; NOWAK, E., “Omega based Portfolio Optimization – a simulation study on Private Equity investments”, Working Paper, University of Lugano, Switzerland, 2006.

J.P. MORGAN, “Risk Metrics”, Technical Document, New York, 1996.

JENSEN, M., “The Performance of Mutual funds in the Period 1945-1964”, *Journal of Finance*, Vol 93, May 1968, n. 2, pp. 389-416.

KAZEMI, H.; SCHNEEWEIS, T.; GUPTA R., “Omega as a Performance Measure”, Working Paper CISDM, University of Massachusetts, Isenberg School of Management, 2003.

KEATING, C.; SHADWICK, W., “A Universal Performance Measure”, *Journal of Performance Measurement*, Spring 2002, pp.59-84.

MACEIRA, M. E. P.; BEZERRA C. V., “Stochastic stream flow model for hydroelectric systems”, in: *Proceedings of PMAPS*, 1997.

MARKOWITZ, H. “Portfolio Selection”, *The Journal of Finance*, Vol.7, n.1, Mar. 1952, pp. 77-91.

PEREIRA M. V. F.; PINTO L. M. V. G., “Multi-stage Stochastic Optimization Applied to Energy Planning”, *Mathematical Programming*, 52, 1991.

PREMIUM SOLVER PLATFORM, Frontline Systems Inc., disponível em http://www.solver.com, acesso em 6/Out/2008 às 16:00

SHARPE, W., “Mutual Fund Performance”, *Journal of Business*, Vol.39, n.1, 1966, pp.119-138.

TREYNOR, J., “How to Rate management of Investment Funds”, *Harvard Business Review,* Vol. 43, Jan-Feb 1965, n. 1, pp. 63-75.

# 70. Cost Analysis of the Wood Value Chain for Heat and Power Generation

**J. Parrilla[1] and W. Fichtner[2]**

[1] Chair of Energy Economics

Brandenburg Technical University of Cottbus

Walther-Pauer-Str. 5, LG 3

D-03046 Cottbus (Germany)

Phone: +49 17696030585, e-mail: javier.parrillamartinez@tu-cottbus.de

[2]Chair of Energy Economics

Institute for Industrial Production

Universität Karlsruhe (TH)

Hertzstr. 16

D-76187 Karlsruhe (Germany)

Phone: +49 721 608 4460, Fax: + 49 721 758909, e-mail: wolf.fichtner@wiwi.uni-karlsruhe.de

Key words: Chips, logs, heat and power stations.

Abstract: The production of heat and electricity is nowadays strongly conditioned by the effect of climate change through the exhaust gases derived from the combustion of fossil fuels. The use of wood as raw material from tree plantations, natural woods and agricultural and industrial wastes represents a possible solution to diminish the $CO_2$ concentration. The construction of Bio Heat and Power Stations (HPS) to be fueled with biomass in form of wood-

based products like chips or logs constitutes an interesting step to both producing clean energy and promoting the agricultural and wooded areas.

Due to the corresponding environmental benefits, the domestic wood combustibles are an important energy resource for heat and power generation. However certain measures must be taken to make the supply chain more cost-effective and efficient. With the aim of better knowing the whole process of the main wood logistic chains a simulation tool has been developed. Within this paper techno-economic parameters of all substantial process steps throughout both value chains of logs and chips are estimated and analyzed. The results of this investigation may be used for socio-economical resource allocation and planning of future energy plants.

## Objectives

In this work chips and logs will be analyzed apart from pellets or briquettes which result from certain densification processes. The production costs of this second group of wood products are higher although their energy per mass unit is also higher [1]. Due to this reason the subject of this study was to focus on the two firstly above-mentioned biomass fuels, which are comparable regarding their final applicability for energy generation on an industrial scale. For both fuels the corresponding biomass value chains have to be scrutinized by analyzing each of the steps happening from felling the trees up to their conversion into energy.

Economic and technical data for each element belonging to the biomass value chain have been collected so that the profitability of the energy generation process in direct competition with that of oil-derived fuels can be assessed for the biomass obtained in areas situated around the HPS. These data involve the parameters concerning all the value chain for the logistic chains of logs and chipped branches. In order to elaborate all the collected data a simulation tool has been implemented thereby modeling the processes of heat and power generation from biomass resources.

## The wood raw material[250]

### Introduction

Forests and cultivation lands like those of fruit trees and other wood crops represent a significant resource of wood biomass predominantly in temperate and tropical regions of the world. The energy use of these biomass stocks could contribute enormously to the reduction of $CO_2$ and the diversification of any national energy mix. Wood logs and wood branches are the most extended and important biomass sources derived from forest areas. Furthermore there are short rotation plantations and the rests of agricultural and industrial activities, thereby completing the whole bio-energy range for provision of wood to the respective logistic chains. Short rotation plantations constitute a promising alternative, but their main disadvantage is the relatively high production costs induced by the cost intensive cultivation processes. Therefore only the wood fraction derived from forest areas and woods as well as the wood agricultural wastes will be considered in this study.

### Means of transport

The wood required for the generation of power and heat usually occurs in natural forests as well as agricultural areas, where it is often rather difficult to work with conventional motor vehicles. Other alternatives for transportation of wood like railway or ship are not considered here because these means of transport either are used for covering long distances or require adequate waterways. Therefore in this case study only trucks with a volumetric carrying capacity of around 36 $m^3$ were taken into account in the different logistic chains [2]. Reference [3] also refers to bigger carrying capacities for transportation of solid biomass (logs, chips and bundles), ranging from 60 $m^3$ to 93 $m^3$. Nevertheless these capacities are exclusively oriented to cover long distances without having to access woodlands and cultivated areas. Table I gathers all the techno-economic data related to the kind of truck chosen for the transportation of wood. This information was taken from sources [2], [3] and [4].

---

[250] For chapters 2, 3 and 4 see also [14].

Table I

| Techno-economic Data of the Means of Transport (Truck) | | |
|---|---|---|
| Technical Data | Units | |
| *Speed* | km/h | 50 |
| *Carrying capacity* | $m^3$ | 36 |
| *Fuel consumption* | l/km | 0.6 |
| Economic Data | Units | |
| *Salary of driver* | €/h | 20 |
| *Truck costs* | €/h | 46 |
| *Diesel price* | €/l | 1.10 |

Specific framework conditions for energy generation

For the economic analysis of each of the biomass value chains studied in this paper an identification of a region was required in order to be able to determine a scenario through which the analytic process operated by the simulation tool can be adjusted to reality. Due to the availability of data and the advanced legislation in the sector of renewable energies (and more concretely on the subsidies granted for the power generation from biomass resources) Germany was selected. The German Renewable Energy Sources Act (EEG) came first into force on April 1st, 2000. Thereafter several amendments (2004 and 2009) have been passed until nowadays introducing some modifications respecting the remuneration obtained through processes of power generation involving biomass resources. In this regard the revision of the year 2004 [5] was taken as valid reference for the economic analysis realized in this study once the overall economic data were collected from works published around that year. This last fact would justify the coherence and reliability of this work without the necessity of updating costs and prices to their real value in 2008 or 2009. With regard to the real figures contributed by this act the most important parameters to be allowed for are the following: Feed-in tariffs of 8.9 €cent/kWh$_{el}$ for those HPS with electric capacity up to 5 MW and 8.4 €cent/kWh$_{el}$ for facilities with an electric capacity larger than 5 MW; whereas heat stations receive no subsidies [5].

On the other hand each energy market has particular reference costs for the production of power and heat generated with fossil fuels. These costs are required for referring the production costs of the energy obtained from biomass to those generated with fossil fuels with the aim of evaluating the potential and profitability of wood as energy resource. For the present economic analysis the production costs of heat generation in Germany were set at 3.5 €cent/kWh.

Technical conditions for wood

Logs and branches are two possibilities how wood products occur when collected from forests and agricultural areas (wood crops). The former comes up as simple trunks put into a pile either on the truck trailer or in certain boxes being loaded on the trailer. The latter follows a process of chipping - according to the feasible processing analyzed in this work, where bundling was excluded - in order to reduce its volume and to consequently increase its energy density. This chipped bulk material is then easily treated and transported by means of pouring into containers. In this study spruces, pines, beeches and oaks have been taken into account for determining the average value for some of the involved physical properties as the density and the heating value both referred to the corresponding water content [6]-[7]. Table II shows the different properties for chips and logs.

Table II

| Properties of Wood Products | | | |
|---|---|---|---|
| | Units | Logs | Chips |
| *Density* | kg/m$^3$ | 408.27 | 234.5 |
| *Heating value* | kWh/kg | 4.025 | 4.025 |

| | | | |
|---|---|---|---|
| *Water content* | % | 18 | 18 |

Furthermore [7] gives these properties for wood regarding two different water contents: 50 % and 18 %. This magnitude reveals the quantity of water contained in the wood and is desired to be as low as possible in order to facilitate the subsequent combustion process. Recently harvested wood usually has a water content of 50% what turns out to be extremely high for being used as biomass resource for energy generation purposes. Hence a drying process already has to be carried out just after felling or thinning of trees by leaving the wood on the surfaces of fields and forests for several months. During this process, water contents not lower than 20 % are reached before wood is transported and then stored at the storage/conversion sites, where water content rates of around 18 % are to be measured either by a further drying process using the heat produced by the HPS or by simply sheltering the wood material from weather conditions.

Technologies for firing wood biomass

In the following chapter different technologies to produce energy out of wood biomass will be presented. It has to be mentioned that these technologies produce different forms of energy – heat and electricity (or both).

Boiler

Boilers to burn wood biomass or more concretely wood chips are available with different capacities. For this study a 5,000 $kW_{th}$ boiler was considered as a representative heating unit used for industrial objectives. Reference [8] provides the main technical characteristics and the corresponding economic parameters of this boiler in order to be able to simulate the overall supply chain “from well to wheel”. Table III gathers data such as the capacity, the efficiency and on the other hand the total investment and the fixed and variable costs.

Table III

| Technical and Economic Data for Boiler | | |
|---|---|---|
| Technical Data | Units | |
| *Effective capacity* | $kW_{th}$ | 5,000 |
| *Efficiency* | % | 85 |
| *Utilization time* | h/a | 5,000 |
| Economic Data | Units | |
| Total investment | €/$kW_{th}$ | 450 |
| Fixed cost | %Invest/a | 2.7 |
| Variable costs | €/MWh | 1.2 |

Amortization period of 15 years, interest rate of 6% and personal costs rate of 50,000 €/a.

Heat and power station with noncondensing turbine

A heat and power station with noncondensing turbine is a very popular possibility to produce steam for industrial use as well as power. For this purpose such a heat power unit was analyzed in this investigation, however taking into account that this HPS is exclusively fueled with wood chips. The technical and economic parameters of this technology have been collected for being showed in Table IV [8].

Table IV

| Technical and Economic Data for HPS (Noncond. Turbine) | | |
|---|---|---|
| Technical Data | Units | |
| *Electric capacity* | $kW_{el}$ | 5,000 |
| *Thermic capacity* | $kW_{th}$ | 23,900 |
| *Electric efficiency* | % | 14 |
| *Total efficiency* | % | 81 |
| *Utilization time* | h/a | 6,000 |
| Economic Data | Units | |
| *Total investment* | €/$kW_{el}$ | 3,850 |
| *Fixed costs* | %Invest/a | 3.5 |
| *Variable costs* | €/$MWh_{el}$ | 3.8 |

Amortization period of 15 years, interest rate of 6%, remuneration from cogeneration of heat at 3.5 €cent/$kWh_{th}$ and personal costs rate of 50,000 €/a.

Power station operated with condensing turbine

Furthermore, power units provided with a steam condensing turbine have been analysed as one option to produce solely electricity. This system actually corresponds to what is scientifically known as the steam Rankine cycle and is completely extended worldwide all through the energy generation sector. The fact of not using the heat produced by the steam turbine means diminishing the overall efficiency. The same technology including the cogeneration of heat would contribute an elevated performance so that biomass supply chain could be further optimized. The following Table V collects the main technical and economic characteristics concerning this power station [8].

Table V

| Technical and Economic Data for PS (Condensing Turbine) | | |
|---|---|---|
| Technical Data | Units | |
| *Electric capacity* | $kW_{el}$ | 20,000 |
| *Thermic capacity* | $kW_{th}$ | 0 |
| *Electric efficiency* | % | 27 |
| *Total efficiency* | % | 27 |
| *Utilization time* | h/a | 7,000 |
| Economic Data | Units | |
| *Total investment* | €/$kW_{el}$ | 2,200 |
| *Fixed costs* | %Invest/a | 3.5 |
| *Variable costs* | €/$MWh_{el}$ | 6.2 |

Amortization period of 15 years, interest rate of 6% and personal

costs rate of 50,000 €/a.

Gasification process and block heat and power station

The gasification of wood biomass is a promising and efficient technology. The gas obtained from the wood subjected to the gasification process is fed into the gas engine of the block heat and power station.

Table VI

| Technical and Economic Data for Gasificator and BHPS | | |
|---|---|---|
| Technical Data | Units | |
| *Capacity of gasificator* | $kW_{gas}$ | 5,000 |
| *Efficiency of gasificator* | % | 70 |
| *Electric capacity* | $kW_{el}$ | 1,900 |
| *Thermic capacity* | $kW_{th}$ | 2,500 |
| *Electric efficiency* | % | 38 |
| *Total efficiency* | % | 88 |
| *Utilization time* | h/a | 6,000 |
| Economic Data | Units | |
| *Total investment* | €/$kW_{el}$ | 3,120 |
| *Operating costs BHPS* | %Invest/a | 2 |
| *Operating costs gasificator* | %Invest/a | 4 |

Amortization period of 15 years, interest rate of 6%, remuneration from cogeneration of heat at 3.5 €cent/$kWh_{th}$ and personal costs rate of 50,000 €/a.

The generated power and heat can improve the profitability of the plant, although the efficiency of the gasificator plays a relevant role throughout the overall generation process. Table VI shows all the required parameters used to analyze this HPS [8].

Biomass integrated gasification combined cycle

The gas cycle of a combined cycle is powered with the gas obtained from the wood submitted to an integrated gasification process. The gasificator is operated with a system based on low-pressure fluidized bed gasification technology with a pressure of 1.5 bar. The most important technical characteristics as well as the corresponding economic parameters of this biomass integrated gasification combined cycle can be found in Table VII [8].

Table VII

| Technical and Economic Data for Gasificator and CC | | |
|---|---|---|
| Technical Data | Units | |
| *Capacity of gasificator* | $kW_{gas}$ | 22,500 |
| *Efficiency of gasificator* | % | 85 |
| *Electric capacity* | $kW_{el}$ | 8,000 |
| *Thermic capacity* | $kW_{th}$ | 12,440 |
| *Electric efficiency* | % | 36 |
| *Total efficiency* | % | 92 |
| *Utilization time* | h/a | 6,000 |
| Economic Data | Units | |
| *Total investment* | €/$kW_{el}$ | 2,240 |
| *Operating costs BHPS* | %Invest/a | 2 |
| *Operating costs gasificator* | %Invest/a | 4 |

Amortization period of 15 years, interest rate of 6%, remuneration from cogeneration of heat at 3.5 €cent/kWh$_{th}$ and personal costs rate

of 50,000 €/a.

## Different logistic chains for provision of wood

### Transport of logs and subsequent chipping at the conversion station

Transportation of wood logs from forests to the conversion site is a suitable way for transporting biomass from woodlands, because of the efficient and cost-effective transportation due to the higher energy density and mass concentration showed by logs in relation to other wood biomass like branches of agricultural or forest wastes. Fig. 1 illustrates the logistic chain for this process where transportation of logs and the subsequent chipping at the conversion station precede the conversion into energy. [2] [9]

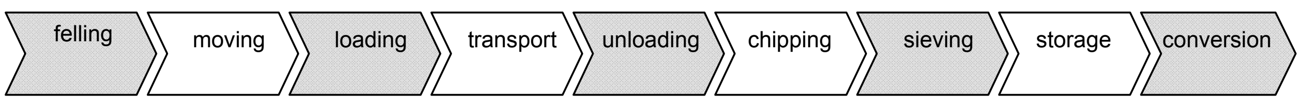



Fig. 1 Representation of the logistic chain for condensed wood biomass (transport of logs)

Furthermore, the option to chip wood logs before being transported has been analysed. The five particular cases examined - covering the most representative biomass technologies for transformation of wood in energy -, highlighted that the chipping of logs was always less appropriate in economic terms if compared to the transportation of compact biomass. These unfavorable upshots were especially identified for the costs associated with the own value chain of this biomass product, thus resulting in higher energy costs before distribution to the net. A series of technical and economic consequences derives from this specific logistic technique, which is not recommended in general for wood transportation due to its low profitability (except for the case of branches and wastes, which will be analyzed in the following section).

## Chipping of branches and transport to conversion station

Apart from logs the wastes from agricultural and forest origin nowadays represent another relevant resource of wood biomass in the form of branches [2] [10]. This wood product has an extremely high volume in comparison to its weight thus involving a decrease of its energy density. So far the only technical viable solution to improve this process is the chipping of these wastes before transporting them to the conversion site, thereby improving not solely the efficiency of the transportation process but also that of the overall value chain. The logistic chain of branches and all kind of low density biomass derived from forests and cultivated areas can be seen in Fig. 2 [2], [11]. As indicated before the chipping process precedes the transportation in order to increase the profitability of the biomass value chain. A further increase of the energy density could be attained through the elimination of the empty spaces - containing only air - from biomass bulk. This possibility actually seems to arise with the introduction of a process of condensation/compaction of branches in order to maximize its energy density. This new more condensed and compacted state of wood biomass might really be identified with certain already existing biomass products behaving under these conditions. Pellets, briquettes or even the bundles mechanically shaped with wood wastes or branches harvested from short rotation plantations obey this idea. Hence they should be analyzed in greater detail as far as their respective logistic chain is concerned from an economic and technical point of view in order to study in depth the technical and economic feasibility of such processes. Up to now a quantitative analysis has not been realized because this would have exceeded the objective of this publication.

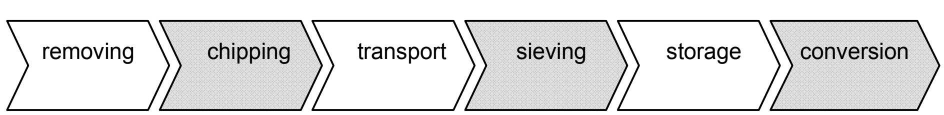



Fig. 2 Representation of the logistic chain for not condensed wood biomass (chipping of branches)

## Economic analysis of the logistic chains

### Cost analysis for the logistic chain of logs

The value chain of logs from forests and agricultural areas consists of a series of elements which form a logistic chain going from felling this biomass raw material until the generation of heat and power. As described before this logistic process introduces a relatively long sequence of steps, each being associated with comparatively higher costs (€cent/kWh) in comparison to those involved for the processing of branches. The reason for these higher costs lies not only in the larger dimension of the chain (up to nine instead of six steps) but as well in the existence of some steps which are extremely cost-intensive like felling and the corresponding moving of logs.

For assessing the economic evolution of the whole process Table VIII introduces the costs assigned to each element belonging to the logistic chain of logs: felling, moving, loading, transport, unloading, chipping, sieving, storage and conversion. The data have been obtained from following sources [2], [4], [6], [7], [8], [9] and [10].

Table VIII

Costs Assigned to the Elements of the Logistic Chain of Logs

| | Felling (€cent/kWh) | Moving (€cent/kWh) | Loading (€cent/kWh) | Transport (€cent/kWh·km) | Unloading (€cent/kWh) | Chipping (€cent/kWh) | Sieving ( €cent/kWh) | Storage (€cent/kWh) | Conversion ( €cent/kWh) |
|---|---|---|---|---|---|---|---|---|---|
| *Boiler* | 0.84 | 0.46 | 0.20 | 0.0092 | 0.13 | 0.47 | 0.19 | 0.09 | 1.07 |
| *Noncond. Turb.* | 5.11 | 2.77 | 1.20 | 0.0563 | 0.80 | 2.86 | 1.20 | 0.56 | 7.22 |
| *P.S. 20 $MW_{el}$* | 2.65 | 1.44 | 0.62 | 0.0291 | 0.41 | 0.79 | 0.60 | 0.29 | 3.97 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| *Gasificat.+BHPS* | 2.70 | 1.46 | 0.63 | 0.0296 | 0.42 | 1.51 | 0.63 | 0.29 | 5.68 |
| *Gasificat.+CC* | 2.34 | 1.27 | 0.55 | 0.0257 | 0.36 | 1.31 | 0.55 | 0.26 | 4.07 |

The costs referred to each element for the different firing technologies represent a rate between the absolute costs involved in the stage and the energy amount (heat or electricity) to be considered. Furthermore this amount depends on the efficiency parameters of each individual conversion system. Therefore these costs are assessed as energy-related costs (€cent/kWh).

The transportation costs - actually only a simple element of this sequence - appear to be quite moderate if compared with those related to the transport of chips from branches. A clear ground explaining this fact is obviously the higher energy density of logs with regard to that of chips thereby entailing lower transportation costs per kWh as showed in Table IX.

Table IX

| Increase of Transportation Costs per Km | | |
|---|---|---|
| | LOGISTIC CHAIN | |
| | Logs (€cent/kWh·km) | Chipped Branches (€cent/kWh·km) |
| *Boiler* | 0.0092 | 0.0161 |
| *Noncondensing turbine* | 0.0563 | 0.0979 |
| *P.S. 20 $MW_{el}$* | 0.0291 | 0.0508 |
| *Gasification + BHPS* | 0.0296 | 0.0515 |
| *Gasification + CC* | 0.0257 | 0.0448 |

The aspects discussed above really determine the entire economy of the heat and power stations presented at the beginning of this work. The generation of heat and power is conditioned to a great extent by some technical parameters like the efficiency of the plants and as well as the type of the final energy carrier generated by the facility, i.e. heat or electricity.

For those stations only generating heat and consequently not receiving the corresponding subsidies the price of heat - before distribution to the net and discounting the wood transportation costs from this quantity - is particularly high especially for the logistic chain of logs as showed in Table X. In the sole case subjected to these conditions (the boiler) these "energy costs deducting transportation costs" derived from Table X are somewhat below the reference production costs of heat generated with fossil fuels (3.5 €cent/kWh). Hence there is a small margin to compete with fossil heat (although transportation costs for the logistic chain of logs are relatively economical), thereby the increasing of transportation costs with the distance speedily reaches the fossil reference costs.

Table X

| Energy Costs discounting Transport Costs | | |
|---|---|---|
| | LOGISTIC CHAIN | |
| | Logs (€cent/kWh) | Chipped Branches (€cent/kWh) |
| *Boiler* | 3.47 | 3.21 |
| *Noncondensing turbine* | -3.87 | -5.40 |
| *P.S. 20 $MW_{el}$* | 2.41 | 2.33 |
| *Gasification + BHPS* | -0.17 | -0.97 |
| *Gasification + CC* | -3.11 | -3.81 |

The energy costs are referred to those production costs arisen before the distribution to the net and including the subsidies and heat remuneration.

Table X illustrates how for the block heat and power station with gasification the energy production costs (discounting the transport costs) – assuming the reference of 0 €cent/kWh as no benefit for the investors of electricity generating facilities – are extremely near of this 0 €cent/kWh level and thus the profitability diminishes for this kind of energy generation. On the other hand for the logistic chain of chipped branches the same Table X makes clear a considerable improvement or reduction of the energy production costs due to the comparatively lower costs involved in this logistic chain.

On the contrary the power stations with a noncondensing turbine and the biomass integrated gasification combined cycle demonstrate how the large contribution of heat produces enough gains to have low energy costs for both logistic chains (discounting the transport cost) thus permitting to have a substantial margin up to the reference level of 0 €cent/kWh (characterized for leading to no benefit for the investors).

Cost analysis for the logistic chain of branches

The logistic chain of chipped branches is characterized by an economic behavior completely opposite to that of the before treated chain of logs. The branches have to be chipped anyway to merely increase their extremely low energy density. Nevertheless after the chipping process this physical property still continues to be quite low regarding that of logs what consequently means that the transportation costs of chips will be considerably higher than in the case of logs.

In contrast with that the costs derived from the rest of the logistic chain (discounting the transportation costs) are not as high as those for logs as detailed in Table X. Fig.2 gives the reasons to understand this reality: on the one hand the number of steps has been reduced to only six and one of the most cost-intensive steps (felling) of the logistic chain of logs is eliminated. Then again, there is a new bulk material – chips – the processing of which all along the value chain is much easier and therefore more economical and so more profitable.

In Table XI the costs for each of the stages of the logistics chain of branches is showed for each technology. The stage conversion presents the same values as those of the logistic chain of logs represented by Table VIII. The reason for that is completely evident so that the investment and the operating costs from the different technologies are the same. For the step storage the coincidence or similarity appreciated for both logistic chains lie on some geometrical properties concerning the wood, which are in relation to the ratio of the bulk density for chips to the density of logs put into a pile.

Table XI

| Costs Assigned to the Elements of the Logistic Chain of Branches | | | | | | |
|---|---|---|---|---|---|---|
| | Removing (€cent/kWh) | Chipping (€cent/kWh) | Transport (€cent/kWh·km) | Sieving ( €cent/kWh) | Storage (€cent/kWh) | Conversion ( €cent/kWh) |
| *Boiler* | 0.67 | 1.10 | 0.0161 | 0.26 | 0.09 | 1.07 |
| *Noncond. Turb.* | 4.10 | 6.68 | 0.0979 | 1.58 | 0.58 | 7.22 |
| *P.S. 20 $MW_{el}$* | 2.12 | 3.46 | 0.0508 | 0.82 | 0.30 | 3.97 |
| *Gasificat.+BHPS* | 2.16 | 3.51 | 0.0515 | 0.83 | 0.30 | 5.68 |
| *Gasificat.+CC* | 1.87 | 3.06 | 0.0448 | 0.82 | 0.26 | 4.07 |

Then again, the process of chipping is observed to be substantially expensiver for the logistic chain of branches if compared to that of logs. This fact is due to the use of low capacity chipper installed at the base of the truck along with the crane. These equipements have chipping costs which are characterized for being quite elevated in comparison with those of high capacity chippers used at the conversion site for processing the logs.

Lastly the development state of the technology applied to the conversion step as well as the investment and operating costs of each heat and power station determine to a large extent the final value obtained for the energy costs of the different technologies.

Outlook: Considering the wood value chains in energy system optimisation

In order to be able to compare different ways to use wood for heat and power generation and to compare these options with other possibilities to produce electricity and heat in a specific region an optimisation model will be used. The starting point for the model-based analysis is the PERSEUS (Program package for emission reduction strategies in energy use and supply) model (see e.g. [12]). PERSEUS is an energy and material flow model applying a multi-periodic linear programming approach. The model determines the “optimal” structure of the future energy system of a region for a typical time horizon between 20 and 40 years. The target function requires a minimisation of all decision-relevant costs within the entire energy supply system of a region. This basically comprises fuel supply and transport costs, transmission fees, fixed and variable costs of the physical assets (operation, maintenance, load variation costs, etc.) and investment costs for new plants. The relevant techno-economic characteristics of the real supply system have been considered by implementing further equations covering technical, ecological and political restrictions. The most important technical restrictions are:

Physical energy and material balances: match of demand and supply, taking into account storage options and time structures of electricity and heat demand (load curves).

Capacity restrictions: transmission capacities, availability of installed capacities, (de)commissioning restrictions, technical lifetime of physical assets.

Plant operation: maximum/minimum hours of full load operation, fuel options, cogeneration options, load variation restrictions.

The main advantage of such a model is the fact, that different possibilities to satify the given energy demand are represented and linked in a bottom-up approach, making it possible to consider the interdependencies between individual measures. To represent the logistic chains mentioned in this paper the model has to be enlarged by the corresponding processes.

The PERSEUS model has been implemented as a PC version that can be run on most commercial PCs. However, due to its high complexity and the resulting large problem size, it requires state-of-the-art hardware components. The model is equipped with an MS Access based data management system that permits easy data handling and a fully automated link to the mathematical module. The model itself is programmed in GAMS [13]. Formatted and structured results become available in MS Excel spreadsheets. In order to solve the problem, commercial solvers like CPLEX can be applied.

## Conclusions

The collection and subsequent energy conversion of wood biomass is realized through two different logistic chains. The logs showing a higher energy density and the branches resulting from lopping processes in forests and agricultural areas shape the basis of the provision of wood in a certain region. The analysis of both value chains raises certain techno-economic advantages and disadvantages with regard to the wood utilization for energy generation and its corresponding profitability.

The subsidies for power production as well as the remuneration for heat are two necessary elements to make profitable this energy activity from wood resources. The upshots of the simulation model used inevitably aim at a necessary approval or - if already existent - an increase of subsidies regarding biomass-fired heat and power plants in order to integrate these technologies in the energy generation mix of a certain region. Moreover, the heat generated at the HPS should be delivered to a potentially growing industrial sector built up around the facility, thus taking advantage of synergies between energy generation and other industrial activities (tourism, tin industry, etc).

## References

C. N. Hamelink, R.A. Suurs, A.P. Faaij, “International bioenergy transport costs and energy balance”, Copernicus Research Institute for Sustainable Development and Innovation, Utrecht University, Biomass and Bioenergy, Elsevier, 2005, pp. 117-125

K. Dovers, S. Opitz, “Biologio. Entwicklung und Ausbau regionaler Logistikstrukturen für Holzbrennstoffe”, Fraunhofer Institut Materialfluss und Logistik IML, 2007, pp. 89-106

S. Frick, F. Müller-Langer, D. Thrän, “Bereitstellung biogener Festbrennstoffe zur Strom- und Kraftstofferzeugung – Bewertung unterschiedlicher Logistikansätze”, Institute for Energy and Environment, 2005, pp. 58-85, Appendix A-22

“Leitfaden Bioenergie: Planung, Betrieb und Wirtschaftlichkeit von Bioenergie“, Fachagentur Nachwachsende Rohstoffe. 4. Edition, 2007.

“German Act for Renewable Energies (EEG)”, Federal Ministry for Environment, Protection of Nature and Security for Reactors, 2004.

“Bioenergie Basisdaten Deutschland”, Fachagentur Nachwachsende Rohstoffe e. V., 2008.

“Handlungskonzept zur energetischen Nutzung von Holz im Kreis Unna und Umgebung”, Energieagentur Lippe GmbH, 2005, p. 24

J. Nitsch, S. Gärtner, “Ökologisch optimierter Ausbau der Nutzung erneuerbaren Energien in Deutschland”, Federal Ministry for Environment, Protection of Nature and Security for Reactors, 2004, pp. 35-45

S. Wittkopf, “Bereitstellung von Hackgut zur thermischen Verwertung durch Forstbetriebe in Bayern”, Dissertation, Chair for Forestry Sciences and Applied Informatics, University of Munich, 2005.

C. Kanzian, B. Fenz, F. Holzleitner, K. Stampfer, “Waldhackguterzeugung aus Schlagrücklass”, Department of Forest and Land Sciences, University für Bodenkultur Wien, 2005, pp. 13-14

“Woodchip fuel specifications and procurement strategies for the Black Hills”, Biomass Energy Resource Center, Montpelier, 2007.

J. Rosen, “The future role of renewable energy sources in European electricity supply: a model-based analysis for the EU-15”, Universitätsverlag, Karlsruhe, 2007.

A. Brooke, D. Kendrick, A. Meeraus, and R. Raman, “GAMS - A User's Guide (Edition December 1998)”, GAMS Development Corporation, Washington, 1998.

J. Parrilla, W. Fichtner, “The impact of transportation costs on the profitability of heat and power generation with wood products”, Proceedings of ICREPQ’09, Valencia, 2009