www.gasandoil.com/ogel/
Issue : Vol. 3 - issue 2
Published : June 2005

Editor-in-Chief
Thomas W. Wälde
twwalde@aol.com
Professor & Jean-Monnet Chair
CEPMLP/Dundee and Principal
Thomas Wälde & Associates

Oil, Gas & Energy Law Intelligence

Integrated Natural Gas-Electricity Resource Adequacy Planning in Latin America
by L.A. Barroso, T.J. Hammons and H. Rudnick

About OGEL

OGEL (Oil, Gas & Energy Law Intelligence): Focussing on recent developments in the area of oil-gas-energy law, regulation, treaties, judicial and arbitral cases, voluntary guidelines, tax and contracting, including the oil-gas-energy geopolitics.

For full Terms & Conditions and subscription rates, please visit our website at www.gasandoil.com/ogel/.

Open to all to read and to contribute

Our aim is for OGEL to become the hub of a global professional and academic network. Therefore we invite all those with an interest in oil-gas-energy law and regulation to contribute. We are looking mainly for short comments on recent developments of broad interest. We would like where possible for such comments to be backed-up by provision of in-depth notes and articles (which we will be published in our 'knowledge bank') and primary legal and regulatory materials.

Please contact **Editor-in-Chief** Thomas Wälde at twwalde@aol.com if you would like to participate in this global network: we are ready to publish relevant and quality contributions with name, photo, and brief biographical description - but we will also accept anonymous ones where there is a good reason. We do not expect contributors to produce long academic articles (though we publish a select number of academic studies either as an advance version or an OGEL-focused republication), but rather concise comments from the author's professional 'workshop'.

This article is intended for publication b y OGEL, 2005

INTEGRATED NATURAL GAS-ELECTRICITY RESOURCE ADEQUACY PLANNING IN LATIN AMERICA

Luiz Augusto Barroso[#,1], Thomas J Hammons[#,2], Hugh Rudnick[#,3]

Abstract: Latin America has emerged in the recent years as one of the most dynamic regions for natural gas and electricity developments. The continent boasts abundant natural gas reserves and high-growth energy markets. The need to diversify away from heavy investments on hydropower and expensive oil is driving many countries to promote natural gas use, especially for power generation. On the other hand, several challenges are being observed, such as the competition between hydro and thermal generation, the breaking of cross-countries natural gas agreements, competition between natural gas for power generation and electric transmission, among others. This paper addresses natural gas-electricity resource adequacy planning for four countries in Latin America (Brazil, Chile, Mexico, Colombia) as well as the perspectives for creation of an integrated market in the Southern cone of Latin America.

KEYWORDS: Integrated natural gas resources, integrated natural gas--electricity market, resource adequacy planning in Latin America, electric power system planning, gas markets, liquefied natural gas planning, integrated resource planning, deregulation, gas supply, gas transport, generation costs, natural gas industry, risk analysis, energy markets, economic efficiency, energy resources, international trade, natural gas industry, system operation.

1. Introduction

Latin America has been in recent years one of the most intensive regions for natural gas and electricity. The region is very hydropower dependent (about 57% of the region's installed capacity is hydro) and the need to diversify away from heavy investment hydropower and expensive oil is driving many countries to promote natural gas use, especially for power generation. Examples of these developments are in Brazil, Chile and Colombia. Other countries, such as Mexico, take advantage of natural gas to displace oil-fired generation. The countries of the region have a great diversity in size, installed capacity, power demand and transmission/natural gas network characteristics (level of meshing and geographical extension). Figure 1 shows the hydropower share in each of these countries and the participation of each country in the region's installed capacity.

Hydropower reserves are still high and the continent boasts abundant natural gas reserves and high-growth energy markets, as shown in Figure 2.

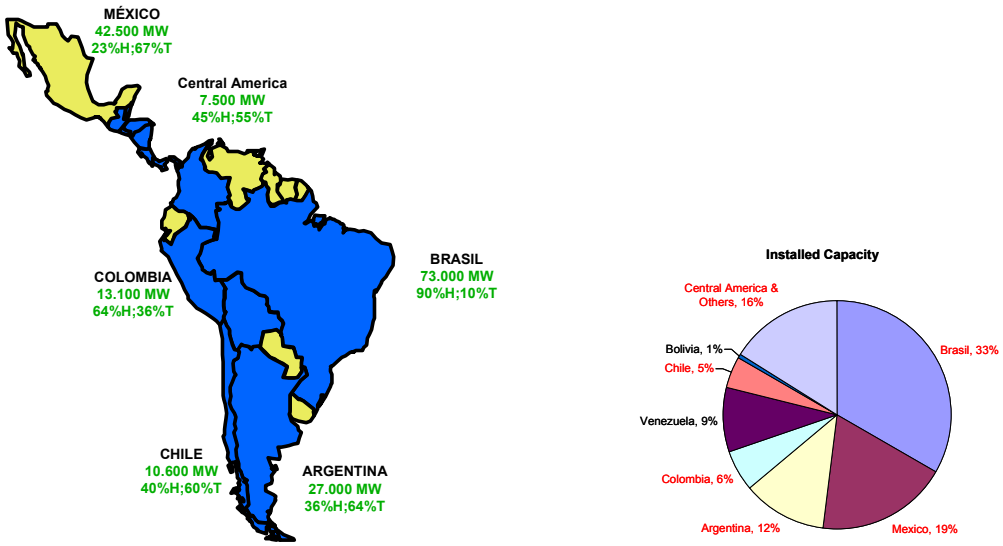
The economic reforms have opened to private investors a number of sectors previously reserved to the state. This has led the region to develop an infrastructure of electricity and natural gas pipelines, both in each country separately as well as cross-border energy interconnections. These interconnections consist of basically cross-border electricity transmission links, power projects at the border (mainly hydro plants jointly owned by different countries) and cross-border natural gas pipelines. Figure 3 shows the main cross-border energy interconnections in the Southern part of Latin America.

[#] Contributors include M Madrigal and G Arroyo (Mexico), J Mejía and A Brugman (Colombia), M Pereira, R Kelman, B Flach, B Bezerra, S Binato and J M Bressane (Brazil), L Sbértoli (Argentina), M Tavares and P Camarota (Brazil/Bolivia).

[1] L.A.Barroso is with PSR/Mercados, a Brazilian consulting group specialized in electricity and gas integrated solutions (E-mail: luiz@mercados.com.br, http://www.mercados.com.br)

[2] T J Hammons is with the University of Glasgow, Scotland, UK. (E-mail: T.Hammons@ieee.org)

[3] H Rudnick is with the Catholic University of Chile, Santiago, Chile and also with Systep Engineering Consultants, which specializes in power-gas (E-mail: H.Rudnick@ieee.org).



Total Installed Capacity (2001): 221 GW (57%H, 43%T)

Figure 1 – Brazil, Mexico, Chile, Argentina, Colombia and Latin America

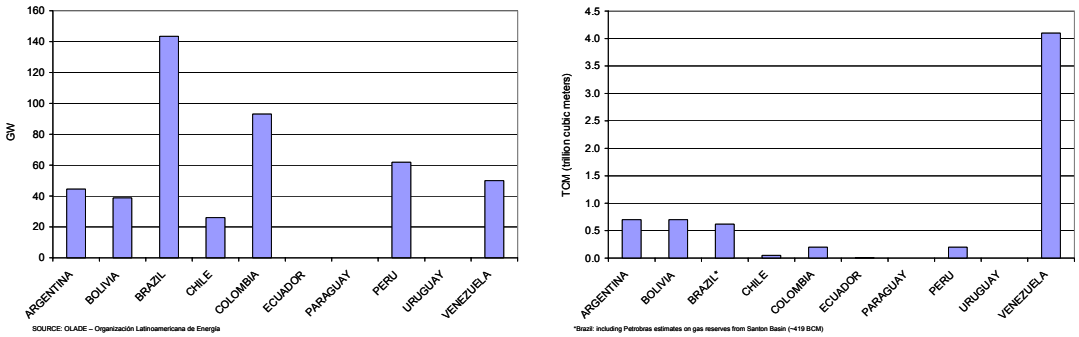


Figure 2 –Latin America Hydro Potential and Natural Gas Reserves

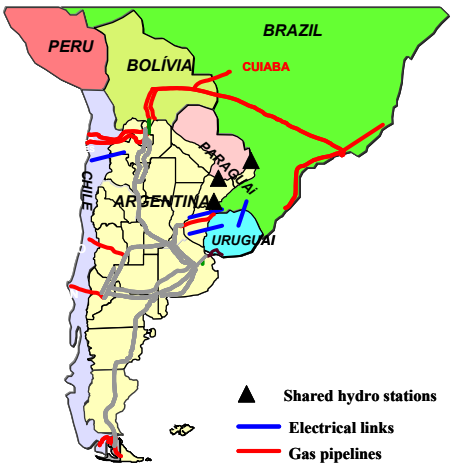


Figure 3 – Southern Cone: Electricity and Gas Cross-Border Interconnections

Because the regional infrastructure is still developing, heavy investments in both generation and transmission investments are required. In those countries where hydropower is an expansion option, it is also necessary to determine the most economic trade-off between cheaper distant hydro, with higher electricity transmission costs, and more expensive "local" gas-fired thermal generation, with lower electricity network costs plus the cost of the correspondent gas pipeline.

Another important issue in Latin America is the multi-country electricity-gas markets. These are a natural evolution to the existing "official" cross-border interconnections, which were originally established by the countries' governments for sharing reserves and carrying out limited economic interchanges. The energy and gas links were originally built as private initiatives and mainly carried out under a local (not regional) framework and without an integrated planning, thus decoupled from each other. The recent episodes in the electricity and gas sectors in the Southern Cone, both in terms of crisis (for example, natural gas supply difficulties in Argentina, that directly affected the Chilean market) and in terms of new opportunities (such as new natural gas sites and new gas pipelines) have brought up and restored the opportunity to work towards robust energy regional integration. Introducing natural gas as one important component of the expansion options for integrated electricity-gas resource planning for the region.

The objective of this paper is to address natural gas-electricity resource adequacy planning in Latin America not referenced in the literature in a convenient form heretofore. Five "case studies" have been chosen for the analysis: an individual analysis of the developments of natural gas in four countries (Brazil, Chile, Colombia and Mexico), and power and natural gas integration in the Southern Cone. Emphasis is on the institutional and operational arrangements adopted in each country, the competition between electricity transmission and natural gas pipelines and the success/difficulties observed in handling recent conflicts in the region that arose from natural gas supply difficulties are provided. A section is devoted to analyze integration of the markets in the Southern part of the region where the strategic value of electricity-gas integration is more intensively discussed.

2. Integrated Gas-Electricity Adequacy Planning in Brazil: Technical and Economical Aspects

Brazil is the largest energy market in South America, accounting for 40% of the continent's energy consumption. On the generation side, the country is hydro-dominated, where 85% of the 90 GW installed capacity and more than 90% of the 384 TWh energy production comes from hydropower. The country has a modest natural gas production, most of which is associated with oil extract. Since 1999, imported gas has been flowing into the country through pipelines from Bolivia and Argentina and in 2003 a discovery of a large offshore natural gas field (Santos field) capable of more than doubling the country's reserves, has been announced.

Despite its gas reserves and imports, Brazil has a relatively undeveloped gas market. Historically, natural gas has contributed very little to Brazil's energy mix. The country has little or no need for space heating; hence there is little market potential for gas in the residential and commercial sectors, and local distribution networks are not very developed. As a result, gas consumption in the country is concentrated in the energy-intensive industries (chemical and petrochemical) that are replacing oil derivatives and electricity use by natural gas. Although the natural gas demand for industrial/vehicle use has been growing at relative high rates – because of the increase in oil prices and government incentives – this demand growth solely is unlikely to justify large investments in gas production and transportation. This means that, at the moment, the power sector is the largest potential market for natural gas, which can provide the necessary anchor demand to spur production and infrastructure investments on natural gas.

However, development of the natural gas industry in an environment where its requirements are very volatile due to the randomness of inflows is a key issue in Brazil. This immediate dependence on gas consumption from power generation creates special challenges for the country, which will now be briefly discussed.

2.1 The Brazilian Electricity and Natural Gas Sectors

2.1.1 The Power Sector

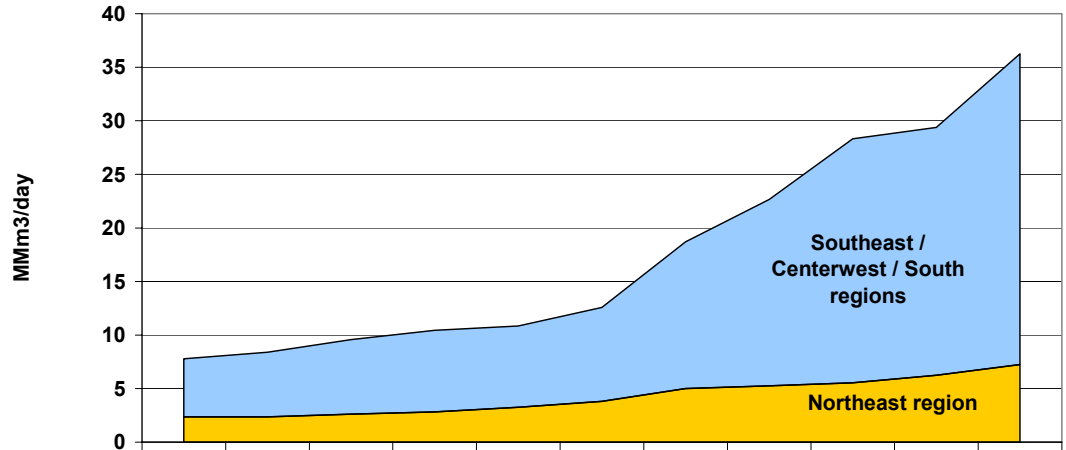
The Brazilian interconnected system had, in 2004, a total installed capacity of about 90 GW. The system is hydro-dominated, with 110 hydro plants distributed in 12 main river systems. Some plants have large reservoirs, capable of multi-year regulation. Thermal generation (28 plants) includes nuclear, natural gas, coal and diesel plants. The area supplied by the system is served by 75,000 km of a meshed transmission network. The main direct international interconnections are the back-to-back links with Argentina, with a maximum flow of 2,200 MW. Power sector reform with emphasis on privatization and competition was initiated in Brazil in 1996. The reform process was disrupted in mid-implementation by severe energy rationing that took place between June 2001 and February 2002. After some regulatory changes that occurred after rationing, a new government took over control of the country in 2003 and launched, in 2004, a new model for the power sector. The main features were: (a) every load must be 100% covered by bilateral financial contracts at all times. All contracts must be "backed" by firm energy certificates; and (b) DisCos must contract their energy through public PPA auctions, with standardized rules and contracts.

2.1.2 The Natural Gas Sector

Brazil has modest proven gas reserves (estimated at 220 billion cubic meters (bcm)), accounting for 3% of South America's total proven reserves. Despite this low level of reserves, Brazil is thought to have substantial potential for new gas resources. In particular, the discovery of a large offshore natural gas field (Santos basin) has just been announced. Even though this field requires very deep sea drilling, its reserves are estimated at 420 bcm, which can double current reserve levels. National gross production levels in 2003 were in the range of 42 MMm^3/day. Production in the recent discovered Santos field are expected to increase this figure in about 20-25 MMm^3/day when it starts operating (current forecasts points for 2009). Since 1999 Brazil has been importing gas from Bolivia through the "Gasbol" pipeline. It is the largest capacity pipeline in Latin America, with 30 MMm^3/day, built by private investors. Imports in 2005 are in the range of 23 MMm^3/day. Since 2000, Brazil has also been importing gas (2,8 Mmm^3/d) from Argentina to supply a 600 MW thermal plant on the Brazilian side of the border between the countries.

Without considering gas for power use, the natural gas consumption levels in 2004 were in the range of 37 MMm^3/day. Most of the gas is used in the industrial sector. Because there is virtually no need for space heating in Brazil, gas use for the residential and commercial sectors remain limited to cooking and water heating. The use of gas for transport has been increasing. This is mostly encouraged by the competitive price of compressed natural gas (about half the price of gasoline when driving the same distance). As can be seen in Figure 4, there has been a strong growth outlook over the last years, where industrial and transportation sectors have been the main growth areas (motivated by government policy and increase in oil prices).

Since the 1990's Brazil has been calling for a larger share of thermal capacity, fuelled mainly by natural gas, in order to reduce dependence on hydroelectricity and to boost natural gas demand. However, little happened until 1999-2000, where under imminence of the energy supply crisis, a program for an incentive for thermal generation was launched in the country. This program resulted in the construction of about 6000 MW of gas-fired plants by 2004. This could correspond to maximum gas consumption in the range of 30 MMm^3/day.



	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004 until Aug
SE/CW/S	5.4	6.0	6.9	7.6	7.6	8.8	13.7	17.4	22.8	23.1	29.0
NE	2.4	2.4	2.6	2.8	3.2	3.8	5.0	5.3	5.6	6.2	7.3
Total	7.8	8.4	9.6	10.4	10.8	12.6	18.7	22.7	28.3	29.4	36.3
yearly growth		7.8%	14.1%	9.2%	3.8%	16.1%	48.6%	21.2%	24.9%	3.8%	23.4%

Figure 4. Brazil: Historical Consumption of Natural Gas (Non-power Use)

As Brazil is a country the size of a continent, several distinct gas markets can be expected to develop, each characterized by its own supply sources, demand centres and transportation networks. Today three natural gas markets in Brazil can be distinguished: the largest and most developed system by far comprises the South, Southeast and Central-West regions. Coastal cities from the Northeast form the country's second natural gas system. The third system, with abundant reserves still to be developed, is the Amazon region, located North in the country. There is planned integration between the Northeast and Southeast. Figure 5 shows the main (cross-regions) natural gas and electricity transportation networks. It can be seen that the gas network is still developing its infrastructure when compared to the existing electricity network.

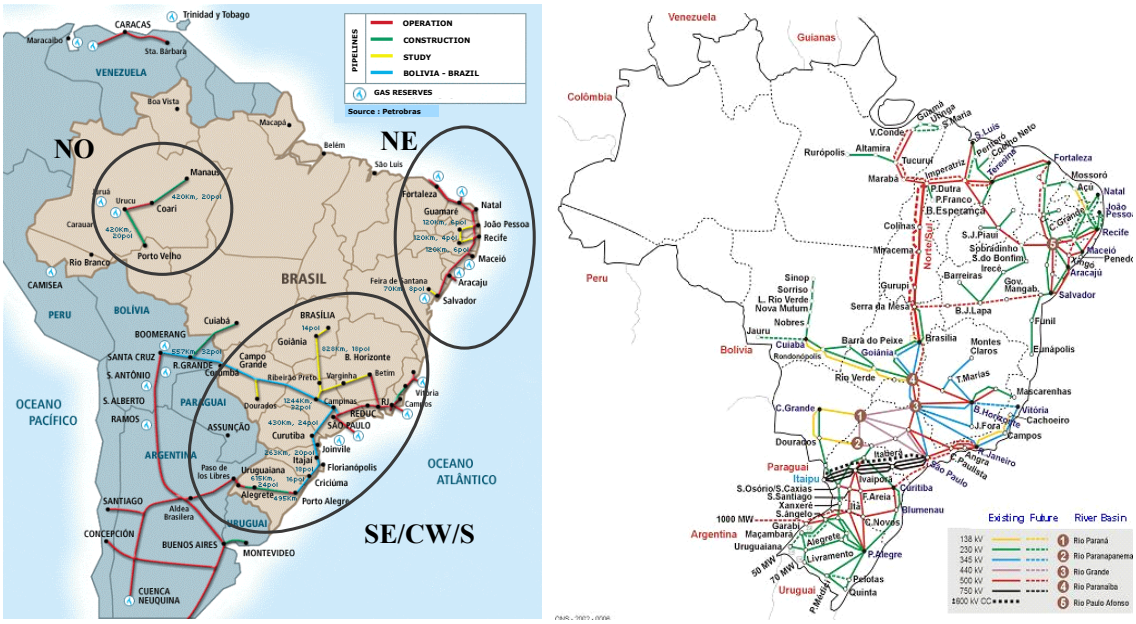


Figure 5. Main Natural Gas and Electricity Transportation Network

Brazil does not yet have a clear policy or guidelines concerning the gas sector. The law that liberalized the petroleum sector in 1997 treats gas as a sub-product of oil. It fails to adequately address the particularities of the gas industry. The Brazilian government is currently (2005) starting to work on a new law for the gas sector, that will address, among others, the role of the private sector; the role of public companies; the structure and market rules for the electricity and gas sector; and the role of gas in electricity generation.

2.1.3 Brazil's Main Challenges in Electricity-Gas Integrated Adequacy Planning

The main challenges in electricity-gas integrated adequacy planning in Brazil are those related to the high dependence of the country on hydropower and in turn the reliance of the gas market on gas consumption for thermal generation to develop. This section details two of these challenges: the challenge of flexibility and the challenge of the integrated electricity-gas scheduling.

2.1.3.1 The Challenge of Flexibility

In hydro-dominated systems thermal generation is generally useful as backup for periods of low rainfall. This means that the existing thermal plants may be idle in periods of high (or average) precipitation, which occurs most of time. This pattern is illustrated in Figure 6, which respectively show the observed short-run marginal costs (proxies for market prices) in the Brazilian South-Southeast system from January 1993 to August 1997 and a more recent historical record.

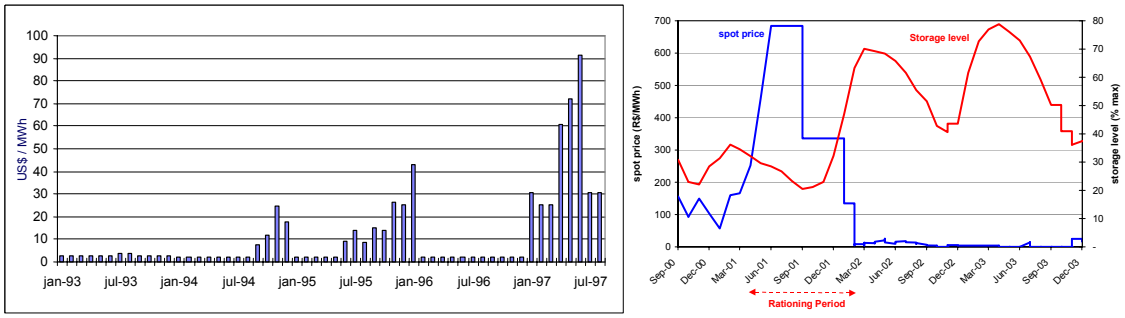


Figure 6 - Historical Monthly Short-Run Marginal Costs

Figure 6 shows that the system marginal cost is very volatile, leading to very "sporadic" dispatch of thermal generation (associated to bad inflow conditions). The reason for this behaviour is that predominantly hydro systems are designed to ensure load supply under adverse hydrological conditions, which occur very infrequently. Hence, most of the time there are temporary energy surpluses, which result in very low marginal costs and no need of thermal dispatch. In turn, if a very dry period occurs, spot prices may increase sharply, and even reach the system rationing cost. An occurrence of a dry period usually calls for the dispatch of all thermal plants "at the same time", which in turn calls for a robust pipeline network capable of meeting this "volatile" gas demand. One of the consequences of this "feast or famine" price characteristic is that it creates a very "volatile" gas demand from power generation. Since it is not economical to build production and transportation infrastructure to be idle most of time, this "irregular" consumption pattern from power generation makes it difficult for the gas-sector to build the necessary infrastructure without mandatory "take or pay" and "ship or pay" clauses on the gas contracts between gas producers and thermal plant owners, which are then used to stabilise, from the gas producer point of view, the irregular cash flow that would arise from market operation of the power plants. On the other hand, these clauses may decrease competitiveness of thermal projects since thermal owners are paying a fixed price for gas independently of use.

In summary, the relatively young state of development of the gas industry in Brazil implies less flexible gas supply contracts to power generators and also means that there is no or little opportunity for power plants to sell their contracted gas on the secondary market on account of the other markets for gas being not very developed.

The discovery of a large natural gas field at Santos and management of the existing reserves poses new challenges to Brazil, as a "market" for these reserves must be found to make feasible their development. This rationale also applies for any effort to expand gas imports from Bolivia and Argentina. Since it is not economical to build a pipeline infrastructure that is underused most of the time, it becomes necessary to develop flexible supply and demand options such as: (i) secondary gas markets; (ii) flexible gas/electricity consumption; (iii) flexible production (e.g. LNG exports) and (iv) storage options such as depleted oil/gas fields and/or hydro reservoir capacity (gas stored as water in hydro plants reservoirs).

2.1.3.2 Integrated Electricity-Gas Operations Planning

In Brazil, the system operator undertakes power system dispatch centrally. The system operator acts as if all plants belonged to the same owner. Hydro plants are dispatched based on their expected opportunity costs ("water values"), which are computed by a multi-stage stochastic optimization hydrothermal scheduling model that takes into account a detailed representation of hydro plant operation and inflow uncertainties [1]. Traditional hydro scheduling models used for system dispatch take into account detailed representation of the power system (including electricity network), but do not take into account representation of constraints of infrastructure (production and transportation) of the natural gas sector. In other words, the approach assumes no constraints in the gas sector. This is not true for a country whose gas transportation infrastructure is still developing and where heavy gas network constraints exist in areas where gas-fired thermal plants are located

This decoupling may imply in dispatch results for the power sector that can be dangerously "optimistic", since the model may consider thermal dispatches that will be "infeasible" due to gas production or transportation constraints. For example, in January 2004, a shortage of hydropower in Northeast Brazil implied the System Operator to dispatch existing gas-fired resources in the region. However, only a third of the gas-fired capacity installed in that region was able to generate due to gas production and transportation constraints, which were not "seen" by the hydro scheduling model.

Therefore, consideration of the gas sector (production and transportation constraints) in operations of the power sector is of great importance to the country and is one of the main challenges.

3. Chile: Uncertainty in Natural Gas Supply

The Chilean power sector, that started an electricity deregulation process in 1982, has experienced several crises over its development that has tested the strengths, or weaknesses, of its market model [2]. The most recent crisis started when the Argentinean government started facing problems with its gas supply and in April 2004 decided to reduce gas exports to Chile. Chile is a country with limited energy resources other than its hydro reserves in the Andes. Its own oil provides less than 10% of the country's needs and its coal is of poor quality so that imported coal has to be used for electric generation. Hydroelectric generation has developed using most of the low cost resources in the central part of the country, and remaining significant reserves are over 2,000 km south of the main load. Argentinean gas arose as an attractive abundant cheap alternative and an energy integration protocol was signed in 1995 with the neighbouring country. Under that protocol, both governments agreed to establish the necessary regulations to allow freedom of trade, export, import and transportation of natural gas. Private investors were strongly behind the process, and invested heavily in several pipelines that crossed the Andes and defined an energy supply path that would rely heavily on efficient combined cycle generation plant technologies. The protocol worked very well and Chile fully relied on Argentina to provide the necessary energy required to sustain its important economic growth. Gas exports grew steadily through several pipelines (Figure 7). The petrochemical industry and the thermoelectric generation became the main users of natural gas (Figure 7). The arrival of this cheap fuel and the efficient generation technologies meant a significant reduction in electricity prices in the main central interconnected system.

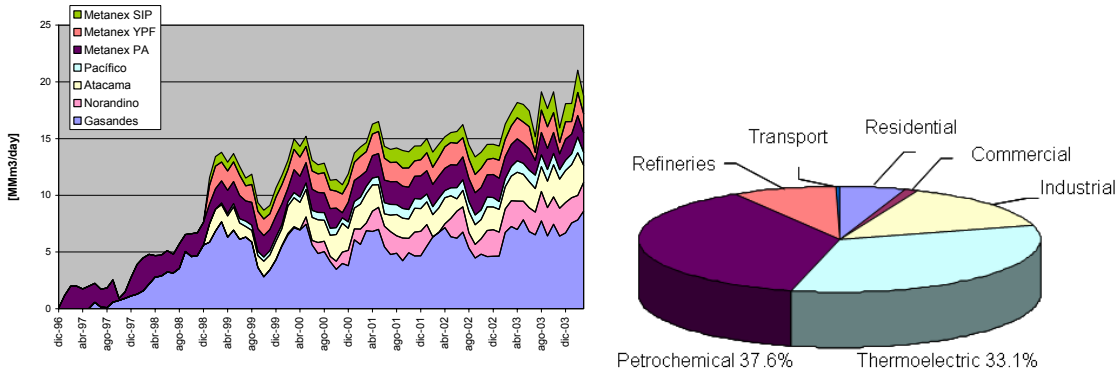


Figure 7. - Natural Gas Exports from Argentina to Chile [2]

Argentina, among other acute problems in the global crisis it is going through, started facing an energy deficit. Natural gas prices were reduced to one third of their previous levels (due to a severe devaluation of the Argentinean peso) and this led to an escalating demand, not necessarily backed by investment in the exploration of new gas fields neither in new pipelines. Given these conditions, the Argentinean government did not comply with its international agreements and decided to favour national supply, to the detriment of the consumers of Chile and other neighbouring countries like Uruguay. Bolivia has significant natural gas resources and it is increasing exports to Brazil and Argentina, helping the later to diminish its crisis. However, given its long-term border disputes with Chile (Bolivia lost its access to the Pacific in a 19th century war with Chile), it denies the fuel to the next-door country.

Chile was not aware of nor prepared for the surfacing conditions. As a demonstration, the National Energy Commission, in its indicative plan of April 2004, projected the building of seven combined cycle natural gas plants in the next ten years, all fed by pipelines from Argentina. Mainly expansions of existing electric transmission corridors were included in that plan. Major new hydro plants and interconnections with other systems were postponed until 2010 or later, gas continued to be the major driver of expansion in a market with demand growing around 7% year. With the crisis developing, the October 2004 indicative plan introduced radical changes to the government view of energy supply expansion. Only one combined cycle plant based on Argentinean gas was considered for 2007. The government decided to bet on liquefied natural gas as the alternative and defined a project to build the necessary installations to import it from abroad (Indonesia, Australia and Algeria being supply alternatives).

But in the deregulated privatized Chilean power market, where private capital is the one making investment decisions, there is little space for the government to act, unless changes to laws are introduced. The electricity price scheme relies essentially on market competitive forces, with only part of it, prices for small consumers (under 500 kW), being regulated by the government.

At the end, it is the cost of different generation technologies that will drive development. And the comparison has to be centred on the particular geographic conditions and infrastructure development of Chile. A recent comparison [2] was made for the Chilean investment environment (local cost of capital taken into consideration), where liquefied natural gas combined cycle plants compete with circulating fluidized-bed boilers fuelled by coal (Table 1).

Table 1. - Cost of Different Generation Technologies, Chile, 2004 [2]

Tecnologies	Investment (US$/kW)	Average generation cost (US$/MWh)	Fuel cost (US$/mBTU)
Reservoirs (400 MW)	1100	25.5	0.0
Run of river hydro (400 MW)	1250	28.7	0.0
Combined cycle natural gas (394 MW)	530	31.6	2.8
Coal circulating fluidized bed (250 MW)	1270	44.5	1.8
Combined cycle liquefied natural gas (394 MW)	530	45.1	4.7
Combined cycle diesel (394 MW)	550	66.8	7.9
Gas turbine (120 MW)	430	103.5	7.9

However, an essential question is troubling investors, what if gas supply from Argentina returns to normal? If a decision is made, for example, to contract liquefied natural gas, and cheaper natural gas starts re flowing without restrictions from Argentina, who will make the lost? High financial exposures may arise depending on decisions made. As indicated, in a deregulated environment, where private investors are the ones that decide expansion, the government is uneasy when faced with an uncertain energy supply that may seriously hurt economic development. The country is returning to high economic growth rates, but not enough to solve basic problems such as unemployment and highly unequal income distribution. Therefore, nobody wants energy deficits to shadow economic development.

Thus, the government is looking for alternatives. Capacity payment regulations are being modified to better take into account unreliable gas supply. A gas "drought" concept was introduced that derates combined cycle plants that do not have alternative fuel arrangements, and therefore reduces their capacity payments. Another alternative being considered is to limit by law the dependence on foreign fuels to a certain percentage of national consumption; the idea is that imports from a particular country shall not exceed a certain value (a similar concept is used in Spain). The idea is not to impact present combined cycle plants using Argentinean gas, but to limit investment in new ones. The advantage is that this would reduce the financial exposures previously indicated, and the liquefied natural gas project becomes a feasible option. Critics of this alternative argue it represents a State intervention that will imply higher long-term energy costs for the country as a whole.

4. Mexico: Growing Interactions between Mexican Gas Markets and Electricity System Planning

The Mexican gas and electricity sectors followed a non-synchronized agenda of reforms. Some of the reforms in the gas sector have been uncompleted and the more profound reforms in the electricity sector have remained idle or without consensus for the last five years. However, the interactions among the two systems, one –the gas sector– with a considerable degree of openness and the other, basically vertically integrated, have not avoided their growing interactions due to new technological and cost development in the gas markets that have direct impacts in electricity systems resource planning. The increasing interactions between the two systems pose important questions among them the need for new planning tools that represent important opportunities for the research community. On the energy side, of increasing importance for Mexican reliable and cost effective supply of gas to the electricity systems are the Liquefied Natural Gas Markets (LNG), which nowadays represent a clear alternative to continental gas supply to Mexico's electricity systems. The dynamics of LNG markets have also had an effect on traditional electricity system planning where more complex tolls for system planning may be required.

4.1 Gas Supply Demand for Electricity Production

Electricity expansion planning in Mexico indicate that less-cost expansion planning of the system will continue to rely in combined cycle plants for the next ten years (Figure 5) as it has done in the last decade.

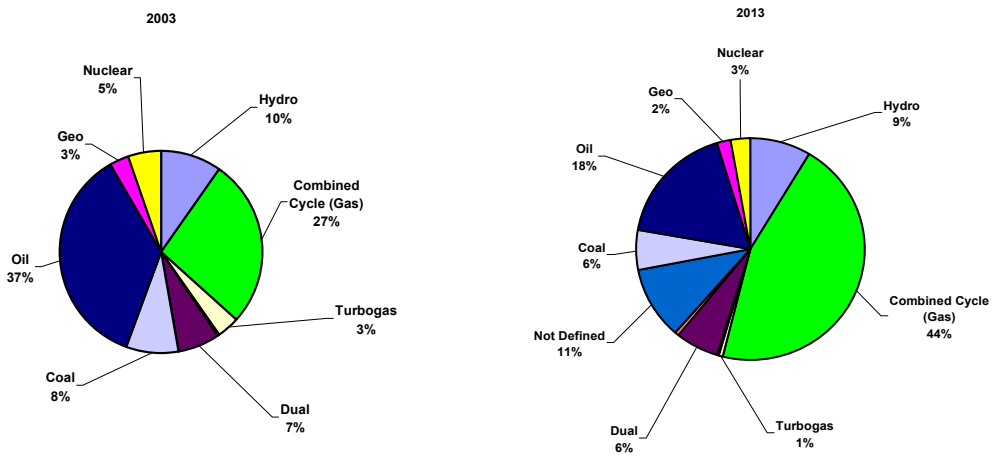


Figure 8. Electricity Generation Installed Capacity Shares by Fuel Type, Actual (2003) and Planned (2013)

The share of gas as fuel for electricity supply will grow from 27% to 44 % of total electricity production from 2003 to 2013 (Figure 9). The increasing extension of the national gas pipeline system and its connection to the US market and the growing worldwide Liquefied Natural Gas Market (see Figure 9) have resulted in interesting interaction among the traditional planning of an almost vertical integrated electricity utility and a more open and mature market for natural gas.

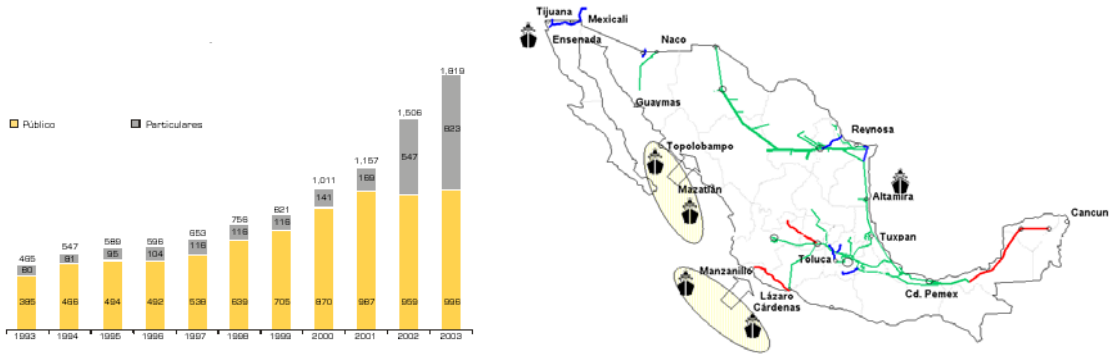


Figure 9. Gas Consumption for Electricity Generation (MM cubic feet/day) and Planned LNG Installations

4.2 Gas/Electricity Network Interactions

A specific project for electricity generation called Tamazunchale consisting of a large combined cycle plant of around 1000 MW required to supply the central region of Mexico was identified by the classic cost-minimization approach used in Mexican electricity system expansion planning. Current models did not capture the fact that the territorial sitting of the plant had different alternatives that would require either: (i) the sitting of the plant beside an existing gas pipeline with the need of a new transmission line to connect the plant or (ii) the sitting of the plant beside an existing transmission line with the need of a new gas pipeline to transport gas supply to the plant. The decision of sitting was left to the investors (i. e to the market) in a bidding process that asked for a 1046 MW combined cycled plant with two different sitting options. Therefore, one important issue is how traditional vertical integrated planning interacted

with a bidding (market) mechanism that asked for a long-term contract for electricity supply with two alternate delivery points resolved the interaction between the Gas/Electricity transport choices for the project.

4.3 LNG/Electricity Expansion Interactions

The increasing consumption of gas in Mexico for electricity production along with the lesser than expected national growth of internal production in gas, indicates that import of gas from the US (Texan or Californian) market trough the national pipeline system will still be an alternative to secure gas supply although not at competitive prices. However, the increasing maturation of the Liquefied Natural Gas Market (LNG) worldwide makes this alternative an even less-cost effective alternative supply of gas if certain considerations are made in the electricity generation expansion plans. This part of the paper will describe how the dynamics of LNG markets cannot easily or directly be incorporated in traditional expansion models and how multiple expansion scenarios are being used in the electricity system expansion models to consider LNG supply for the combined cycle plants. The results show how possible shifts in electricity system expansion can aggregate demand for gas to a particular level that may make LNG an alternative less-cost alternative to supply gas to electricity plants rather than using pipeline gas from US markets trough the national system.

5. Natural Gas and Electricity Market Issues in Colombia

Colombia has numerous primary energy resources: Oil and associated natural gas in the Interior region of the country, free natural gas in the Atlantic Coast region, hydroelectric resources mainly in the Andean Mountains and extensive coal deposits both in the Atlantic Coast and the Interior regions. Hydroelectricity is used to serve around 65% of the electricity market; the remaining 35% is served by coal and natural gas fired plants. Natural gas is also used in oil refining, industrial, residential, commercial and transportation uses. As in Brazil, development of the natural gas industry in an environment where its requirements are very volatile due to the randomness of river discharges is a key issue in the Colombian energy sector.

5.1. The Natural Gas Market

Natural gas in Colombia has been a non-internationally traded energy product, and therefore its development and use has been subject to growth of the local gas market. Average supply of natural gas in Colombia during 2003 was 595 MBTU/Day, 478 MBTU/Day of it produced in the Atlantic Coast fields. It is expected that in 2007 an interconnection gas pipeline with Venezuela will start operation and, therefore, should enable natural gas exports to such country during several years and, eventually, allowing future natural gas imports. This interconnection would enlarge the Colombian gas market, enabling international natural gas trades to develop the Colombian natural gas reserves.

Development of the natural gas industry in Colombia is recent. Although there were local natural gas uses since the 1950's, its massive utilization started in the middle of the 1970's in the Atlantic Coast region with the utilization of free natural gas reserves located in such a region. In the middle of the 1980's a Government plan accelerated natural gas service extension towards urban centres. Later on, in the decade of the 1990's, another incentive plan was implemented; its main component was the gas transportation infrastructure, in operation today connecting the gas fields with main consumption centres. The above actions have been complemented with an increase of natural gas reserves due to new findings in the Interior of the country, the start of a new regulatory framework for the natural gas market, and by the dynamics of new natural gas demands. In particular, since the start of this Plan, 3010 MW of new gas fired thermal plants have been installed which represent 22% of the total electricity generating capacity installed in the country.

Demand for natural gas in Colombia has been growing significantly, subject to volatility due to gas consumption for thermoelectricity that reached an annual average of 304 MBTU/Day for use in 1998.

Natural gas consumption in Colombia was 589 MBTU/Day in 2003, of which 181 MBTU/Day for electricity generation.

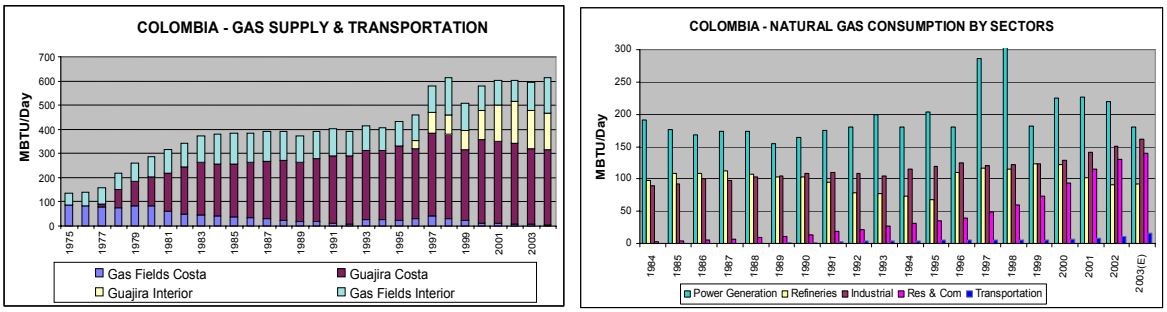


Figure 10. Gas Supply, Transportation and Supply Outlook

UPME, the government unit for energy planning, estimates that natural gas demand would reach around 750 MPCD by 2010, at which time the Colombian natural gas supply capacity should be increased to around 900 MPCD if the natural gas export program to Venezuela of 150 MPCD is accomplished.

Natural gas demand for electricity generation in the country is subject to large volatility. It is highly seasonal due to the nature of the Colombian power system, which has a large hydroelectric component. River discharges are substantially affected by El Niño phenomenon. Its occurrence implies large thermoelectric use to compensate for the decrease in hydroelectric generation. Guerrilla attacks to the transmission infrastructure are another source of natural gas demand uncertainty since it forces thermal generation in some areas without hydroelectric resources.

There has been a relevant investment from state and private companies in later years in order to connect main production gas fields to the principal consumer centres around the country through the construction of new gas pipeline grids. Estimates of natural gas demand in Colombia in sectors different from electricity generation assume that the Atlantic Coast regions have the largest and most developed markets. Under such assumptions, highest demand increases would occur in the Colombian Interior region as a result of natural gas penetration that would occur in residential, industrial and transportation sectors.

The forecasted natural gas demand in the industrial sector is being influenced by strict environmental regulation on emissions since year 2000. Here, environmentally aggressive fuels formerly used for industrial consumption have been substituted by natural gas in the sector.

5.2 Electricity – Gas Market Issues

Natural Gas and Electricity markets have strong links in Colombia and therefore there are several issues related to the interaction among them, such as:

a) Capacity Charges: Large hydroelectric component of the Colombian installed capacity implies that some of the natural gas fired plants have very low dispatch probability but they are required to guarantee supply reliability. Main issue related to this is the design of an appropriate capacity charge mechanism to create the financial incentives for the installation, operation and maintenance of these types of plants without creating economic adverse distortions in the operation and expansion of the system.

b) Power transmission and gas transportation charges: achievement of optimal integrated operation and expansion of power and gas transportation systems require correct incentives given by an appropriate scheme of regulated charges. Colombia has a simplified stamp and deep connection charge scheme for power transmission while complex distance related charges are applied to gas transportation, creating perverse incentives to integrated power-gas system optimal operation and expansion. In

addition gas demand volatility arising from randomness of hydroelectric generation constitutes a challenge.

c) Natural gas vs. Electricity markets: Colombian electricity market is a price bid based highly competitive market with more than 30 generators participating while the Colombian natural gas market is reduced to a few participants requiring regulated wellhead prices. Even though the regulatory agency has given the signal to open the gas market this constitutes a regulatory challenge given the related market power issues. Also, the complexity of the natural gas based electricity generation cost structure within a main hydroelectric bid based market constitutes an issue to be addressed to incentive optimal power system operation.

d) Market surveillance: international experience of bid based power markets demonstrates the need of a market surveillance mechanism to prevent inefficiencies due to eventual market power actions and to guarantee appropriate market development. In the Colombian case, inclusion of the gas market in the surveillance scheme is a critical issue needing to be solved.

6. Power and Natural Gas Integration in the Southern Cone – Past, Present and Future

6.1 Background

Regional power integration in the Southern Cone of Latin America had its inception before any political and economic partnership projects, and exhibits a wealthy history of shared undertakings and a variety of physical links and exchanges. In its early stages, a characteristic of the way regional power integration evolved in this region was the development of bi-national hydro plants. This development gave rise to a parallel integration of the very high voltage networks existing in the region and to the implementation of a large exchange capacity, which has not always been properly utilized. In the 1990's, as a consequence of the growing trend toward development of a regional block, Power and Natural Gas Integration Protocols were signed within the Southern Cone, in parallel with market reform measures. At this point, the challenge was to interrelate a supra-national regulatory framework structuring and promoting the development of mainly private investment projects with the prospective integration and liberalization of gas and power trade. In this context, high capacity works were implemented in the power sector as private undertakings, such as the 2000 MW (Brazil – Argentina) connection. Natural gas connections were also implemented between Argentina, Bolivia, Brazil and Chile. In addition, integrated projects involving gas exports and power generation were also developed. Figure 3 shows the main electricity-gas cross-border interconnections in the region.

The regional integration process was ultimately adapted to the primary resource matrix available in each country, with increasing expectations as regards the satisfaction of local demand with foreign supplies. As already mentioned in section 3, a noteworthy case was that of Chile, which undertook a program involving the change of its power supply on the basis of gas imported from Argentina. A similar situation, but to a lesser extent, arose in Brazil with Bolivian gas.

This scheme was geared toward the full utilization of the existing network capacities and the generation of new links. The coexistence of firm exchanges (based on long-term contracts) and spot exchanges was not conflictive, as the market operated on the basis of capacity surplus. The full utilization of the internal power and gas network capacities led the systems to a border situation where the interaction between natural gas and power, a characteristic feature of this new stage, took on a dominant role in the rationale of system development. Towards 2002, when the whole system suffered the shock of the Argentine crisis, the regional system, without exhibiting features of an open market, already showed the following traits: (i) Long term gas operations: exports from Argentina to Chile and Brazil; exports from Bolivia to Brazil; (ii) Long term power operations: capacity and energy exports from Argentina to Brazil; (iii) exports from bi-national entities (hydro plants) from Paraguay to Argentina and Brazil; (iv) spot operations: exchanges at bi-national power stations, exports from Brazil to Argentina and Uruguay.

The integration scenario has shown some signs of stagnation in the last couple of years, especially in view of the relative isolation of individual plans and a stronger emphasis on self-sufficiency at the national level.

6.2 Regulatory and Commercial Situation

During the last few years, the pace of reforms has slowed down at international level, and market organization at national level is undergoing active reviews. Without having fully retreated from the systems implemented in the 1990's, transition periods are under way both in Argentina and Brazil, with a higher degree of participation by the State in sector management. This review includes the destination of "free" supplies (freely contracted supplies), which imposes some limits on the deregulation process envisaged in the early stages. Perhaps the interpretation of the supply crises that occurred in different places and with varying characteristics (rationing in Brazil, power shortages in California) has been especially important in this sense. Such crises, which were contemporary to the reform process, gave rise to doubts as to the true roots of the problems.

However, bearing in mind that these are complex phenomena, there is a linking thread which brings together the various difficulties experienced, which is the role of investment and the capacity, or lack thereof, of the current systems to guarantee the replacement and expansion of the facilities with sufficient anticipation. This aspect, which is a general truth for any utility, was worsened by the relative decline of external investment flows in the Region in the late 1990's.

The other area affected by the changes and restrictions appearing in the first years of the century were the integration of the markets at regional level: the regulatory frameworks governing interconnections have proven to be inadequate, despite the many protocols and agreements in force. In a context of strong national debates, protectionist or isolationist schemes imposing restrictions on the compliance with contractual conditions have been retaken. It is as if the contracts freely entered into by private parties lacked a smooth relationship with the guarantee of supply in each country.

An aspect contributing to the integration is the progress made as regards operating regimes and the coordination of load dispatches and network usage, all of which was facilitated by the long working experience with interconnected systems. It is true that competition has taken place with respect to the firm and uninterruptible access to the networks. The role distribution between the public and private sectors is on hold. Although the high rate of privatizations that characterized the 1990's has slowed down, no significant re-nationalizations have taken place. In Argentina, Chile and Brazil this has resulted in a mixed system sporting a wholesale market with significant private participation.

Reviews have focused mainly on the search for more effective regulation and control and on the adjustment of the pricing systems both at the wholesale and retail levels in order to ensure efficient, low-cost procedures that, in turn, make the financing of any required investments feasible. In this sense, a review is being made of the role of the capacity and energy supply contracts with distributors, traders and large consumers and their relation with the spot pricing systems.

6.3 Southern Cone Integration Issues

Regional energy integration is key to development. It is a project dating back quite a few years and in full development. However, at present there is a need to guarantee stable rules of the game and dispute settlement mechanisms based on agreements made at the highest political level. Today, there are a large number of outstanding issues related to integration in the Political, Institutional and Regulatory Areas. Examples of these issues, include:

a) Guidelines for the future of economic integration and regional policies. The complementary and alternative political and economic integration processes (Mercosur, FTAA, etc.) include and determine infrastructure and services integration projects. Within this supra-sect oral framework,

some noteworthy aspects are homogeneous tax treatment and the stabilization of export and import authorization regulations;

b) Adaptations of existing energy integration protocols under the light of recent events (crises of the power and gas contracts between Argentina, Chile, Brazil, Bolivia, etc.). There is a need for higher-hierarchy multinational agreements with a larger degree of flexibility in order to adapt to particular situations that may affect performance. To align policies and regulations among the various countries is an important step that would encourage spot and long-term exchanges.
c) Fostering the stabilization of mechanisms aimed at establishing price benchmarks for exchanges and eliminating circumstantial distortions.
d) The tendency to integrate open and competitive markets with long-term contracts and spot exchanges should be maintained, since such markets allow minimizing supply costs in the long-term. For this purpose, it is essential to develop effective non-discriminatory treatment mechanisms for demand and local and foreign supply, within the framework of liberalization and regional trade opening.
e) At present, capital market conditions are not positive for the sector. This causes delays in expansion projects. An integrated activity could increase fund availability for the various types of works: hydro stations, thermal power stations, power and natural gas transport, etc.

Regional integration should not only include but also advance beyond infrastructure connections and individual exchanges. Ideally, free, long-term and spot exchange markets should be created between regional producers and consumers, with due safeguards against crises or emergencies. Regional integration is not just one more option; it is an obligation that must be undertaken in order to reduce social and environmental costs in the region. For this purpose, commitments at the highest level and stable national and international policies are required, in order to promote investment and efficient operation by adequately distributing the roles between the public and private sectors.

7. Conclusions

The primary challenge for Latin American countries is to ensure sufficient capacity and investment to serve reliably their growing economies. The region has emerged as one of the most dynamic areas for natural gas and electricity developments. On the other hand, the high dependence of some countries such as Brazil and Colombia on hydropower creates some challenges for the smooth insertion of gas-fired generation. Countries like Chile are facing the challenge of "gas supply under uncertainty", since the so far stable gas import contracts with Argentina turned to be "uncertain". Another important issue in the region is multi-country electricity markets, which are a natural evolution to the existing "official" international interconnections, which in turn were originally established by the countries' governments for sharing reserves and carrying out limited economic interchanges. The creation of a regional market is a natural step towards economic efficiency and economic growth. While there are important opportunities for both electric and gas integration within the region, some important aspects remain to be discussed, such as the compatibility of regulatory frameworks, taxes systems and the stability of long-term contracts.

8. Acknowledgement:

This work is based on the summaries of presentations of the panel session on "Integrated Natural Gas – Electricity Resource Adequacy Planning in Latin America", chaired by L.A.Barroso, T.Hammons and H.Rudnick, to be held at the IEEE General Meeting, San Francisco, 2005. The authors gratefully acknowledge the valuable contributions of the panellists M Madrigal and G Arroyo (Mexico), J Mejía and A Brugman (Colombia), M Pereira, R Kelman, B Flach, B Bezerra, S Binato and J M Bressane (Brazil), L Sbértoli (Argentina), M Tavares and P Camarota (Brazil/Bolivia).

9. For Further Reading

[1] L.A.Barroso, M.Pereira, B.Flach, B.Bezerra, J.M.Bressane, R.Kelman, "Integrated Gas-Electricity Adequacy Planning in Brazil: Technical and Economical Aspects", Proceedings of IEEE General Meeting, San Francisco, 2005.

[2] H. Rudnick, "Electricity Generation and Transmission Expansion under Uncertainty in Natural Gas", Proceedings of IEEE General Meeting, San Francisco, 2005.

[3] G.Arroyo, M.Madrigal, "Growing Interactions between Mexican Gas Markets and Electricity System Planning", Proceedings of IEEE General Meeting, San Francisco, 2005.

[4] J.Mejía, A.Brugman, "Natural Gas and Electricity Market Issues in Colombia", Proceedings of IEEE General Meeting, San Francisco, 2005.

[5] L.Sbertoli, "Power and Natural Gas Integration in the Southern Cone: Past, Present and Future", Proceedings of IEEE General Meeting, San Francisco, 2005.

[6] M.Tavares, P.Camarota, "The Role of Natural Gas as an Instrument for the Energy Integration in Latin America", Proceedings of IEEE General Meeting, San Francisco, 2005.

[7] Information on Latin-American deregulation in www.ing.puc.cl/power

[8] IEA – South American Gas – Daring to tap the bounty, IEA Press, 2003.

10. Biographies

Luiz Augusto Barroso has a BSc in Mathematics, an MSc in Operations Research and is working towards a PhD degree in Systems Engineering (optimization) at the Federal University of Rio de Janeiro, Brazil. He joined Mercados de Energia/PSR group in 1999 and has been involved in several studies and research in the following areas: (i) economic studies and financial evaluation of projects; (ii) energy trading, risk management and physical-financial optimization in energy markets; (iii) system planning studies; and (iv) regulatory assessment to private investors and institutions. In the case of Brazil, he has been participating directly in the conceptual design and critical analysis of a power sector model, including proposals for improvements of the regulatory framework and market conditions. More recently, he has been working on tariff revision of the gas companies in the Brazilian system and in studies related to the insertion of natural gas in the Brazilian power system. He has been developing methodologies for strategic pricing in competitive energy markets and in energy auctions. He has been an invited speaker on energy deregulation and market issues in workshops, courses and talks in Brazil and many countries in Latin America, in USA/Canada, in Europe, and in Oceania. He is the author and co-author of more than 30 papers in refereed journals and conference proceedings.

Thomas J. Hammons, an IEEE Fellow, graduated from Imperial College, London, UK with First Class Honours and has DSc, PhD and BSc degrees in Electrical Engineering. Currently he is Chair of International Practices for Energy Development and Power Generation IEEE. He is Past Chair IEEE UKRI Section for which he received the IEEE Regional Activities Board Region 8 Sustained Membership Growth Award in both 2000 and 2001, and Past Chair IEEE UKRI Power Engineering Chapter for which he received the PES Outstanding Large Chapter Award in 2003. He is a member of the teaching faculty of the Faculty of Engineering, University of Glasgow, Scotland, U.K. Prior to this he was employed as an Engineer in the Systems Engineering Department of Associated Electrical Industries, Manchester, U. K. He was Professor of Electrical and Computer Engineering at McMaster University, Hamilton, Ontario, Canada in 1978-1979. Dr Hammons is a Founder Member of the International Universities Power Engineering Conference (Convener 1967, Permanent Secretary 2005). He is the author/co-author of over 350 scientific articles and papers on electrical power engineering. He has lectured extensively in North America, Africa, Asia, and both in Eastern and Western Europe. He is registered European Engineer in the Federation of National Engineering Associations in Europe.

Hugh Rudnick, an IEEE Fellow, graduated as an electrical engineer from the University of Chile, Santiago, Chile. He received the M.Sc. and Ph.D. degrees from the Victoria University of Manchester, Manchester, U.K. Currently he is with the Catholic University of Chile, Santiago, Chile and also with Systep Engineering Consultants, which specializes in power-gas system planning and operations issues. His research activities focus on the economic operation, planning, and regulation of electric power systems that specializes in power-gas system planning and operations. He has been a consultant with utilities and regulators in different countries, the United Nations and the World Bank, mainly on the design of deregulation schemes and transmission and distribution open access tariffs.