

# We are IntechOpen, the world's leading publisher of Open Access books Built by scientists, for scientists

6,900

Open access books available

186,000

International authors and editors

200M

Downloads

Our authors are among the

154

Countries delivered to

TOP 1%

most cited scientists

12.2%

Contributors from top 500 universities



WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index  
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?  
Contact [book.department@intechopen.com](mailto:book.department@intechopen.com)

Numbers displayed above are based on latest data collected.  
For more information visit [www.intechopen.com](http://www.intechopen.com)



## Integrated Natural Gas-Electricity Resource Adequacy Planning In Latin America

Natural gas (NG) is considered as one of the most promising sources to supply the world energy demand, with a consumption expanding at a very accelerated pace. The largest use still is for industrial heating. The second largest use is for electric power generation, which experienced a strong growth after the development of combined-cycle generation technology (CC-NG) in the 1980s. Besides efficient, CC-NG is competitive in modules quite smaller than those of other technologies, such as coal. This has contributed to foster the implementation of power plants based on CC-NG in electricity markets worldwide and created interdependency between the electricity and the gas sectors.

Latin America boasts natural gas reserves and high-growth energy markets. The need to diversify away from heavy investments in hydropower and expensive oil has driven many countries to promote the use of natural gas, especially for power generation. This was facilitated given the abundant reserves of gas in several countries in the region, particularly Venezuela, Argentina and Bolivia, and their interconnection with other markets. These developments were coupled with additional challenges, such as (i) the competition between hydro and thermal generation in a heavily hydro balanced region, (ii) the building up and later breaking of cross-country natural gas agreements, (iii) the competition between natural gas and other resources for power generation and electric transmission, and (iv) the development of the natural gas industry in an environment where its requirements are very volatile due to the randomness of hydro inflows.

More recently, liquefied natural gas (LNG) started to be considered an option to ensure the adequacy of natural gas supply for power generation. Brazil and Chile are leading the implementation process of regasification facilities. However, the region has also potential to become an exporter of LNG in the medium-term once the potential gas reserves that require deep drilling become commercially available.

This chapter addresses natural gas-electricity resource adequacy expansion and planning in Latin America. Five “*case studies*” were 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. The emphasis is on the institutional and operational arrangements adopted in each country, and the competition between electricity transmission and natural gas pipelines. The success/difficulties observed in handling recent conflicts in the region that arose from natural gas supply difficulties are also provided. A section devoted to analyze the introduction of LNG in the region is also presented.

12.1 Introduction

Latin America has been in recent years one of the most intensive regions for natural gas and electricity development [1]. The region is very hydropower dependent (about 57% of the region’s installed capacity is hydro) and the need to diversify away from heavy investments in hydropower and oil is driving many countries to promote use of natural gas, 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 great diversity in size, electrical installed capacity, electrical power demand, and electrical transmission/natural gas network characteristics (level of meshing and geographical extension). Figure 12.1 shows the share of hydro and thermal power and the installed capacity in each country in the region.

Hydropower reserves are still high and the continent boasts abundant natural gas reserves and high-growth energy markets, as shown in Figure 12.2.

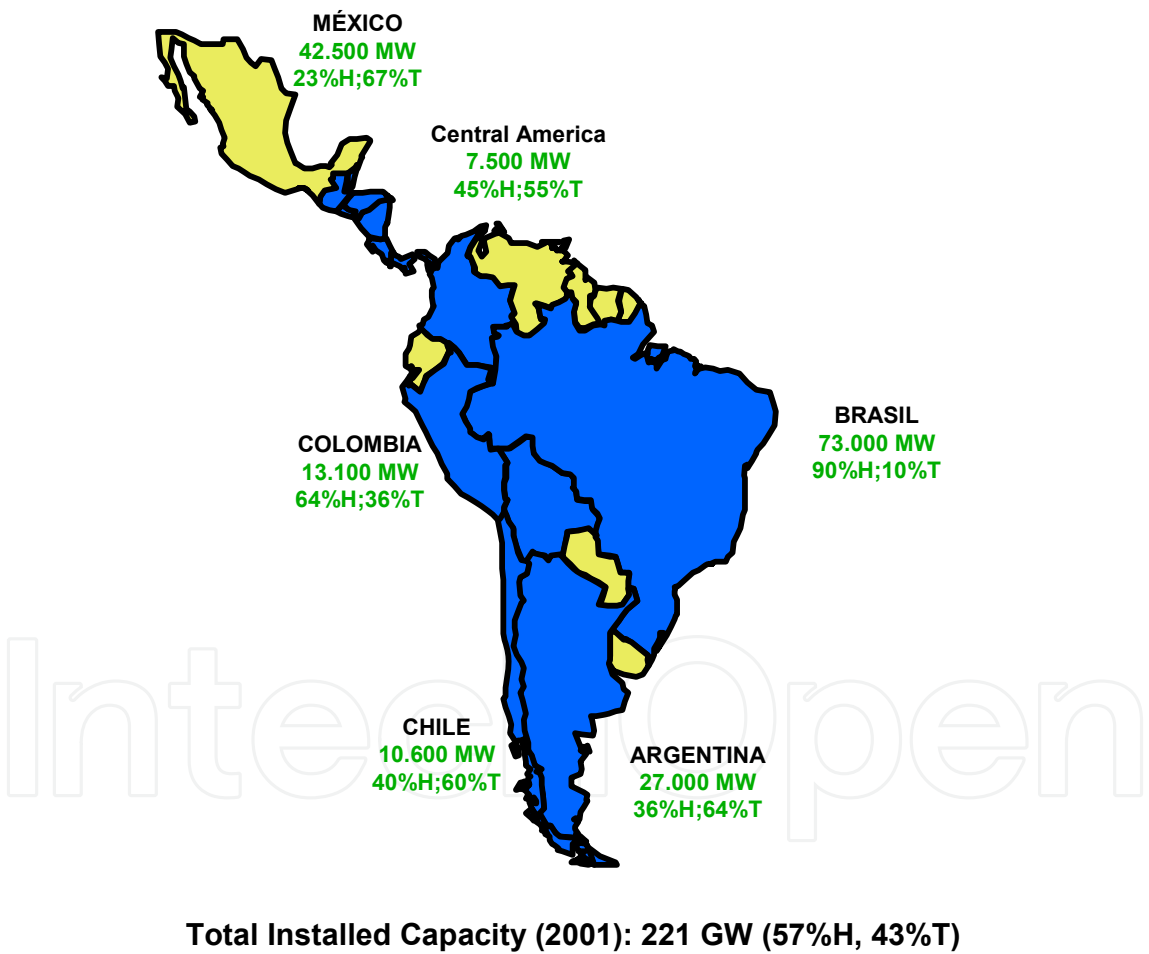


Fig. 12.1. Installed Capacity in Latin America: Brazil, Mexico, Chile, Argentina, and Colombia, etc

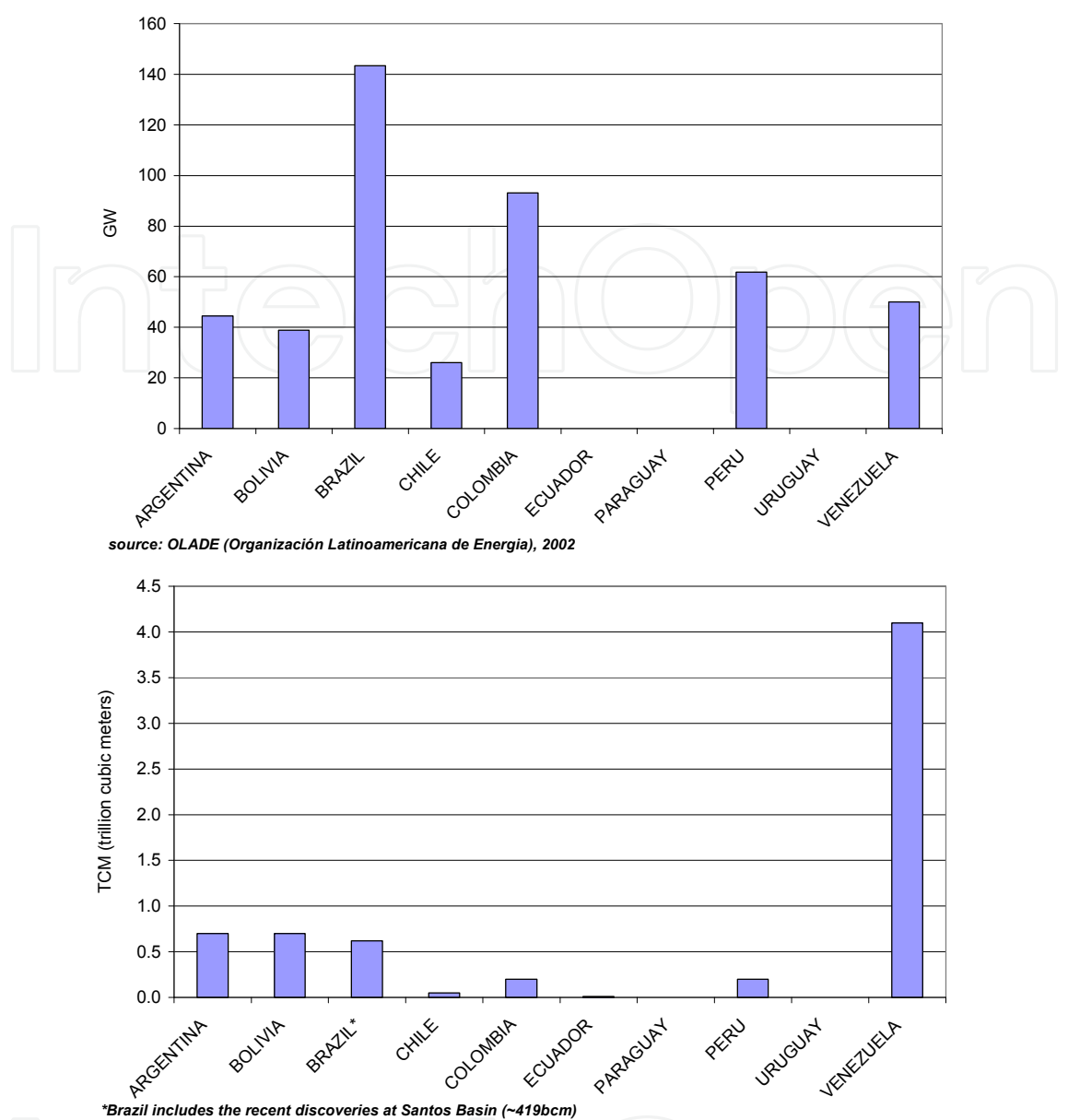


Fig. 12.2. Hydro Potential and Natural Gas Reserves in Latin America

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 12.3 shows the main cross-border energy interconnections in the Southern part of Latin America.

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 or coal fired thermal generation, with lower electricity network costs plus the cost of the correspondent gas pipeline.

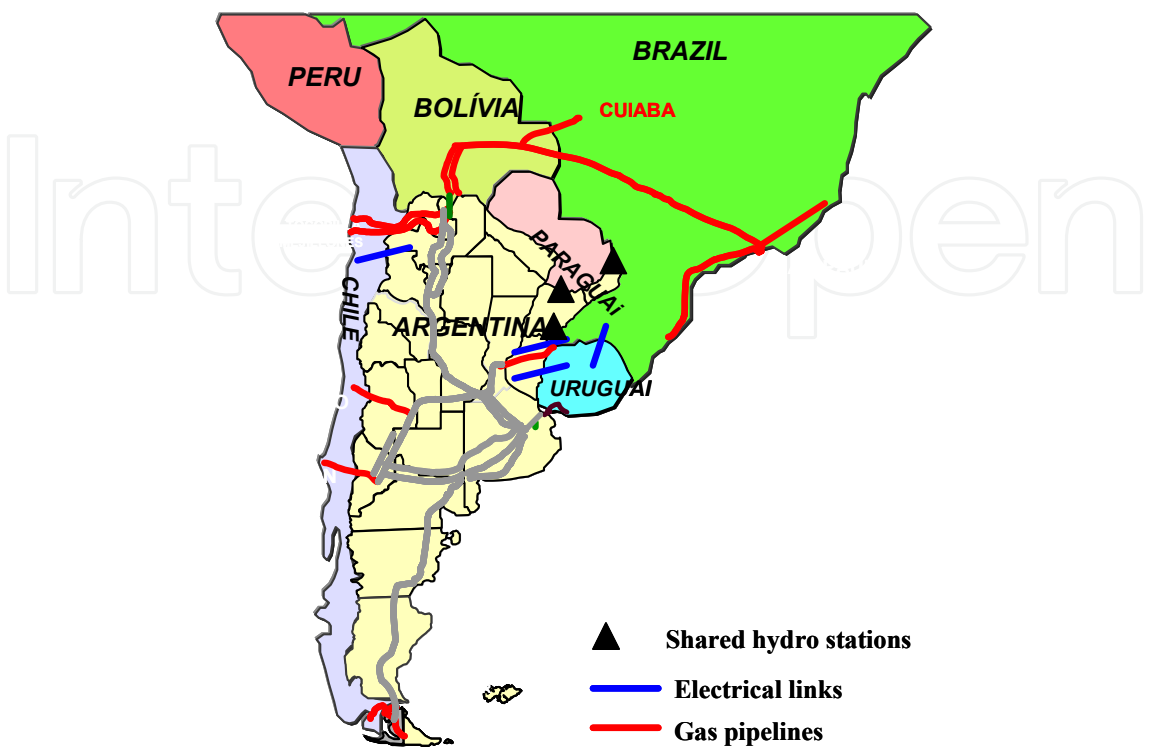


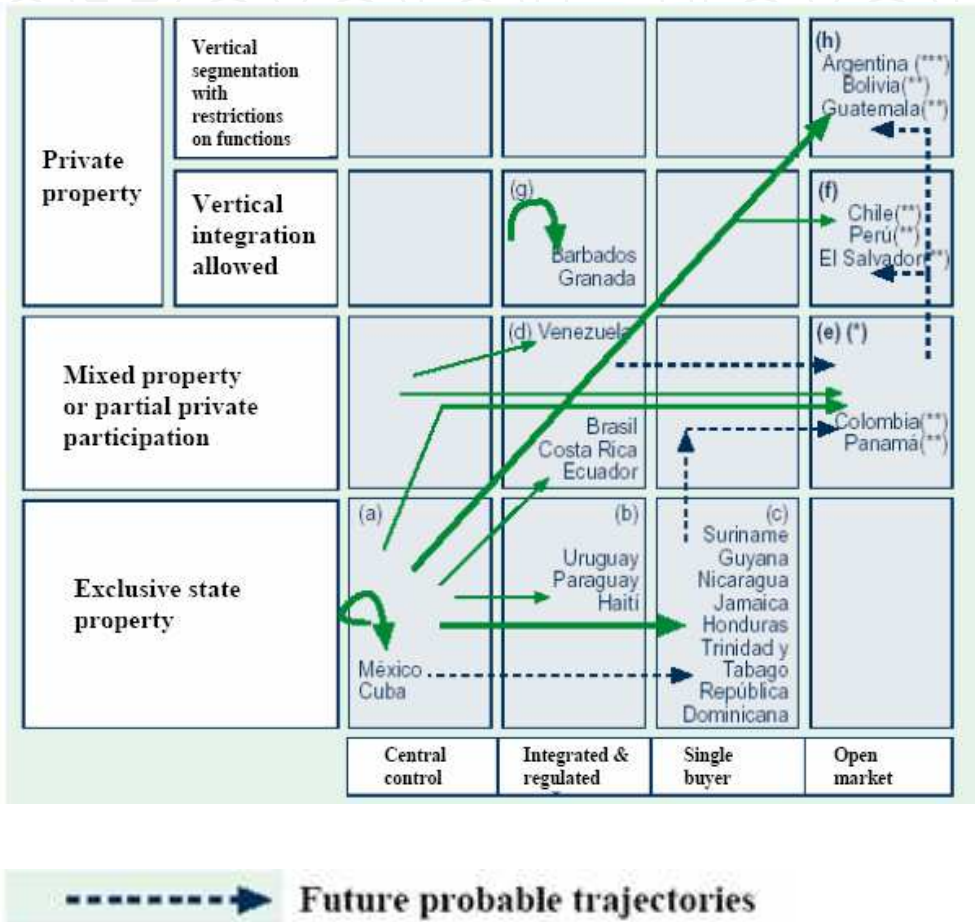
Fig. 12.3. Southern Cone: Electricity and Gas Cross-Border Interconnections

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. A significant development took place, as Bolivia and Argentina became abundant natural gas suppliers for Brazil and Chile, providing a fuel that was economically and environmentally attractive for the receivers. The energy and gas links were originally built as private initiatives and were mainly carried out under a local (not regional) framework and without integrated planning and were thus decoupled from each other. 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 and the Brazilian markets) 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. Nevertheless, the environment is one of mutual mistrust among countries to build back any dependence of energy supply. As explained next, the difficulties faced by Chile after a unilateral cut of gas transfers from Argentina, breaking mutual government agreements, will make it very difficult to formulate any energy integration between those two countries.

12.2 Electricity and Gas Deregulation

The electricity and gas industries in the region experienced deregulation processes in several countries in the region, which made them evolve from centrally State controlled industries

to privately driven ones, as illustrated in Figures 12.4a and 12.4b and explained in Chapter 17. Both Chile and Argentina formulated open markets in both sectors, creating market competitive conditions where feasible. A completely open market driven sector is that of the gas distribution to final consumers in Chile, where no prices are fixed by the government, as it is understood that competition naturally arises among different fuels. For example, natural gas can be replaced by bottled liquefied gas, so that neither is regulated, and price balances are reached when several suppliers compete for the market.

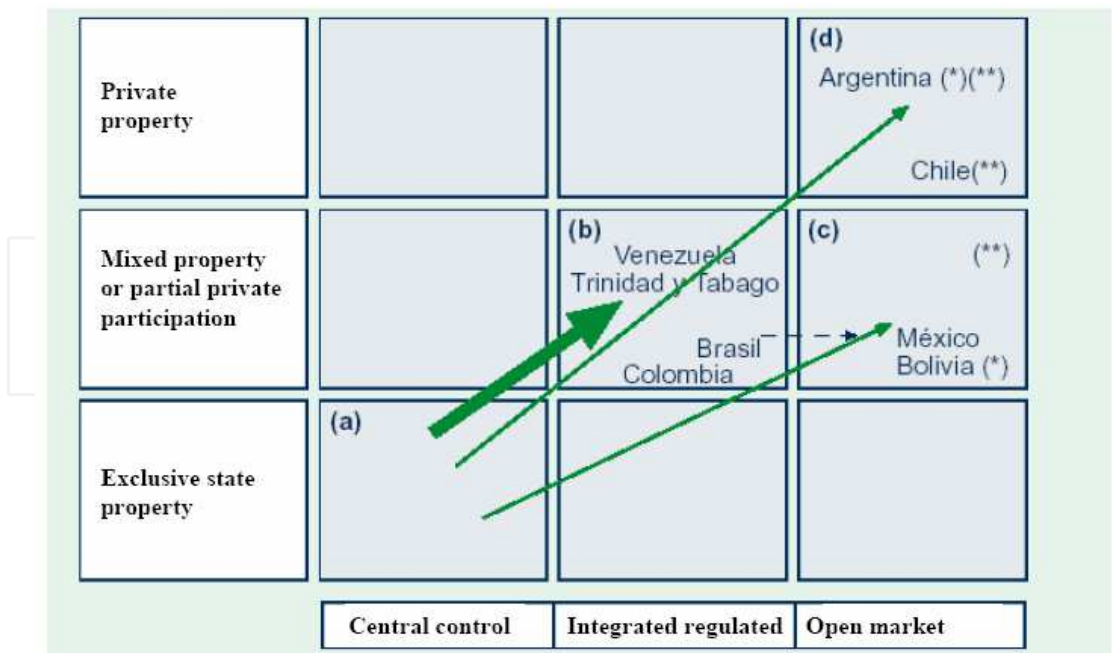


Source: Cepal, 2003 [13])

Fig. 12.4a. Electricity Sector Reform Process

These coherent processes in both electricity and gas have facilitated their interaction and competition, stimulating hybrid solutions, which used the technical and economic advantages of both. For instance, private investors can transmit energy as natural gas through pipelines or as electricity through transmission lines, either generating electricity at the gas field end or at the consumption end. Additionally, regulations facilitated this competition by forcing open access schemes to monolithic transport facilities that were built in several countries in the region. Figures 12.4a and 12.4b describe in general the deregulation process of the electricity and gas industries in the region.





(Source: Copal, 2003 [13])

Fig. 12.4b. Gas Sector Reform Process

12.3 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 electricity generation side, the country is hydro-dominated. 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 that replaced oil derivatives and electricity use by natural gas. Although the natural gas demand for industrial/vehicle use has been growing at relative high rates, this demand growth solely is unlikely to justify large investments in gas production and transportation. This implies that, at the moment, the power sector is the largest potential market for natural gas, which can provide the necessary anchor to spur production and infrastructure investments in this sector.

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 in the electricity-gas integration. Theses challenges will now be briefly discussed.

12.3.1 The Brazilian Electricity and Natural Gas Sectors

The Brazilian interconnected power system had, in 2007, a total installed capacity of about 100 GW. The system is hydro-dominated: 85% of the 100 GW installed capacity and more than 90% of the 400 TWh energy production comes from hydropower. Some plants have

large reservoirs, capable of multi-year regulation. Thermal generation includes nuclear, natural gas, coal and diesel plants. The area supplied by the system is served by 80,000 km of a meshed transmission network. The main direct international interconnections are the back-to-back links with Argentina, with a maximum transfer capacity 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 a severe energy rationing that took place along 9 months in 2001 - 2002.

Following some regulatory changes that occurred after rationing, a new model for the power sector was launched in 2004. The main objectives of this new model are to provide more secure conditions for investors and assure security of electricity supply. A review and assessment of this power sector model are provided in greater detail in [2,3] and in Chapter 17 of this book. Its main highlights are: (a) every load (regulated plus deregulated consumers) must be covered 100% by bilateral financial contracts at all times and all contracts must be “backed” by firm energy certificates; and (b) Discos must contract their energy through public Power Purchase Agreements (PPA) auctions, with standardized rules and contracts of different maturities.

The objective of rule (a) is to enforce security of supply by a contract obligation with physical coverage. The need to cover with contracts load growth will drive the system's expansion, and if the system is 100% contracted and contracts have physical coverage, then supply reliability is assured within the ‘supply risk’ defined in the calculation of the physical coverage capacity of each plant (firm energy in case of hydro). In turn, the objective of rule (b) is to promote the most efficient purchase mechanism for regulated consumers and provide secure conditions for investors. Regulated auctions for new energy are carried out on a least-cost basis three or five years in advance of delivery. This is to give enough time to build the project. Long-term PPA (15 to 30 years) is offered to investors and can be used as collateral with banks to obtain financing. In addition, all competing projects in the auction must have a prior environmental license in order to reduce environmental risk in the future. Energy supply auctions have been constantly carried out in the country since 2004. The first auction to contract new energy was carried out in 2005 and was of great interest to international investors looking to South America's energy market. Candidate suppliers included a wide variety of technologies, comprising new hydro projects, gas, coal and oil-fired plants, sugarcane biomass and international interconnections. Overall, the auctions until now contracted some 10 GW including a mix of technology from all candidate suppliers.

On the natural gas side, Brazil has proven gas reserves (are estimated at 220 billion cubic meters (bcm)), accounting for 4% 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) was announced in 2004. Even though this field requires very deep sea drilling (4000 m), its reserves are estimated at 420 bcm, which can double the level of the current reserves. National gas production (available to market) is in the range of 27 MMm<sup>3</sup>/day. Production in the recent discovered Santos field are expected to increase this figure in about 20~25 MMm<sup>3</sup>/day when it starts operating (current forecast is 2011). 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<sup>3</sup>/day, built by private investors. Imports in 2005 were in the range of 26 MMm<sup>3</sup>/day. Brazil used to import gas (2.8 MMm<sup>3</sup>/d) from Argentina to supply a 600 MW thermal plant on the Brazilian side of the border between the countries. However, as will be discussed later, Argentina has struggled to meet its own domestic gas needs and has started cutting exports to Chile and Brazil.

Without considering gas for power use, natural gas consumption in 2007 was in the range of 48 MMm<sup>3</sup>/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). There has been a strong growth outlook over recent years, where industrial and transportation sectors have been the main growth areas (motivated by government policy and increase in oil prices).

Since the 1990s Brazil has been calling for a larger share of thermal capacity to be fuelled mainly by natural gas. This is 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. This program resulted in the construction of about 7000 MW of gas-fired plants by 2005 (out of a planned 14,000 MW capacity). This corresponded to maximum gas consumption in the range of 35 MMm<sup>3</sup>/day, about the same amount as the entire 'non-power' gas demand. In addition, thermal plants' dispatch depends on the hydrology: if the system is 'wet', the entire electricity load can be met with hydro generation alone.

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 centers and transportation networks. Today three natural gas markets can be distinguished in Brazil: 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. Integration between the Northeast and Southeast is planned.

Figure 12.5 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.

As opposed to the power sector, Brazil currently 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 by-product of oil. The Brazilian government worked on a new law in 2008 for the gas sector.

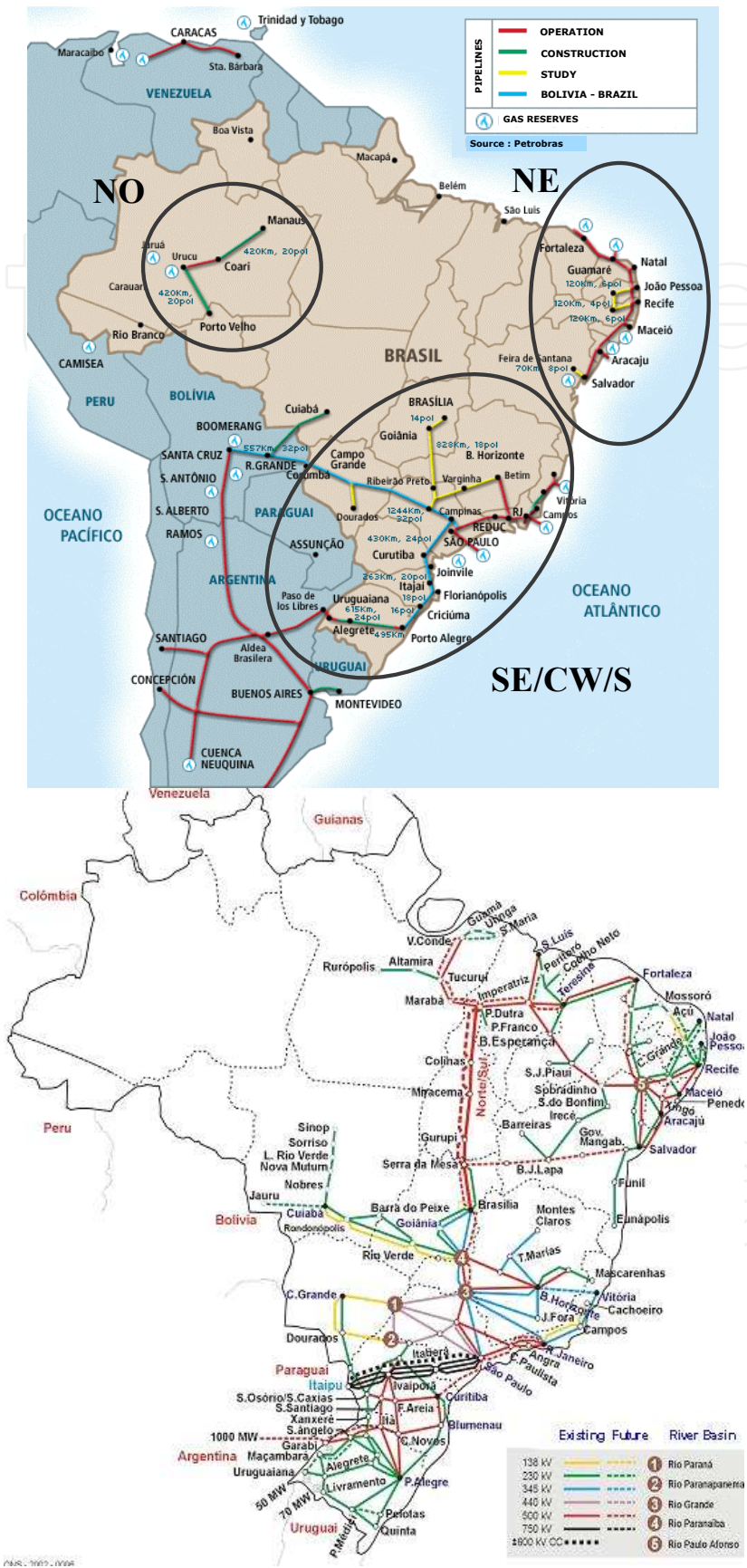


Fig. 12.5. Main Natural Gas and Electricity Transportation Network

12.3.2 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 three of them: operating flexibility, integrated electricity-gas operations planning and flexible LNG supply.

12.3.2.1 The challenge of operating 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 12.6, which shows a recent record of the observed energy market prices in the Brazilian Southeast system.

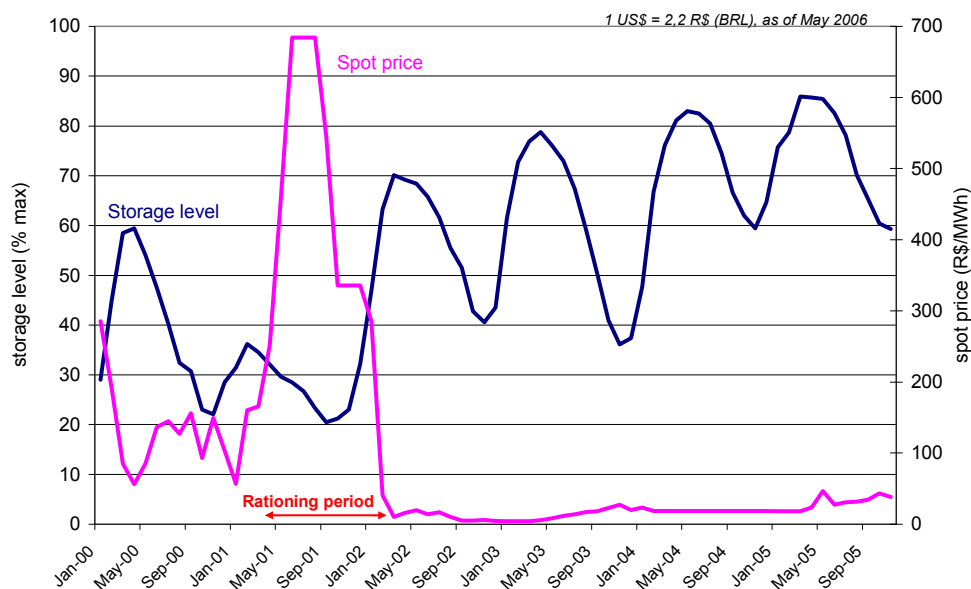


Fig.12. 6. - Historical Monthly Short-Run Marginal Costs

Figure 12.6 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 behavior is that predominantly hydro systems are designed to ensure load supply under adverse hydrological conditions, which occur very infrequently. Hence, for most of the time there are temporary energy surpluses, which result in very low market prices and no need of thermal dispatch. In turn, 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 for most of the time, this “irregular” consumption pattern from power generation creates a complex problem for investment decisions in new gas fields and in new pipelines that may be either excessive or insufficient depending on hydrological conditions. Take or

pay and ship or pay clauses on the gas contracts between gas producers and thermal plant owners are mandatory to alleviate part of the financial uncertainty: these clauses are used to stabilize, 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 decrease competitiveness of projects since thermal owners are paying a fixed price for gas independently of use. Thus, hydropower or flexible oil-fired and coal tend to be cheaper expansion supply options.

One alternative to alleviate these fixed expenses is to allow the pre-purchased gas to be resold in a secondary market whenever the gas-fired plants are not dispatched. In this scheme, flexible contracts would be offered (e.g. auctioned) to industrial consumers, who in turn would switch to an alternate fuel when the gas supply is interrupted due to thermal dispatch. The revenues obtained with the flexible contracts could be used as an extra income to reduce the fixed-costs of thermal plants. In addition, two consumers would be sharing the same gas infrastructure, thus optimizing investment needs.

#### 12.3.2.2 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 [4]. Traditional hydro scheduling models used for system dispatch take into account a 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 decoupling may imply dispatch results for the power sector that can be dangerously "*optimistic*". This is because 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 30% 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, an integrated modeling of the gas sector (production and transportation constraints) in operations of the power sector is one of the main challenges – and was analyzed in [5].

#### 12.3.2.3 Integration of flexible LNG supply

In end-2006 a "*dispatch test*" performed by Aneel (power sector regulator) in the gas thermal power plants disclosed that the concern about gas supply and demand balance was actually legitimate, because about 50% of the tested capacity in the South/ Southeast-Center West Regions did not manage to produce energy due to fuel deficiency. The reason for the lack of fuel was two fold: (i) lack of local gas supply (non-power consumption grew at a faster pace than local gas supply) and (ii) difficulties with Bolivian and Argentinean gas imports. In particular, the latter cut gas supply to Brazil to prioritize the supply of its own market. This has affected directly a 2,200 MW interconnection with Brazil and a 600 MW gas-fired plant.



In an effort to increase the natural gas supply in the country and to reduce the dependence of its neighbors, Petrobras announced in 2006 the construction of re-gasification stations, so as to import LNG, from 2009, to the Southeast and Northeast Regions. These gas imports would come from LNG exporters such as Trinidad & Tobago and Nigeria and Petrobras decided to implement mobile floating storage re-gasification units (FSRU).

Since the scheduling of LNG ships must be done some time before the actual need, observe that there is an uncertainty relating LNG supply and thermal needs, highly influenced by hydrology: if scheduled well beforehand, better gas prices can be obtained but higher is the uncertainty of hydrology on thermal dispatch; if scheduled close to the delivery, the uncertainty on hydrology is smaller but the gas price might be higher. Therefore, once more, it becomes necessary to develop flexible supply and demand options. Concepts discussed include: flexible (interruptible) gas contracts for the industry and storage options such as the use of hydro reservoir capacity. For example, delivered gas but not used could be stored as water in hydro reservoirs for future use (as a “call” option). These issues will be discussed in more detail in section 12.7.

#### **12.4 Chile: Uncertainty in Natural Gas Supply**

Chile was a pioneer worldwide in liberalizing the electrical generation segment in 1982, introducing a competitive and private market, where the entrance of new agents depends on the economic signals that the investors gather from the market. Therefore, in Chile the decision as what are the technologies to be developed essentially relies in private investment evaluation. The government is solely limited to generate the conditions so that it is possible to reach economic efficiency.

The process of liberalization and deregulation of the electricity market was companioned by the privatization of the existing state owned electrical companies. Currently, the governments influence in the sector is limited mainly to regulation functions, indicative expansion planning and to the fixation of the electrical tariffs for regulated clients. Historically, objectives as the diversification of the power matrix and the environmental sustainability has conformed a secondary level. The development of the generation segment has occurred in a frame of a technological neutrality as far as the technologies and fuels used, having all types of energy sources to compete in similar conditions of quality and price. 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 imported coal has to be used for electric generation. Hydroelectric generation has developed using most of the low investment cost resources in the central part of the country, and remaining significant reserves are over 2,000 km south of the main load [7]. Although at present the Central Interconnected System (SIC) has a generation park with presence of different power generation technologies, 15 years ago supply presented a markedly hydroelectric component, with a participation of 78% in the total installed capacity. Figure 12.7 shows the evolution of the generation capacity in the SIC.

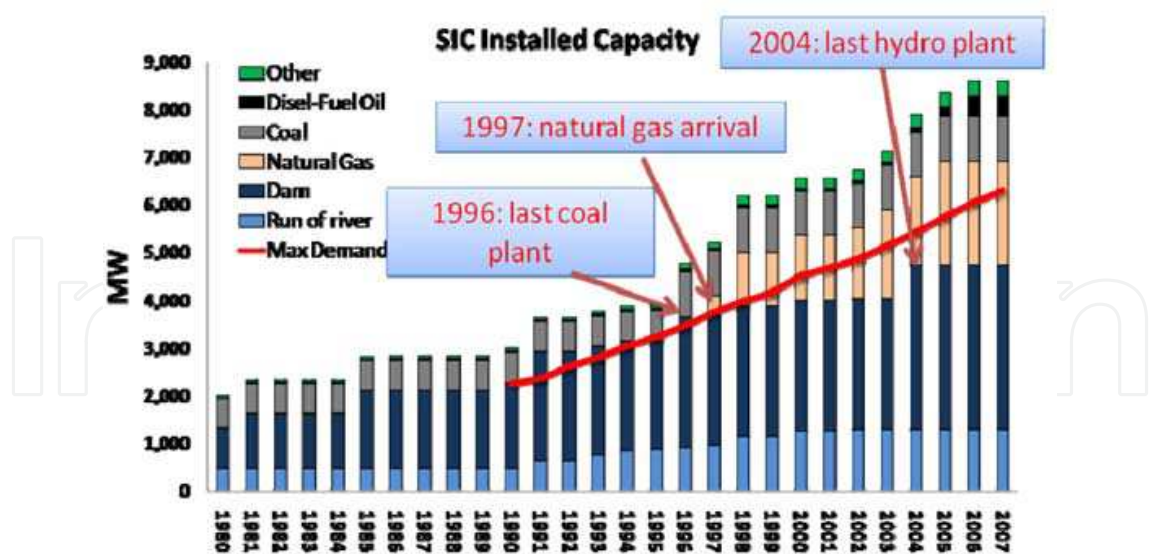


Fig. 12.7. Installed Capacity Evolution in Central Interconnected System

The conditions created for market competition in electricity drove private investors to look for more economic technologies and fuels. Argentinean gas arose as an attractive abundant economic alternative, coupled to the availability of the low investment required by efficient combined-cycle generation technologies. With the private interest to use the gas and the support of both the Argentinean and Chilean governments, an energy integration protocol was signed in 1995 between both countries. 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 invested heavily in several pipelines that crossed the Andes and defined an energy supply path that would rely heavily on combined cycle generation. 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 four international pipelines (Figure 12.8). The petrochemical industry and the thermoelectric generation became the main users of natural gas (Figure 12.8).

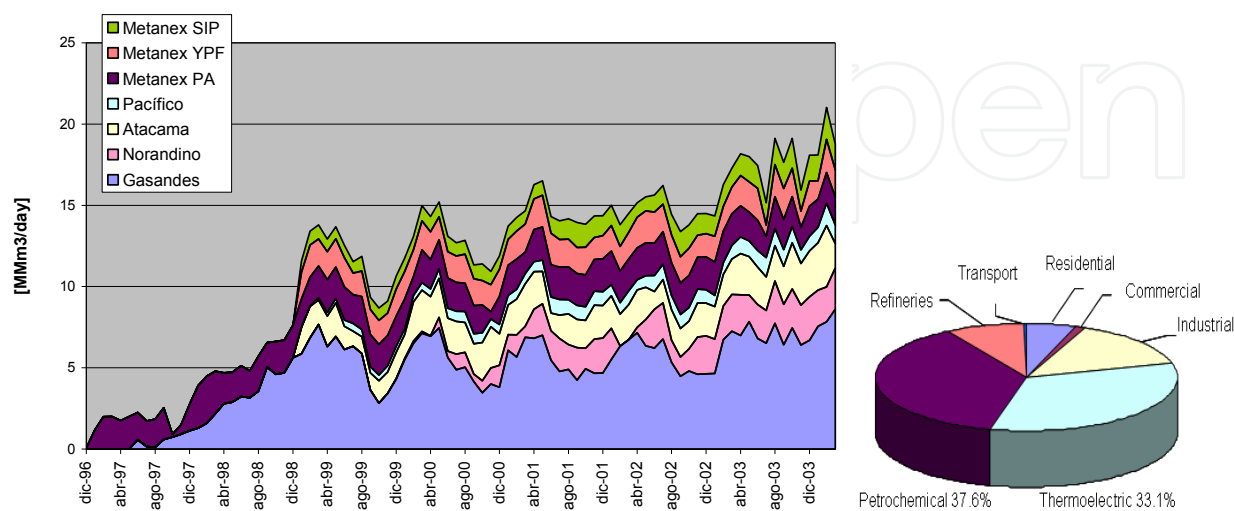


Fig. 12.8. Natural Gas Exports from Argentina to Chile [6]



The arrival of this economic fuel and the efficient generation technologies meant a significant reduction in electricity prices in the main central interconnected system. The energy spot price in the 1994 -2007 period is shown in Figure 12.9 together with the energy generation composition between thermal and hydro sources. A more balanced energy matrix was achieved with the arrival of natural gas from Argentina, but still very dependent on hydrological conditions, as can be seen in the 1997-1999 period, where high spot prices and supply restriction were faced as the consequence of intense droughts in the country.

However, when a macroeconomic economic crisis started affecting Argentina in 2001, the country changed dramatically its government policies, among them those relayed to energy, electricity and gas included. State returned to control energy prices, freezing them and not relating them to the real costs of production. Argentina 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. This led to problems with its gas supply. Then, unilaterally, the Argentinean government, violating its agreements with Chile, in April 2004 decided to reduce gas exports to Chile. The Chilean power sector since the electricity deregulation process started has had several opportunities to have the strengths and weaknesses as a market model tested, and this was a particular major blow [6]. Figure 12.10 shows Argentinean gas import restrictions in the 2004-2008 periods.

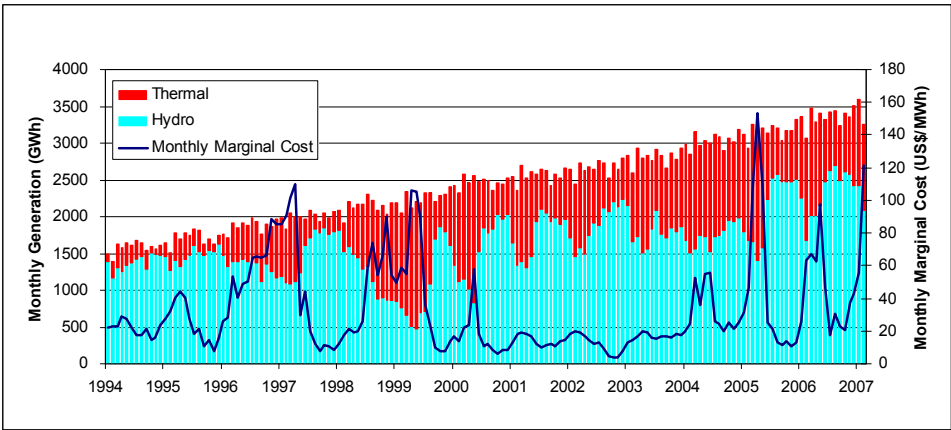


Fig. 12.9. SIC Hydrothermal Generation Structure and Marginal Cost

The non compliance by the Argentinean government of its international agreements, deciding to favor national supply, was not only detrimental to the consumers of Chile, but also to the neighboring countries of Uruguay and Brazil. 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 adjacent country.

Chile was neither aware 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 decade, 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% per 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 LNG as the alternative and defined a project to build the necessary installations to import it from abroad.

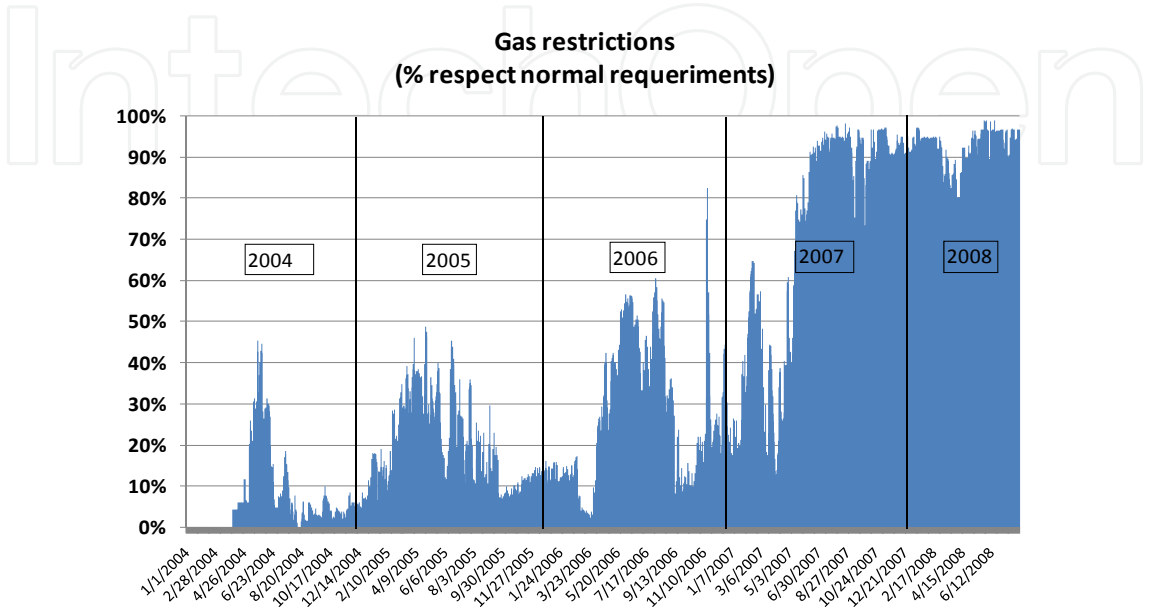


Fig. 12.10. Argentinean Gas Import Restrictions

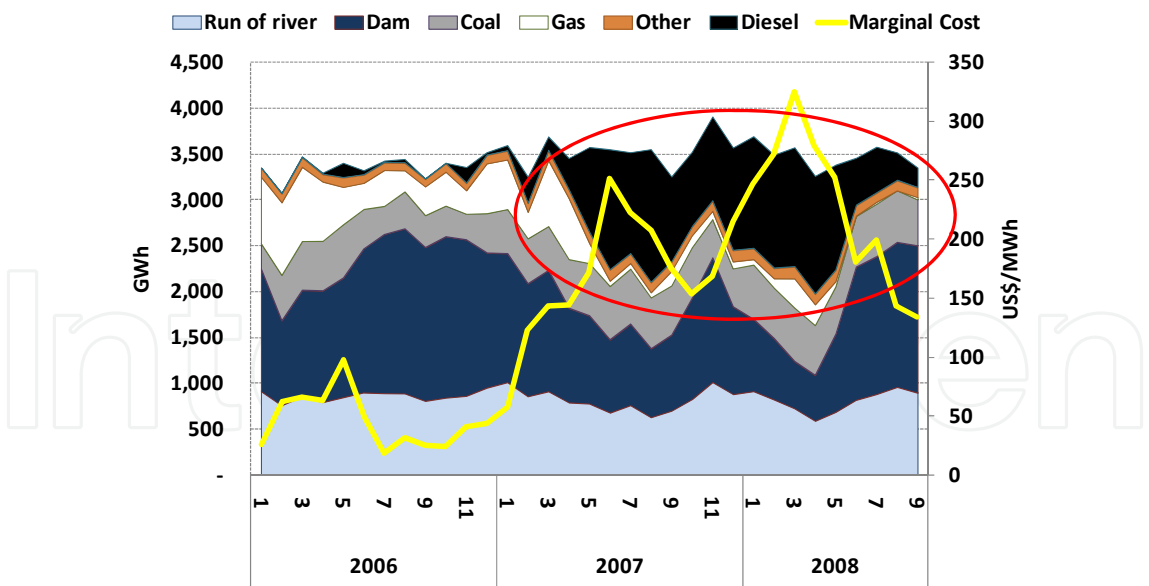


Fig. 12.11. Energy Generation by Source and Marginal Cost in SIC

As a consequence of the growing natural gas restrictions from Argentina, which reached 100 % as of 2008, combined cycle plants replaced the suspended fuel with diesel, facing fuel costs that were several times higher, as can be seen in Figure 12.11, were energy generation by source and spot market prices are showed.

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.

In retrospect, it is the cost of different generation technologies that will drive development. And the comparison has to be centered on the particular geographic conditions and infrastructure development of Chile. A recent comparison [6] was made for the Chilean investment environment (local cost of capital taken into consideration); where LNG combined cycle plants compete with circulating fluidized-bed boilers fuelled by coal. Cost of different generation technologies are stated in Table 12.1.

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

Table 12.1. Cost of Different Generation Technologies, Chile, 2004 [6]

However, an essential question troubled investors at the time of the crisis, what if gas supply from Argentina returns to normal? If a decision was made, for example, to contract a coal investment, and cheaper natural gas starts re flowing without restrictions from Argentina, who will make the cost? 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. At the time, Chile was returning to high economic growth rates, therefore, nobody wanted energy deficits to shadow economic development. Thus, the government looked for alternatives. Capacity payment regulations were modified to better take into account unreliable gas supply. A gas “drought” concept was introduced that de-rates combined cycle plants that do not have alternative fuel arrangements, and therefore reduces their capacity payments. Another alternative was considered, but discarded, was to limit by law the dependence on foreign fuels to a certain percentage of national consumption; the idea was that imports from a particular country should not exceed a certain value (a similar concept is used in Spain). Critics of this alternative argued it represented a State intervention that would imply higher long-term energy costs for the country as a whole. The LNG in Chile is discussed in more details in section 12.7.

In order to incentive investments in new generation capacity, the government went ahead and introduced a major regulation change in 2005 by introducing energy auctions for long term contracts to supply regulated end users. These auctions are based on up to 15 year contracts to be signed with distribution companies, at prices set in a bidding process, as explained in depth in Chapter 17. Through this major reform, risk could be reduced and new investment started flowing, as it can be seen in Table 12.2. Because of the lack of confidence in regional energy suppliers, the energy matrix shifted to local hydro development and coal fired plants, leaving the LNG to a backup role.

Year	MW			
	Coal	Gas	Diesel	Hydro
2008	-	-	373	-
2009	139	240	232	155
2010	924	-	-	172
2011	482	-	-	327
2012	445	-	-	553
2013	-	-	-	705
2014	250	-	-	660
2015	-	-	-	-
2016	300	-	-	500
2017	300	-	-	-
TOTAL	2.840	240	605	3.072

Table 12.2. New Investment in Power Generation in Chile, 2008 (NEC, April 2008)

Along the disputes that arose on the Argentinean government not to comply with the international agreements on gas supply, the Chilean government chose not to go into an international litigation, believing that a permanent political negotiation would be more fruitful in the short term solution of the gas supply problem. This was also supported by observing the long disputes that were taking place between Argentina and its foreign lenders and with foreign companies and investors that had their interested affected by the crisis.

12.5 Mexico: Growing Interactions Between Mexican Gas Markets And Electricity System Planning

The Mexican gas and electricity sectors have followed a non-synchronized agenda of reforms [8]. Some of the reforms in the gas sector have not been completed and the more profound reforms in the electricity sector have remained idle or without consensus for recent years. 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. These interactions have direct impacts in electricity system resource planning. The increasing interactions between the two systems pose important questions. Among them is the need for new planning tools that represent important opportunities for research. On the energy side, of increasing importance for Mexico for the reliable and cost effective supply of gas to the electricity systems is LNG. This represents 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.

12.5.1 Gas Supply Demand for Electricity Production

Electricity expansion planning in Mexico indicates that least-cost expansion planning of the system will continue to rely in combined cycle plants for the next ten years (Figure 12.12). This has been the case in the last decade.

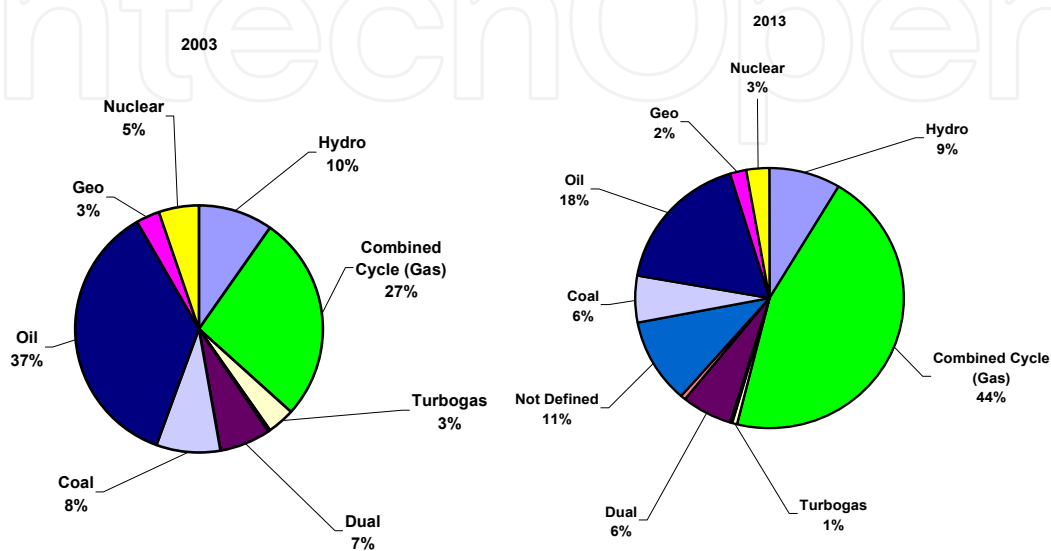


Fig. 12.12. Electricity Generation Installed Capacity Shares by Fuel Type, Actual (2003) and Planned (2013)

The share of gas as fuel for electricity supply will grow from 27% to 44 % of total electricity production from 2003 to 2013. The increasing extension of the national gas pipeline system and its connection to the US market and the growing worldwide Liquefied Natural Gas Market 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. Gas consumption for electricity generation (MM cubic feet/day) and planned LNG installations in Mexico is indicated in Figure 12.13.

12.5.2 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 that is used for the 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 cycle plant with two different sitting options. Therefore, one important issue was 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. This issue had to be resolved for the interaction between the Gas/ Electricity transport choices for the project.

12.5.3 LNG/Electricity Expansion Interactions

The increasing consumption of gas in Mexico for electricity production along with the lesser than expected national growth of the internal production of gas indicates that import of gas from the US (Texan or Californian) market through the national pipeline system will still be an alternative to a secure gas supply, although not at a competitive price. However, the increasing maturation of the LNG market worldwide makes this alternative an even less cost-effective alternative for supply of gas if certain considerations are made in the electricity generation expansion plans. Therefore, a basic challenge for Mexico is to incorporate the dynamics of LNG markets in traditional expansion models in order to better capture the costs and benefits of LNG as a supply source for the country instead of using pipeline gas from US markets through the national system.

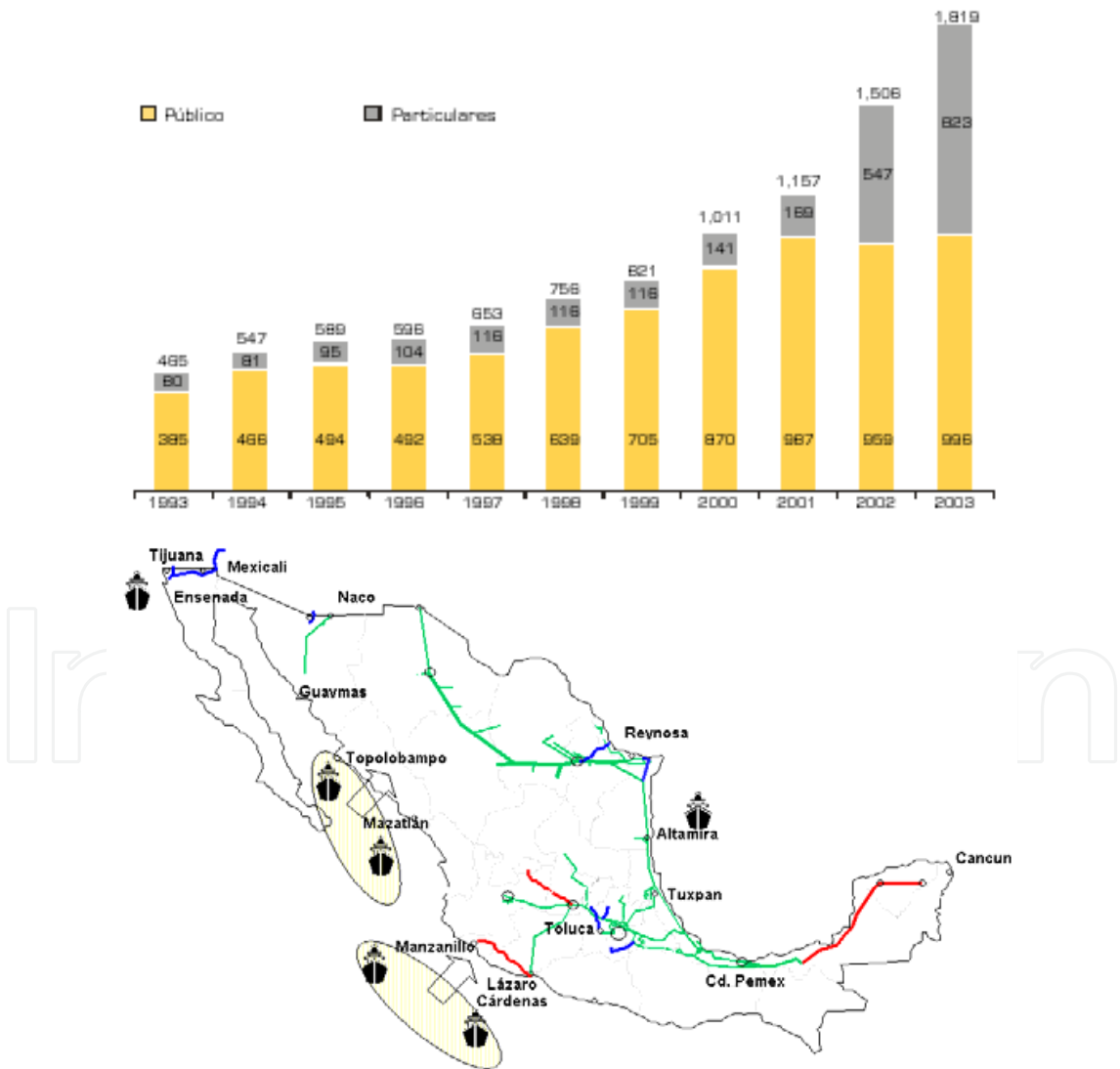


Fig. 12.13. Gas Consumption for Electricity Generation (MM cubic feet/day) and Planned LNG Installations



### 12.6 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. As in Brazil, development of the natural gas industry in an environment where its requirements are very volatile due to randomness of river discharges is a key issue in the Colombian energy sector.

Development of the natural gas industry in Colombia is recent. Although there were local natural gas uses since the 1950s, its massive utilization started in the middle of the 1970s in the Atlantic Coast region with the utilization of free natural gas reserves located in the region. In the middle of the 1980s a Government plan accelerated natural gas service extension towards urban centers. Later on, in the 1990s, another incentive plan was implemented. Its main component was for gas transportation infrastructure. It is in operation today connecting the gas fields with main consumption centers. The above actions have been complemented with an increase of natural gas reserves due to new findings in the Interior, 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 plants have been installed, representing 22% of the total power capacity in the country.

Demand for natural gas in Colombia has been growing significantly, subject to volatility due to gas consumption for thermoelectricity that in 1998 reached an annual average of 304 MBTU/day. Natural gas consumption in Colombia rose to 589 MBTU/day in 2003, of which 181 MBTU/day was for electricity generation. 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 an interconnection gas pipeline with Venezuela will start operation in 2007. This will enable natural gas exports to the country for several years and, eventually, will allow future natural gas imports. This interconnection would enlarge the Colombian gas market, enabling international natural gas traders to develop the Colombian natural gas reserves.

The gas supply, transportation and supply outlook in Columbia is indicated in Figure 12.14.

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 that has a large hydroelectric component. River discharges are substantially affected by the 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 uncertainty in demand for natural gas since it forces thermal generation in some areas that do not have hydroelectric resources.

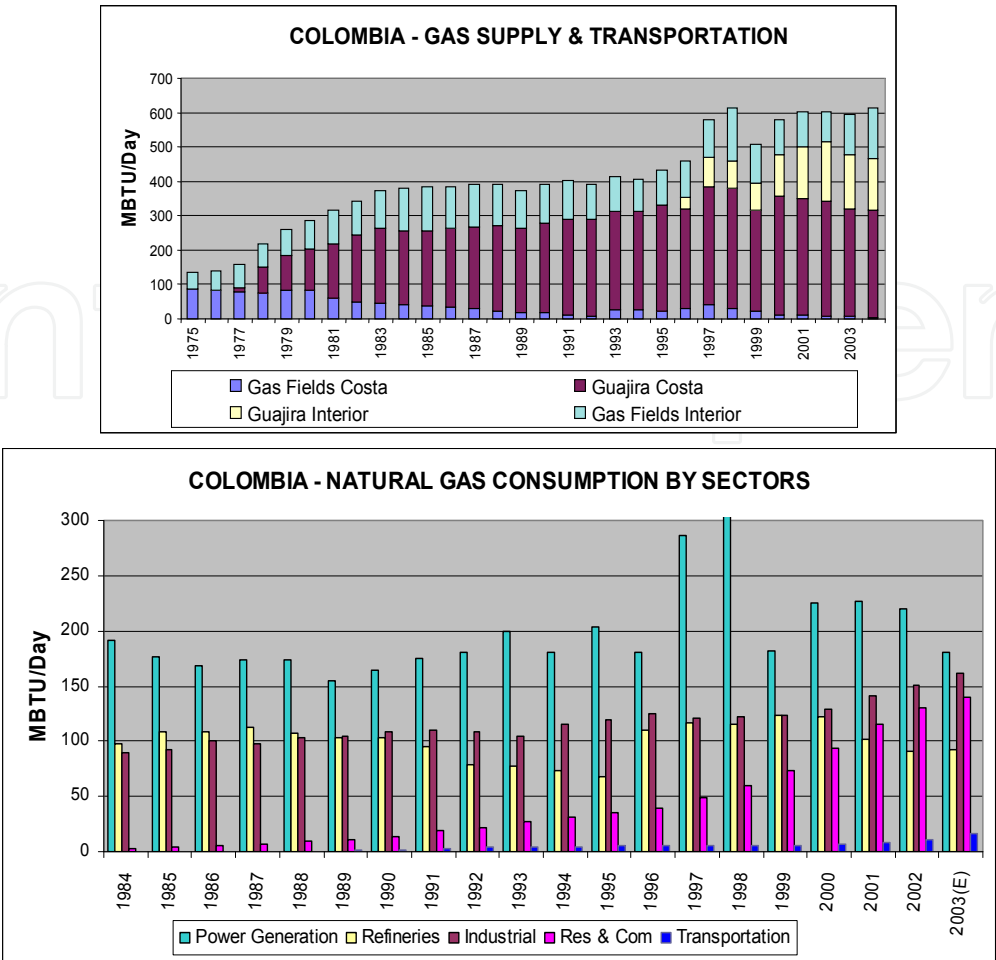


Fig. 12.14. Gas Supply, Transportation and Supply Outlook

There has been a relevant investment from state and private companies in recent years to connect main production gas fields to the principal consumer centers 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, the highest demand increases would occur in the Colombian Interior region. This is a result of natural gas penetration that would occur in the residential, industrial and transportation sectors.

The forecasted natural gas demand in the industrial sector has been influenced by strict environmental regulation on emissions since year 2000. Environmentally aggressive fuels have been substituted by natural gas in the sector.

Natural Gas and Electricity markets have strong links in Colombia and there are several issues related to the interaction between them [8]. These include:

- a) Capacity Charges: The large hydroelectric component of the installed capacity in Colombia implies that some of the natural gas fired plants have very low dispatch probability but are required to guarantee supply reliability. The main issue related

to this is the design of an appropriate capacity charge mechanism to create financial incentives for the installation, operation and maintenance of these types of plants without creating economic adverse distortions.

- 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. This creates perverse incentives to integrated power-gas system optimal operation and expansion. In addition, volatility in gas demand (from randomness of hydroelectric generation) constitutes a challenge.
- c) Natural Gas vs. Electricity Markets: The 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 for 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 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 that needs a solution.

## 12.7 LNG in South America

As discussed previously, LNG is increasingly at the heart of energy policymaking in South America. The rationale behind LNG projects varies among countries and sometimes within the same country. However, there are three main drivers behind LNG import and export projects in South America.

- a) Gas imbalances: the first reason for importing or exporting LNG is related to the region's natural gas balance: there are countries or sub regions with gas surpluses and others with deficits. Brazil, for example, has a growing potential natural gas market and still not enough gas production. Given the large distances and the geographical obstacles, it is not always possible or economical to export or import pipeline gas. LNG imports are being sought as a way to increase gas supply. On the other hand, countries with abundant gas resources, such as Peru and Venezuela, are looking at LNG exports as a way to market their natural gas and monetize their reserves;
- b) Security: the second reason is geopolitical and is related to energy security and the diversification of natural gas supplies and markets. In Brazil and Chile imports from neighboring countries have proven to be unreliable and further dependence on supply from a single country is deemed to be undesirable. LNG might become a way to diversify gas supply and some bargaining power in the discussion with

- regional suppliers. Similarly, Peru could export gas regionally by pipeline, but the LNG export option is considered less politically charged than pipeline.
- c) Flexibility of gas supply: the third reason for LNG imports is related to the nature of gas demand and a growing need for flexibility in gas supply. Because of the hydro predominance in the region, gas-fired dispatch is very much volatile and flexibility is an attractive attribute. However, flexibility comes at a price and it remains to be seen whether LNG is a cost-effective way of achieving supply flexibility. Specifically, in Brazil a large portion of gas demand is linked to the power sector and is highly variable because of the country's dependence on hydropower. LNG imports are deemed to provide more flexibility at a lower cost than building large pipelines.

This section analyzes the introduction of LNG in Chile and in Brazil.

### 12.7.1 Main Challenges for LNG in Chile

As discussed in section 12.4, since 2004 Argentina has struggled to meet its own domestic gas needs and has started cutting exports to Chile. Total annual exports to Chile have been falling since 2005 and cuts started to be frequent and recently (2007) have reached as high as 95 percent of committed volumes on several occasions, as shown in Figure 12.10. Restrictions have affected mainly the thermal power sector and the industrial sector, forcing power plants and industrial consumers to switch to costlier fuels.

In response, Chile has launched a program to import LNG not only to supply additional gas demand but also to replace decreasing Argentine exports. An LNG terminal is being constructed in Quintero, Central Chile. Figure 12.15 shows the terminal's location. Its construction is well advanced; the terminal started partial operations in second quarter 2009, with full-scale operation by late 2010.

A pool of off takers including State owned oil company ENAP, power generator Endesa Chile, and gas distributor Metrogas was created. In early 2006 the pool selected UK gas company BG Group both to supply LNG and to construct the terminal. Off takers have already contracted 6 MMcm per day of regasification capacity (final capacity could be as high as 12 MMcm per day). Other off takers (mainly power plants) is expected to soak up the additional capacity. The plant is being constructed with a possible expansion in mind (a third tank would bring capacity to 20 MMcm per day).

Plans for another LNG regasification terminal in northern Chile have also been announced, led by Codelco, the State owned copper mining company. This system is much more dependent on gas. About 58% of capacity is gas fired, as the region has none of the hydro potential of the center and south. There are no connections between the SING and the SIC power grids, nor are there any connections between the respective gas networks. The mining companies are the main off takers of gas-based electricity in the north. However, in this region LNG would face a direct competition from coal imports and coal-based power generation.

There is yet no indication of the price at which GNL Chile will buy the LNG but it is certain to be much higher than the current import price from Argentina yet lower than the price of oil products (mainly diesel oil) currently used to replace missing gas. LNG's competitiveness with other fuels and sources of power will be critical for the development of LNG imports. Chilean gas consumers may agree to pay a premium for supply security, given the risk embedded in Argentine gas imports. However, as much of the gas is used in power generation, LNG will need to be competitive with other fuel sources (such as coal, hydro, etc). Investors in the power sector are betting that coal will be more competitive than LNG and are already building new power plants based on that fuel, with LNG being considered to play a backup function, for existing combined cycle plants, rather than a basis for generation expansion.

It is important to notice that LNG installations are being developed essentially with the government driving the initiative, in one case through the State owned oil company ENAP and in the second through the also State owned mining company Codelco. In a liberalized market like the Chilean one, this has been justified on political grounds, on the interest of the government to secure energy supply, making the country independent from Argentina.

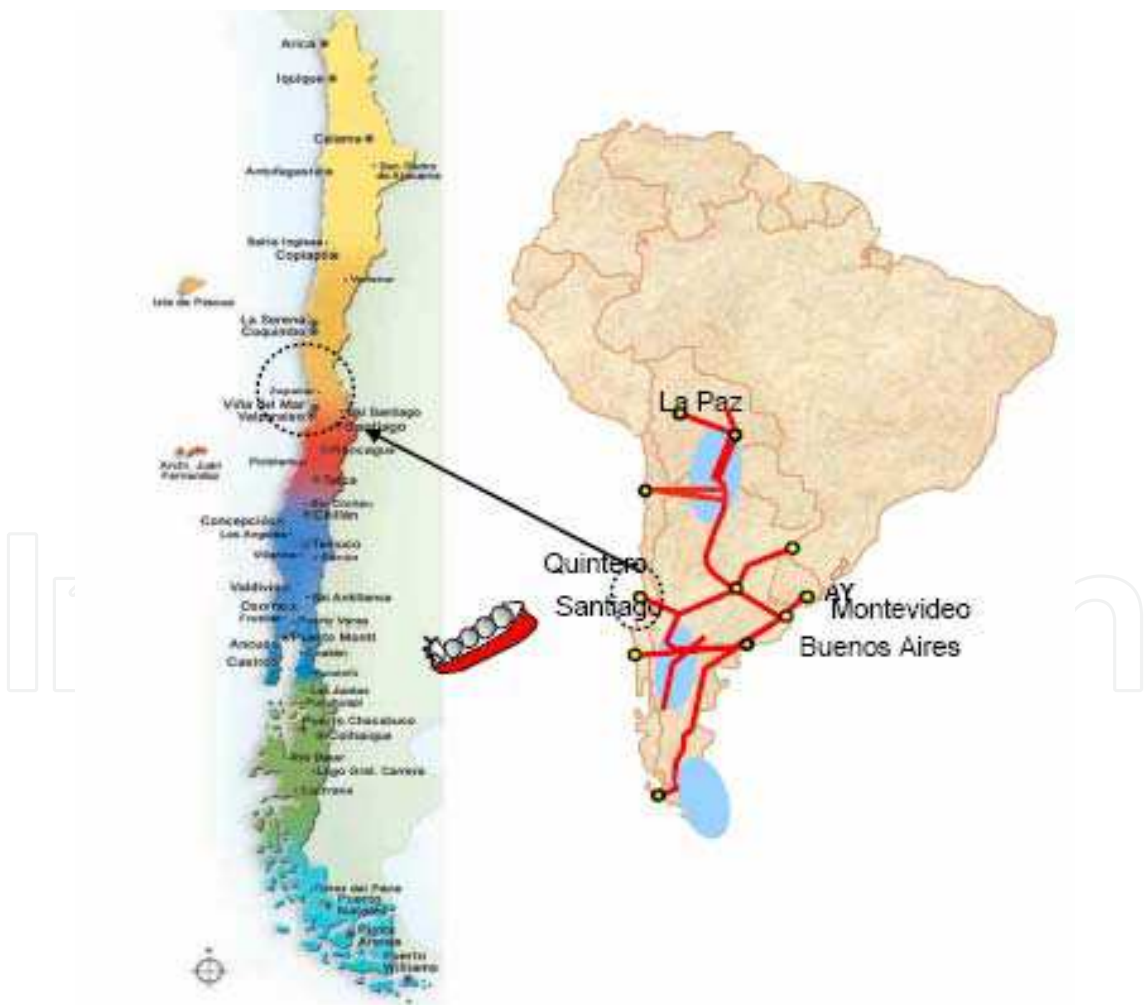


Fig. 12.15 Quintero’s Terminal Location



### 12.7.2 Main Challenges for LNG in Brazil

The question of natural gas supply for thermal generation has been the object of concern by the authorities ever since the conception of the new model for the Electrical Sector. As discussed in section 12.3, Petrobras announced recently (2006) the construction of re-gasification stations, so as to import liquefied natural gas (LNG), from 2009, to the Southeast and Northeast Regions, in order to increase the natural gas supply in the country.

#### 12.7.2.1 The business model: LNG flexible supply

The introduction of LNG is observed with interest by the electrical sector, for three main reasons: (i) to diversify gas supply sources, (ii) a contract market with shorter ranges and greater flexibility has been emerging. This way, ships for LNG delivery may be contracted according to consumption needs and, thus, have the potential for rendering flexible the natural gas supply to thermal power plants and other clients; and (iii) it is possible to build thermoelectric plants located relatively close to the major LNG delivery ports, thus avoiding investment (fixed costs) in gas pipelines.

In this manner, the final cost to the consumer of thermal energy produced from LNG may become more attractive. This because the flexible supply of gas provided by LNG permits thermal power plants to be operated in the mode of complementing hydroelectric production and, therefore, fossil fuel to be saved. As discussed in [5], the final consequence of this operation is the reduction of energy cost to the consumer. Actually, Petrobras announced its intention of contracting LNG to supply the Brazilian market in a flexible manner.

The business model to procure flexible LNG contracts is innovative and very challenging given the LNG volumes at stake and the current tightness of the LNG international market. The idea is to take advantage of the recently developed short-term LNG market and to sign a contract with flexibility clauses. This could be an option contract whereby an LNG provider to US market would divert ships to Brazil at Petrobras's convenience.

#### 12.7.2.2 Challenges for LNG supply

Nevertheless, although LNG may provide flexibility in gas supply to thermal power plants, it has one important characteristic: its price (as a commodity) strongly depends on how much in advance its order is placed. For example, a LNG order placed one year in advance can normally have a fixed price, since the vendor has the possibility of contracting adequate hedges against the oscillations of the strongly uncertain and volatile international prices. On the other hand, a LNG order placed just a few weeks in advance has a price above that of usual references, associated to the opportunity cost of displacing this gas with respect to its destination market, and increased by an "urgency rate". For instance, a LNG request for "next month" may involve the displacement of a ship intended for the United States market which has a reference price corresponding to that associated to Henry Hub. In this case, the price for the Brazilian market would be, at least, the opportunity cost of this gas (Henry Hub price) increased by a spread (e.g., 10%).

In this context, an important decision problem for the LNG buyer consists in determining, each year, the shipping schedule so as to fulfill gas demand and to minimize its purchase



price. This problem becomes more complex on account of the features of the electrical sector's natural gas consumption, which is potentially high and has a strong uncertainty component, as the National System Operator has the prerogative of setting thermal plants in motion without advance notice.

At first sight, the only way to solve this conflict between anticipation of fuel order and uncertainty as to the moment of thermal plants dispatch would be the construction of physical reservoirs for LNG storage. However, the cost of these reservoirs would be very high, if the gas storage capacity were sufficient to cover the period of thermal plants operation, which could last some months. It is at this point that the concept of a virtual reservoir appears: instead of storing gas in a physical reservoir, in order to generate later electric energy, one possibility would be to pre-generate this electric energy as soon as the previously programmed LNG shipments arrive, and to store this energy in the form of water in the system hydro plants reservoirs, as energy credits for the future use by thermal power plants. This way, the dispatch needs would be matched to the LNG supply logic. The concept of virtual reservoir was recently introduced in the Brazilian market rules.

### 12.7.2.3 Virtual gas storage: gas stored in hydro reservoirs

As described above, the expectation of a LNG order for gas to be used in thermal dispatch may be frustrated by the occurrence of a more favorable hydrology than that expected. In this case, the requested natural gas would not be needed after the arrival of the liquefied gas carrier ships at the re-gasification stations. Symmetrically, a less favorable hydrology than that expected could lead to the need of an "*immediate*" thermal dispatch, not allowing sufficient time for the arrival of the ship carrying the required fuel.

An interesting mechanism to relieve this problem can be found in the very physical characteristic of the Brazilian hydroelectric system: the presence of reservoirs with large storage capacities provides a storage flexibility which could be used by thermal power plants to store as equivalent water, through a "*forced dispatch*", the delivered natural gas that otherwise would not be used. In this case, the thermal power plants would retain a credit of natural gas stored in the hydro plants reservoirs in the form of water, meaning that hydroelectric storage could be used as a buffer by thermal plants so as to permit the storage of non-utilized natural gas.

The following steps describe a simplified version of the virtual reservoir scheme:

- (1) Assume that a ship has just arrived, carrying sufficient LNG to supply 2 GW avg of thermal generation for one week. Assume, also, that the ISO announced that it intends to dispatch 50 GW avg of hydroelectric plants next week.
- (2) The thermal power plant notifies ISO that it intends to pre-generate 2 GW avg; ISO reschedules hydroelectric plants generation to 48 GW avg, so as to accommodate thermal plant pre-generation.
- (3) ONS records in the accounts the reservoirs storage reduction as if hydro plants had actually generated the scheduled 50 GW. In other words, the physical volume of the water stored in the reservoirs will be greater than the accounted stored volume.

- (4) The difference between physical and accounted storage (corresponding to the pre-generated 2 GW avg) is credited to the thermal plant as an energy option (*"call option"*) that may be actuated at any moment.
- (5) Finally, assume that some time later ISO announces that it intends to dispatch 48 GW avg of hydroelectric energy and 2 GW avg of thermoelectric energy. As mentioned above, the thermal plant may decide to generate physically (if, by a coincidence, a new LNG ship happens to have just arrived) or to apply the option of using the stored energy. In the latter case, the thermal plant follows a procedure inverse to that of item (2): it notifies ISO that it is going to utilize its stored energy, and ISO reschedules the hydroelectric generation to 50 GW avg.

The great risk for the thermal producer in this arrangement is that of water spillage from the physical reservoir: in this case, *"accounted"* hydroelectric energy will be spilled before the *"physical"* energy.

Of course, the procedure to be implemented involves more complex aspects, not addressed in this Chapter, such as transmission restrictions, storage management for the various hydroelectric plants, and compatibility with the mechanism of energy reallocation, among others. Yet, in brief, virtual storage utilization permits, through a swap operation, to accommodate the need to order LNG without affecting the system optimum policy and operation, thus favoring the ingress of flexible gas supply and the possibility of preparing strategies for its cost reduction.

### 12.7.3 Virtual Gas Storage and Smart Electricity-Gas Swaps

Finally, the introduction of flexible LNG supply in the region can bring up several opportunities to integrate the electricity and gas markets in the region. This is because energy swaps with LNG are much more economical than the proposed point-to-point pipelines. An example of gas-electricity integration is the so-called *"gas exports from Brazil to Chile without gas or pipelines"*. Essentially, Chile purchases 2000 MW of electricity from Brazil, for delivery to Argentina (via the Brazil-Argentina DC link). The power from Brazil now displaces 2000 MW of gas-fired thermal generation in Argentina, which frees up 10 MM<sup>3</sup>/day of natural gas supply, which is (finally) shipped to Chile.

Another example is the use of LNG against the proposed *"Southern Gas Pipeline"*, from Venezuela to Brazil and Argentina. A more rational solution would be to send LNG from Venezuela to the Northeast region of Brazil, thus decreasing the need to send gas from the Brazilian Southeastern region to the Northeast. The surplus production is then sent by LNG to Montevideo, and from there through an existing pipeline to Buenos Aires.

Many other possibilities can be designed but, in essence, LNG brings opportunities for intelligent and economic integration of the regional energy market.

### **12.8 Power and Natural Gas Integration in the Southern Cone – Past, Present and Future**

Regional power integration in the Southern Cone of Latin America had its inception before any political and economic partnership projects [10,11]. It 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 1990s, 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 integrate 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 2200 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, as shown in Figure 12.3.

The regional integration process was ultimately adapted to the primary resource matrix available in each country, with increasing expectations as regards satisfying local demand with foreign supplies. As discussed in Section 12.4, Chile undertook a program involving 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 full utilization of existing network capacities and the generation of new links. The coexistence of firm exchanges (based on long-term contracts) and spot exchanges were not conflictive, as the market operated on the basis of capacity surplus. The full utilization of 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.

The integration scenario has shown some signs of stagnation since 2003, especially in view of the relative isolation of individual plans and a stronger emphasis on self-sufficiency at the national level. Energy independence has become a goal in a region where there are still no international legal frameworks that support integration processes not to be altered at mid road, as it did happen between Argentina and Chile and between Bolivia and Brazil.

### 12.8.1 Regulatory and Commercial Situation

During the last few years, the pace of reforms has slowed down at the international level, and market organization at national level is undergoing active reviews. Without having fully retreated from the systems implemented in the 1990s, transition periods are under way both in Argentina and Brazil, with a higher degree of participation by the State in sector management.

An important area affected by these changes was 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 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 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 firm and uninterruptible access to the networks. The role of distribution between the public and private sectors is on hold. Although the high rate of privatizations that characterized the 1990s 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. This is 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.

### 12.8.2 Southern Cone Integration Issues

Regional energy integration is the 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 include and determine infrastructure and services integration projects. Within this supra-sectarian framework, some noteworthy aspects are homogeneous tax treatment and the stabilization of exports 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.
  - f) Creation of flexibilities and integrated electricity-gas swaps in the region using the existing infrastructure. For example, Brazil could export electricity to Argentina, thus displacing gas-fired generation and freeing more gas to be exported from Argentina to Chile. These types of arrangements should become common in the region.

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 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, to promote investment and efficient operation by adequately distributing the roles between the public and private sectors.

## 12.9 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. In this sense, each country has adopted a different scheme to achieve the target of electricity and gas supply adequacy. Over recent years, these different schemes have had positive and negative repercussions. Among the countries analyzed, the different schemes, the degrees of market evolution, and market opening have resulted in active electricity markets (in Brazil, Chile, Argentina, Colombia), and gas markets (in Argentina, and Colombia). No country has been able to develop an active integrated electricity-gas market. Resource adequacy planning has always been carried out separately and characterized by the particularities of each country.

The high dependence of some countries such as Brazil and Colombia on hydropower creates 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 have turned out to be *"uncertain"*. A promising issue in the region is multi-country electricity markets. These 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, but important aspects still remain to be discussed, such as the compatibility of regulatory frameworks, tax systems, the political stability of long-term contracts, and need to harmonize supply adequacy actions in the region.

More recently, LNG has emerged as an attractive option. However, South America is a latecomer to the LNG business. Other regions and countries have already incorporated this external natural gas supply source in their portfolios for many years. However, some opportunities could arise from this late arrival. In particular, the evolving rules of the global LNG market could allow for more flexible supply. This, in turn, brings opportunities for intelligent and economic integration of the regional energy market. The energy swaps with LNG are much more economical than the proposed point-to-point pipelines. An example of gas-electricity integration is the so-called “*gas exports from Brazil to Chile without gas or pipelines*”. Essentially, Chile would purchase 2000 MW of electricity from Brazil, for delivery to Argentina (via the existing 2,000 MW Brazil-Argentina DC link). The power from Brazil would displace 2000 MW of gas-fired thermal generation in Argentina, which would free up 10 MM<sup>3</sup>/day of natural gas supply, which would be (finally) shipped to Chile.

Finally, the ultimate amount of LNG imported will depend crucially on the development of the natural gas reserves in the region. The region has significant reserves and the challenge is how to monetize them and serve the regional and sub regional markets. The situation varies widely among LNG importers: there are countries with growing potential natural gas reserves (Mexico), which was not discussed in this Chapter; those with very little potential (Chile) and those with substantial reserves but still not enough to supply their large market potential (Brazil). The result will likely be a mix of and local/regional gas with LNG playing a smaller, but still important role in balancing supply and demand.

### 12.10 Acknowledgements

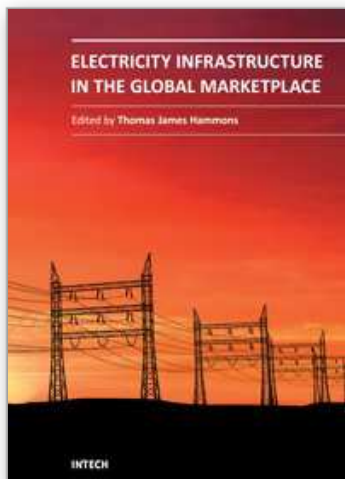
This Chapter has been compiled by Dr. Luiz A. Barroso, PSR, Rio de Janeiro, Brazil; Chair of the IEEE PES W.G. on Latin America Infrastructure; Bernardo Bezerra, PSR, Rio de Janeiro, Brazil, Sebastián Mocarquer, Systep, Chile and Dr. Hugh Rudnick, Pontificia Universidad Catolica de Chile, Chile. Contributing authors include B. Flach (PSR, Brazil), M. V. Pereira (PSR, Brazil), R. Kelman (PSR, Brazil), R. Moreno (Systep, Chile), M. Madrigal (Worldbank, USA), G. Arroyo (CFE, Mexico), J. Mejía and A. Brugman (Colombia) and L. Sbértoli (Sigla, Argentina). The Chapter is primarily based on an up-date of the papers presented at the Panel Session on “*Integrated Electricity and gas Resource Adequacy Planning in Latin America*” at the IEEE-PES 2005 General Meeting (GM2005) in San Francisco ([6-11]).

### 12.11 References

- [1] IEA – South American Gas – Daring to Tap the Bounty, IEA Press, 2003.
- [2] M. Pereira, L. A. Barroso and J. Rosenblatt “Supply adequacy in the Brazilian power market” Proceedings of the IEEE General Meeting, Denver, 2004 – Available at <http://www.psr-inc.com>



- [3] H. Rudnick, L.A. Barroso, C. Skerk, and A. Blanco. "South American Reform Lessons – Twenty Years of Restructuring and Reform in Argentina, Brazil and Chile". IEEE Power and Energy Magazine, Vol. 3, (4) July/ August 2005, pp. 49-59.
- [4] M.V.Pereira, N. Campodónico, and R. Kelman, "Long-term hydro scheduling based on stochastic models", Proceedings of EPSOM Conference, Zurich, 1998 – Available at <http://www.psr-inc.com>
- [5] B. Bezerra, R. Kelman, L.A. Barroso, B. Flack, M.L. Latorre, N. Campodonico and M.V. Pereira. "Integrated Electricity-Gas Operations Planning in Hydrothermal Systems". Proceedings of the X Symposium of Specialists in Electric Operational and Expansion Planning, Brazil, 2006, pp. 1-7.
- [6] H. Rudnick, "Electricity Generation and Transmission Expansion under Uncertainty in Natural Gas". Proceedings of IEEE 2005 PES General Meeting, San Francisco, 2005, paper 05GM1094, pp. 1-2.
- [7] H. Rudnick, "Energy Risk in Latin America: the Growing Challenges". Keynote paper, Proceedings of the International Conference on Energy Trading and Risk Management, November 2005, IEE, ISBN 9780863415807G.
- [8] J.M. Mejía and A. Brugman, "Natural Gas and Electricity Market Issues in Colombia". Proceedings of IEEE 2005 PES General Meeting, San Francisco, 2005, paper 05GM0311, pp. 1-4. T J Hammons and J S McConnach. Proposed Standard for the Quantification of CO2 Emission Credits, Electric Power Components and Systems, Taylor & Francis, Vol. 33, (1), pp. 39-58, 2005. L.
- [9] L. Sbertoli, "Power and Natural Gas Integration in the Southern Cone: Past, Present and Future". Proceedings of IEEE 2005 PES General Meeting, San Francisco, 2005, paper 05GM0310, pp.1-4.
- [10] M. Tavares, "The Role of Natural Gas as an Instrument for the Energy Integration in Latin America". Proceedings of IEEE 2005 PES General Meeting, San Francisco, 2005, paper 05GM0313, pp.1-3.
- [11] L. A. Barroso, B. Flach, R. Kelman, B. Bezerra, J. M. Bressane, and M. Pereira. "Integrated Gas-Electricity Adequacy Planning in Brazil: Technical and Economical Aspects". Proceedings of IEEE 2005 PES General Meeting, San Francisco, 2005, paper 05GM0160, pp. 1-8.
- [12] L.A. Barroso, H. Rudnick, S. Mocarquer, R. Kelman and B. Bezerra LNG in South America: the Markets, the Prices and the Security of Supply - IEEE PES General Meeting 2008, Pittsburgh, USA.
- [13] H. Pistonesi, C. Chavez, F. Figueroa, H. Altomonte, "Energy and Sustainable Development in Latin America and the Caribbean: Guide for Energy Policymaking", Project CEPAL-GTZ-OLADE. Second Edition, Santiago, Chile, 2003.



## **Electricity Infrastructures in the Global Marketplace**

Edited by

ISBN 978-953-307-155-8

Hard cover, 802 pages

**Publisher** InTech

**Published online** 27, June, 2011

**Published in print edition** June, 2011

This book discusses trends in the energy industries of emerging economies in all continents. It provides the forum for dissemination and exchange of scientific and engineering information on the theoretical generic and applied areas of scientific and engineering knowledge relating to electrical power infrastructure in the global marketplace. It is a timely reference to modern deregulated energy infrastructure: challenges of restructuring electricity markets in emerging economies. The topics deal with nuclear and hydropower worldwide; biomass; energy potential of the oceans; geothermal energy; reliability; wind power; integrating renewable and dispersed electricity into the grid; electricity markets in Africa, Asia, China, Europe, India, Russia, and in South America. In addition the merits of GHG programs and markets on the electrical power industry, market mechanisms and supply adequacy in hydro-dominated countries in Latin America, energy issues under deregulated environments (including insurance issues) and the African Union and new partnerships for Africa's development is considered.

**Thomas James Hammons** (Fellow IEEE 1996) received the B.Sc. degree in Engineering (1st Class Honors), and the DIC, and Ph.D. degrees from Imperial College, London, UK. He is a member of the teaching faculty of the School of Engineering, University of Glasgow, Scotland, UK. He was Professor of Electrical and Computer Engineering at McMaster University, Hamilton, Ontario, Canada in 1978-1979. He is the author/co-author of over 440 scientific articles and papers on electrical power engineering and is Editor of a book on Renewable Energy that was published by INTECH in December 2009. He has lectured extensively in North America, Africa, Asia, and both in Eastern and Western Europe.

Dr Hammons is Past Chair of the United Kingdom and Republic of Ireland (UKRI) Section IEEE and Past Chair of International Practices for Energy Development and Power Generation of IEEE. He is also a Past Chair of the IEEE PES Task Force on harmonizing power-engineering standards worldwide and Past Permanent Secretary of the International Universities Power Engineering Conference. He is a Chartered Engineer (CEng) and a registered European Engineer in the Federation of National Engineering Associations in Europe.

### **How to reference**

In order to correctly reference this scholarly work, feel free to copy and paste the following:

T. J. Hammons (2011). Integrated Natural Gas-Electricity Resource Adequacy Planning In Latin America, Electricity Infrastructures in the Global Marketplace, (Ed.), ISBN: 978-953-307-155-8, InTech, Available from: <http://www.intechopen.com/books/electricity-infrastructure-in-the-global-marketplace/integrated-natural-gas-electricity-resource-adequacy-planning-in-latin-america>



#### **InTech Europe**

University Campus STeP Ri  
Slavka Krautzeka 83/A  
51000 Rijeka, Croatia  
Phone: +385 (51) 770 447  
Fax: +385 (51) 686 166  
[www.intechopen.com](http://www.intechopen.com)

#### **InTech China**

Unit 405, Office Block, Hotel Equatorial Shanghai  
No.65, Yan An Road (West), Shanghai, 200040, China  
中国上海市延安西路65号上海国际贵都大饭店办公楼405单元  
Phone: +86-21-62489820  
Fax: +86-21-62489821

IntechOpen

IntechOpen

© 2011 The Author(s). Licensee IntechOpen. This chapter is distributed under the terms of the [Creative Commons Attribution-NonCommercial-ShareAlike-3.0 License](https://creativecommons.org/licenses/by-nc-sa/3.0/), which permits use, distribution and reproduction for non-commercial purposes, provided the original is properly cited and derivative works building on this content are distributed under the same license.

IntechOpen

IntechOpen