Effects of Liberalisation on the Dynamics of Hydro Based Electricity Supply Industries: The Case of Colombia

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Abstract

The objective of the investigation described in this paper is to explore how the structure of ownership affects the sustainability of the Colombian liberalised power system which is highly reliant on hydroelectric capacity and therefore highly vulnerable to seasonality. To a large extent, investment behaviour, and its effect on the ownership structure of electricity supply industries (ESIs), determine future capacity expansion patterns as well as security of supply. One important aspect of investment behaviour under liberalised markets is that it is indeed characteristic of different types of companies (i.e. private, public). Not only the demands on the returns to investment vary from firm to firm, also their market share aims, portfolio development goals, ability to close a sound financing scheme (e.g. raise capital, leverage financing) and risk tolerance among others, can be essentially different.

The research framework focused on three methodological steps: a) a series of interviews were conducted with relevant private and public companies operating in the Colombian power system (i.e. public companies, IPPs, multinational energy companies) in order to identify the key variables that drive their investment behaviour, b) a system dynamics model of the Colombian ESI that integrated the behaviour of different companies was developed and tested, and c) a series of scenarios that could reflect different ownership shares were designed in order to test the effect of ownership on system's expansion and sustainability (i.e. reserve margin).

The results of the investigation show two important aspects: 1) the liberalisation of the market does not ensure the long term security of supply needs of the system (i.e. the reserve margin shrinks with time, leaving the system highly vulnerable to seasonality), b) the role of public companies is crucial since they play a key role in the maintenance of minimum levels of reserve margin. The discussion of the paper then focus on the need to devote more efforts to the development and strengthening of public companies without necessarily divesting them. This conclusion could be extended to other Latin

American countries that are in going through the transitional stages of reform such as Brazil.

I Introduction

Over the last fifteen years, the power sectors of many nations of the world have been privatised and subsequently liberalised with various degrees of success from both the technical and economic points of view.

Although the reforms from centrally planned to market driven systems have incorporated elements characteristic of the economic, institutional and political conditions of each country, a few models of liberalization have emerged and evolved with relatively well defined institutional structures and regulatory frameworks[1].

The steps of the reform as well as the sequencing followed towards full liberalisation (i.e. with regards to changes in ownership and regulatory frameworks) have played a key role in the definition and development of today's market-oriented power sectors. Indeed, the development of the liberalised electricity supply industries of different countries have produced varied patterns of investment which have resulted in characteristic ownership structures (i.e. private, public, mixed).

To a large extent, investment behaviour and its effect on the ownership structure of an electricity supply industry determine future capacity expansion patterns with associated levels of reliability, technology mix and carbon emissions baseline.

One important aspect of investment behaviour under liberalised markets is that it is indeed characteristic of different types of companies (i.e. private, public).

Many factors influence firm behaviour under liberalisation. Not only the demands on the returns to investment vary from firm to firm, also their market share aims, portfolio development goals, ability to close a sound financing scheme (e.g. raise capital, leverage financing), risk tolerance and others can be essentially different.

In Latin American countries, the models used to determine long term system capacity expansion (e.g. SUPER OLADE BIDS, EMEPODE) do not however capture this important structural aspect of the market-oriented power systems. Rather, investment decisions on capacity additions are aggregated and based only on the economic and technical characteristics of projects (i.e. as if only one type of firm was following a least

[1] Models of liberalisation are described in Bacon and Besant-Jones 2002, Guash and Spiller 1999 and Newbery 1999.

cost investment criteria). Other models consider either an exogenous expansion plan or assume and inversely proportional non-linear relationship between the price of electricity and the reserve margin, which ultimately predict a sustained capacity expansion.

Indeed, the differentiated investment and strategic behaviour of companies determine the long term capacity expansion rates and patterns, as well as the type of investments. Given the differences in the behaviour of different types of public and private firms it seems necessary to investigate its effect on ownership structure, capacity expansion, reserve margin and technology mix[2].

This paper explores the case of predominantly hydroelectric systems through the analysis of the Colombian system. The intention of this paper is to explore how the structure of ownership affects the sustainability of such type of system.

Accordingly, the next section focuses on the structural characteristics of the Colombian electricity supply industry. Based on empirical evidence, in section III, the behaviour of different types of companies is described and discussed. Section IV analyses the effect of different ownership structures on capacity expansion with a sequencing of scenarios that resembles the steps followed after the liberalisation. Section V provides with a discussion on the results.

II Ownership Structure and Investment Patterns Colombian ESI

The analysis of the Colombian electricity supply industry (ESI) is particularly relevant for the purposes of analysing the evolution of liberalisation and in particular the dynamics of ownership share for the following reasons:

[2] Other authors have already explore this aspect of liberalized electric markets. Derek Bunn and Erik Larsen developed in 1992 a system dynamics model to analyse the electricity market of England and Wales. They investigated the sensitivity of reserve margin to factors influencing investment behaviour as well as the role of the capacity payment. Later on, Bunn and Larsen used the model to test different scenarios and expanded it to include the gas sector (see Larsen and Gary, 2000).

- It is a fully liberalised system with an eight-year experience in wholesale market transactions and the application of several regulations affecting investment decisions and technology choice.
- Colombia is a good example in which both public and private firms coexist and thus comparisons on their relative behaviour and objective functions can be carried out. The sector is characterized by a 44 percent share of public ownership and a 56 percent share of private ownership.
- It presents an interesting case since this is a liberalised market strongly influenced by seasonality.
- Whilst the system is in need of *firm capacity* additions in the form of thermal generation to avoid future black outs and lower price volatility, investors are increasingly reluctant to participate given the prevailing low electricity prices and the lack of economic incentives.
- There is still uncertainty as to what types of economic or market-based instruments could promote the additions of non-hydro based capacity as well as to what extent regulatory bodies should intervene and when.

Structure of the System

The total net installed capacity of the Colombian National Interconnected System (SIN) as of 2001 reached 13.167 GW. Most of this installed capacity is hydro-based (about 66%) making the system highly reliant on hydropower availability. The thermal generating capacity is 75% gas based with the balance 25% corresponding to coal and fuel oil fired generation.

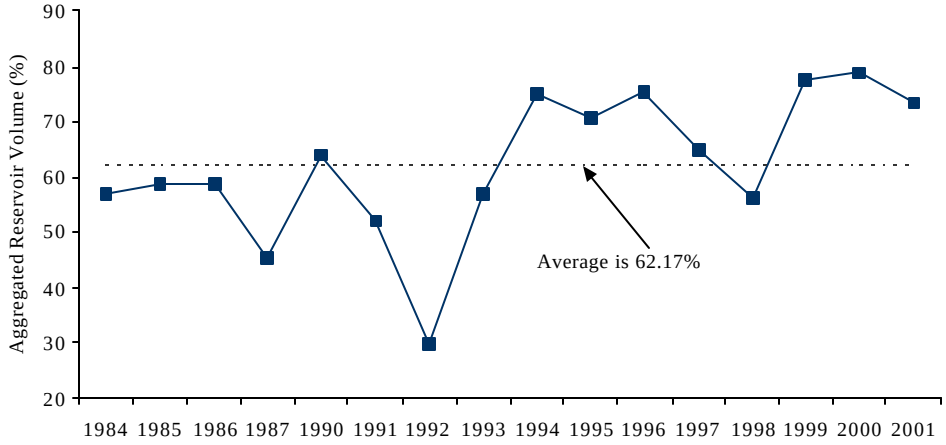
Economic recessions in Colombia have affected the demand for electricity. Demand growths were either very low or negative between 1996 and 1999. However, after the year 2000, and as the economy recovers[3], the electricity demand has exhibited an increasing trend.

Seasonality

[3] The average annual growth for GDP in Colombia grew from a negative 4.1% in 1999 to a positive 2.8% in 2000. An average rate of 4.7% is expected for the period 2002 to 2004 (World Bank, 2002).

Given the high share of hydroelectric capacity in the Colombian power system, the system is highly vulnerable to changes in rain patterns (i.e. seasonality). In the period 1990-2001, four dry years (i.e. with associated low hydroelectric utilization capacity) affected the Colombian electricity supply industry (ESI), including the droughts of 1992 and 1997/1998 due to El Niño phenomenon. During these droughts the water levels of hydroelectric plants' reservoirs dramatically lowered. The following graph shows the evolution of the aggregated reservoir volume of hydroelectric plants in the system.

FIGURE 1 Aggregated Reservoir Volume[4] of Hydroelectric Plants in Colombia (Annual Average) Period 1984-2001



Sources: www.creg.gov.co, www.upme.gov.co

As shown in Figure 1, Colombia had a critical drought in 1992 (with associated blackouts) and wet years in the period 1994-1996[5] with high aggregated reservoir volumes. During wet years, the availability of hydroelectric generation was sufficient to fulfil the demand in almost 100 percent for which thermal power plants were hardly dispatched over this period[6]. During dry seasons thermal power plants are called to attend the portion of the demand that can not be supplied by hydroelectric generation (i.e. mid merit to peak load).

[4] Includes all reservoirs in the country.
[5] Extremely wet years are known as La Niña phenomena, as it is the opposite effect to El Niño event.
[6] Hydroelectric generation serves the base-load demand in the "merit order" structure of Colombia. Thermal generators enter in mid or peak load depending on the system's demand. The availability of hydroelectricity therefore determines whether thermal generators are dispatched or not.

However, during highly critical events or droughts, thermal generators have not been able to fulfil the demand gap since they don't have enough *firm* capacity in place to attend this need. Indeed, the Colombian system, with its low electricity prices and poorly designed economic incentives, has not been successful in maintaining the required reserve margin[7] for a system with such a high hydroelectric capacity share.

Economic Dispatch and Structure of the Wholesale Market

Electricity generation pricing and merit order dispatch in the Colombian power sector are based on "energy price bidding" by generators for a day ahead estimated hourly demand. The price or bid offer of the last unit dispatched defines the "system marginal price" of generation. For the particular case of the Colombian pool market, the bids reflect only the costs of production (i.e. the variable costs, comprising mainly fuel and operational costs) as mandated by the regulatory framework (CREG resolution 100 of 1997)[8]. All dispatched spot market participants are however paid the system's marginal price, hence allowing the recovery of capital investments, specially to those plants with very low variable costs and sunk investments (e.g. such as large hydroelectric plants and generally those supplying the base load).

Capacity Payment in Colombia

In Colombia a "capacity payment" has been established to deal with the problem of recovering investments, and therefore having a better price signal for investing in new plants (especially for those that are generally dispatched at the peak and are vulnerable to seasonality, such as gas based power plants).

According to regulation CREG Resolution No.116, the generating agents that contribute to the system with firm power, under estimated critical hydrology conditions during the dry season (summer time) receive the capacity payment which is equivalent to the monthly fixed cost of the most efficient technology with lower capital costs. Since 1997

[7] Reserve margin in a system with high share of hydroelectric capacity should be no lower than 30%.

[8] Evidence on bid prices can be found in www.isa.com.co and www.cnd.com.co where historical data on dispatching operations is kept. Participant agents might however exercise different pricing strategies depending on the seasonality and other factors. These strategies are included in the model described below, however, there are not the subject of discussion in this particular paper. For more information see Elizondo, Mandal, Leach (2003).

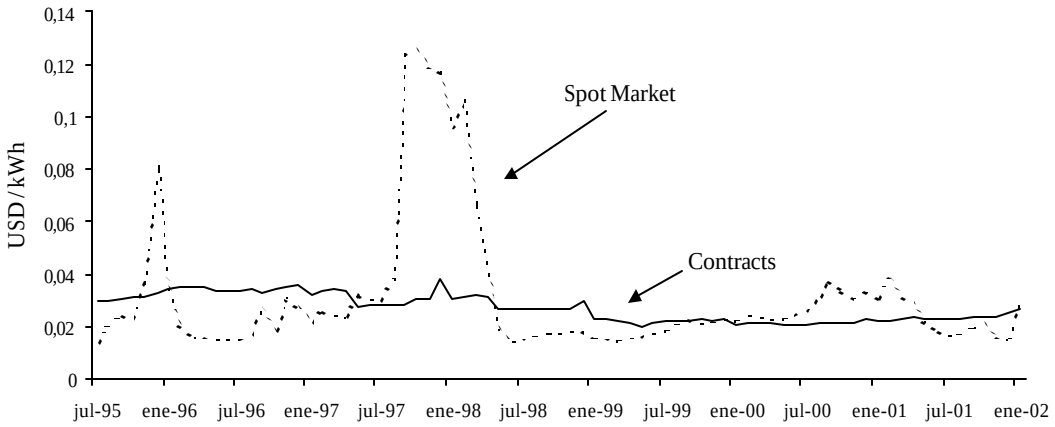
the capacity element has been set at **5.25USD/kW-month** (i.e. corresponding to an open-cycle gas turbine). The Capacity payment guarantees a minimum flow of revenues to those generating agents that contribute with firm power to the system.

Payments and settlement is done in the Pool, incrementing the pool electricity price to buyers and transferring payment to generators on the basis of KWh sold.

Evolution of Electricity Prices

The Colombian electricity market has been acquiring experience year by year after the liberalisation in 1995. The performance of the market, in terms of electricity prices is provided in Figure 2 below:

FIGURE 2 Spot and Contract Markets Monthly Average Price
Period July 1995-January 2002



Sources: Unidad de Planeacion Minero Energetica (UPME), www.upme.gov.co, with annual exchange rates from the Economist Intelligence Unit (EIU).

At present, and because of the high volatility exhibited by the system's marginal price (SMP) in the pool, about 80% of the demand is supplied through contracts, with only 20% of the demand being transacted in the spot market (TERA, 2000).

Ownership Analysis

The ownership structure of the Colombian Electricity Supply Industry is described in Table 1 below. In terms of electricity generation, the sector is characterized by a 44 percent share of public ownership and a 56 percent share of private ownership, as shown in the table below.

Table 1 Market Size and Firm Participation in the Colombian ESI (2001)

Name	Total MWs	Share %	Hydro	Gas	Coal/Oil
PUBLIC COMPANIES					
Empresas Publicas de Medellin (EEPPM)	2595.95	19.71	2125.95	470	
ISAGEN SA	1695	12.87	1410	285	
Public Companies contributing with less than 3%	1537	11.68	719.73	266	552
TOTAL PUBLIC	**5828.68**	**44.27**	**4255.68**	**1021**	**552**
PRIVATE COMPANIES					
EMGESA S.A. + Betania (ENDESA)	3036	23.06	2814		222
EPSA / Chivor (ABB, AES Corporation assets)	1520	11.54	1520		
Independent Power Producers (IPPs)	2596	19.72		2441	155
Co-generators	76.1	0.58	9	67.1	152.78
Private Co's contributing with less than 1%	110.8	0.84	81.8	29	
TOTAL PRIVATE	**7338.9**	**55.73**	**4424.8**	**2508.1**	**558.78**
TOTAL	**13167.58**	**100**	**8680.48**	**3529.1**	**1023.8**

Sources: Private Participation in Infrastructure Data Base (World Bank 2001), Colombian Energy Planning Unit (UMPE 2002), various companies annual reports.

According to a study on market power for the Colombian ESI developed by Hagler-Bailly (TERA,2000), the generation activity in Colombia constitutes a moderate oligopoly (i.e. about 30% of the market is served by many small agents). The Herfindhale Index (HHI) is indeed higher during critical hydrologic conditions.

Evolution of Private and Public Company Investments

After the reform of the power sector in Colombia, both private and public generating companies invested in capacity additions in the electricity supply industry. In the period 1995-2001, Independent Power Producers (IPPs) added a total of 2580 MWs of thermal power generation. Public utilities on the other hand installed a total of 1310 MWs since the liberalization in 1995 including a 405 MW hydroelectric plant in 2001.

Table 2 Private and Public Investment Period 1995-2001

Type	IPPs	Public Utilities
Hydro	-	405
Coal	165	150
Gas	2415	755
TOTAL	2580	1310

Source: FIPSI Data Base, World Bank, UPME and other.

IPPs however have reduced the rate of investments in Colombia for a variety reasons but mainly due to three events: a) an increase over the past years in the number of guerrilla attacks[9] to transmission towers and other infrastructure assets, b) a substantial increment in the price of natural gas after 1999 and most importantly due to c) the low electricity spot and contract prices exhibited by the market. Regulatory uncertainty regarding the *capacity payment* has also influenced the interest in further investments. Public utilities on the other hand increased their rate of capacity additions after 1997, investing more in thermal generation than in hydroelectric power plants. In fact, public utilities have expressed their intention of increasing the thermal share of their portfolio of power generating units within the next 5 to 10 years[10]. The historical investment behaviour of both private generators and public utilities set the basis for the expected capacity additions to the Colombian ESI. This is described below.

[9] Guerrilla attacks are included in the model described below.
[10] Interviews with Walter Navarro, Empresas Publicas de Medellin (EEPPM) and Ismael Concha, Unidad de Planeacion Minero Energética (UPME).

III The Behaviour of Public and Private Enterprises

This section draws from a series of interviews with private and public firms operating in the Colombian system and in Latin America conducted in the period 2000-2002[11].

The elements that influence the decision of companies on whether to invest or not in capacity additions as well as on the type of technology, timing and geographic location of the investments are diverse. Indeed, the combination of elements affecting the dynamics of deregulated energy systems increases the complexity of the decision making process and associated risk management.

Managers of energy firms however prioritise only a few of these elements based on their ownership structure, size, portfolio composition, ability to close financing schemes as well as their various corporate objectives and strategies.

In the context of liberalisation the characteristics that mark the differences between private and public firms have to some extent departed from the conventional wisdom.

For instance, despite the increase in guerrilla attacks after 1996 and the relatively low electricity demand rates exhibited at the time (0.5 to 2%), Endesa Spain[12] sought to increase its regional market share and invested in about 3,000 MW of divested power generating assets in Colombia in 1997.

Independent power producers (IPPs) have entered the various electricity markets of Latin America despite their degree of liberalisation focusing mainly on achieving specified levels of returns to investment.

Public utilities that were not divested and operate under the rules of electricity markets strive towards integrating commercial principles into their business practices while keeping some of the social objectives that have historically determined their behaviour (i.e. investments respond to the security of supply needs associated to the system).

Public monopolies, such as the Mexican Federal Commission of Electricity (CFE) have understood the strategic importance of improving transparency and internalising private-like economics into their practices (e.g. periodically reporting the status of their cash-flows).

[11] The interviews included managers of EEPPM, InterGen, AES Corporation and Endesa Corporation among others.

[12] . In 1999, Endesa Spain (previously unrelated to Endesa Chile) secured control of the Chilean company after a long and complex process that involved first gaining control of Enersis, and then aggressively competing with Duke Energy to obtain the additional shares needed for acquiring Endesa Chile (Del Sol 2002).

Today, electricity sectors are operated by different types of private and public firms with ownership compositions that determine to a large extent their development.

With the intention of gaining insight into the investment behaviour of power generating companies operating in the Colombian ESI, semi-structured interviews were conducted with both experts of the system and managers of a sample of companies playing a key role in Colombia and in other Latin American countries. The results were incorporated into the design of a system dynamics model for the Electricity Supply Industry of Colombia (see Annex I for a description of the model).

In this section, the behaviour of different types of companies is described and discussed.

Section IV then analyses the effect of different ownership structures on capacity expansion with a sequencing of scenarios that resembles the steps followed after the liberalisation.

A Investment Behaviour of Private Companies

To capture the behaviour of different private firms operating in Colombia various managers of the following companies were interviewed:

i) ENDESA Corporation (with a market share of 23%)[13],

ii) AES Corporation given its ownership share in EPSA, Chivor and TermoCandelaria (combined share of 13.7%) as well as its relevant regional participation,

iii) Intergen, a firm that operates as an independent power producer (IPP) not only in Colombia (i.e. ThermoEmecali) but also in various systems of the Latin American region[14],

iv) El Paso Corporation, actively operating and investing in Brazil as an IPP.

The analysis was complemented with the evaluation of the investment patterns of private companies participating in the Latin American region (particularly those that

[13] Interviews included managers with experience in the operation of both Endesa-Spain and Endesa-Chile.

[14] Managers interviewed had positions at the regional level rather than at the local level (e.g. managers of EMGESA were not interviewed, rather various managers of Endesa Chile and Endesa Spain were reached).

have invested in the Colombian ESI[15]) and with the review of annual reports and relevant literature. To the extent possible and in order to preserve confidentiality, the results have been aggregated in terms of behaviour. Accordingly, the following sections summarise the behaviour of two types of private companies a.1) Multinational Energy Companies (MNECs) and a.2) Independent Power Producers (IPPs)

a.1) Multinational Energy Companies (MNECs)

Large multinational utilities such as Endesa, Southern Energy, Duke Energy and CMS Energy Corporation have followed investment patterns that are characterised by their desire to expand their investments and operations at both country and regional levels (see Table 3 below).

While some of these firms have invested in *greenfield* or merchant power plants, the majority such as Endesa Spain have mainly focused their investments on the purchase of divested assets (see Annex II). Indeed, the high demands for the returns to investment set by some of these companies (which reflect their low levels of tolerance to diverse sources of risk) have prevented their participation in *greenfield* or merchant capacity at the country and regional levels.

The interviews with various managers of Endesa-Chile and Endesa-Spain revealed the following simple rules for the simulation of the behaviour of EMGESA in the Colombian context[16]:

- EMGESA will strive towards maintaining the maximum market share allowed by the regulator.
- EMGESA will therefore invest in the amount of capacity required to maintain this maximum allowed level of market participation.
- EMGESA will invest in the most economically competitive power generating technology available if the internal rate of return (IRR) associated to this type of power plant is equal or higher to the firm's pre-established level of return to

[15] For this analysis, the Private Sector and Infrastructure Data Base (FIPSI) of the World Bank (2001) was used.

[16] For a empirical data (in the form of "quotes") see Elizondo (2003) or the working paper Elizondo (2003), Expansion and Behaviour of Energy Comp anies Operating in Latin America, Imperial College of Science, Technology and Medicine, www.env.ic.ac.uk/research/epmg/GabrielaCV.html

investment, which is equal or higher to the hurdle rate associated to the market.

- It assumed that EMGESA has no restrictions in financing the amount of capacity needed to fulfil its market share goals.
- EMGESA has an investment planning horizon of three years.
- As a conservative measure the firm considers "worse case" scenarios of electricity demand, electricity price, fuel prices and other relevant indicators when calculating the return to investment.

TABLE 3. Private Participation in Latin American Power Sectors (Top 20) (2000)

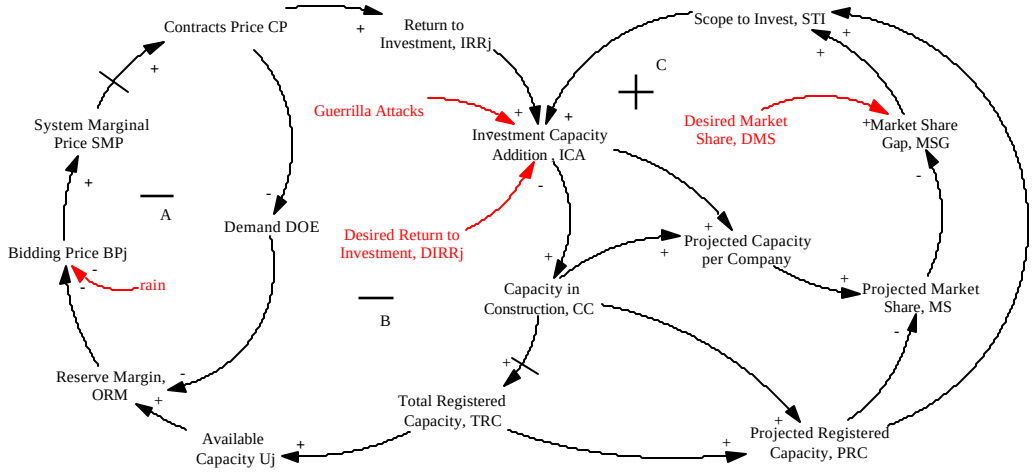
	Share in Region	Company	MW
1	24.5	AES Corporation[17]	18,968
2	16.3	Endesa Corporation	12,652
3	9.7	Southern Energy Inc[18]	7,574
4	7.2	Duke Energy[19]	5550.7
5	7.1	Tractebel	5518
6	6.8	Gener (Chilgener)	5282
7	5.3	CMS Energy Corp	4118
8	3.9	Enron Corp	3007
9	3.1	Iberdrola	2413
10	2.8	Akasaka Corp	2180
11	2.8	Electricite de France	2158
12	2.6	IATE SA	2046
13	2.3	Shell Corporation	1800
14	2.2	Amoco	1732
15	2.1	TransAlta Corp	1650
16	2	InterGen	1534
17	1.9	AIP	1450
18	1.8	Chilquinta	1379
19	1.7	El Paso Energy Int	1343
20	1.7	Argon	1320

Source: Elizondo, 2003

[17] AES is one of the largest IPPs in the US, considered also a global power company.
[18] Southern Energy Inc. is a subsidiary of Southern Company, the largest power generator of the USA. It is in fact a public utility holding company (EIA 1999).
[19] Duke Energy is a subsidiary of Duke Energy Corporation, the 5th largest investor generator of the USA. This company has embarked on an aggressive growth plan to become a leading energy company and is now one of the largest combined electric power and natural gas companies in USA (EIA 1999).

Figure 3 presents the loops characteristic of this type of behaviour. The balancing feedback loops **A** and **B** denote the wholesale market. The reinforcing feedback loop **C** (i.e. STI-ICA-CC-TRC-PRC-STI or STI-ICA-CC-TRC-PRC-MS-MSG-STI)) denotes the strategic decision of MNECs, which leads to investment in capacity. Additionally, the model considers guerrilla attacks as the number of bombed transmission towers (i.e. at specified levels EMGESA would either increase its demand for return to invest or consider not to invest)[20].

Figure 3 Loops Characteristic of EMGESA's Investment Behaviour



Source: Elizondo (2003)

[20] After 1996 the number of bombed transmission towers increased dramatically reaching about 400 in 2000. In interviews with managers of Endesa Spain, this proxy was established. For a empirical data (in the form of "quotes") see Elizondo (2003) or the working paper Elizondo (2003), Expansion and Behaviour of Energy Companies Operating in Latin America, Imperial College of Science, Technology and Medicine, www.env.ic.ac.uk/research/epmg/GabrielaCV.html

a.2) Independent Power Producers (IPPs)

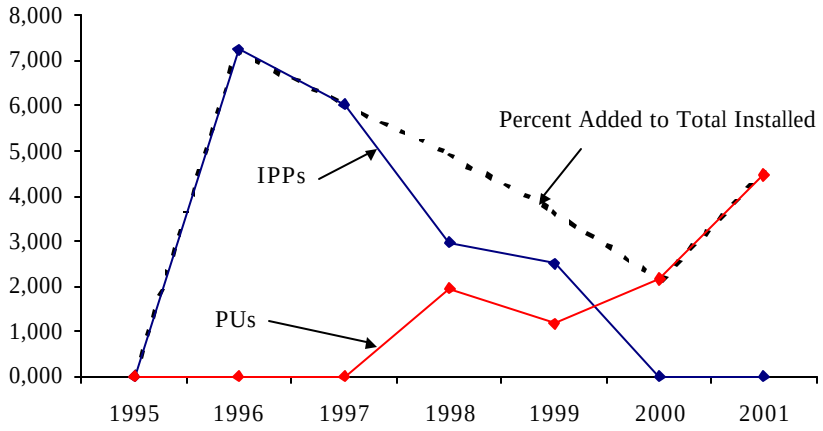
IPPs investment inflows to the electricity generating segment of the Colombian power system started before the privatisation in 1993 with the installation of a merchant 100 MWs gas-fired power plant built and operated by KMR power corporation, (i.e. later acquired by AES Corporation) and the participation of other financing groups. With the opening of the wholesale electricity market in 1995, other IPPs entered the system with gas or even coal-based power generating plants adding a total of 2160 MWs of thermal capacity in the period 1995-1997 (i.e. more than 15% of total installed capacity at the time) (see Figure 4 below). An analysis of the investment patterns of IPPs in the Latin American region has demonstrated the participation of IPPs in mainly greenfield investments (Elizondo, 2003).

IPPs were not only attracted by the liberalisation and the fact that Colombia was in need of firm capacity to avoid rationing during dry years or extreme events such as El Niño, also the spot and contracts electricity prices, although still volatile, were well above the region's competitive average. These conditions were considered positive signals for investment. IPPs investments after 1996 were however affected mainly by the following circumstances: a) consecutive wet years that affected the dispatching of thermal plants, b) regulatory inconsistencies (e.g. non-transparent allocation of capacity payment among generators offering firm energy), and c) extremely low electricity prices.

At the global level, events such as the Enron financial collapse and the energy crises in California provoked a lack of confidence from the part of banks and financial institutions on energy developers. After 2001, IPPs faced serious barriers in acquiring equity and their required levels of debt[21].

[21] In the past, IPPs aimed at maximizing the debt of a project as banks required debt to equity ratios with at least a 70/30 weight. Indeed, the ability to raise debt or opening lines of credit was seen as an indicator of the confidence of banks and other lenders on energy companies. However, after the Enron's fall lenders became more cautious and companies are expected to finance their businesses with a higher proportion of capital (i.e. debt to equity ratios are about 60/40 at the moment) (Elizondo, 2003).

Figure 4 Investment Patterns as a Percentage of Total Installed Capacity



Sources: Elizondo (2003)

The model represents the behaviour of IPPs (e.g. Intergen, AES Corporation, ABB) based on the following premises:

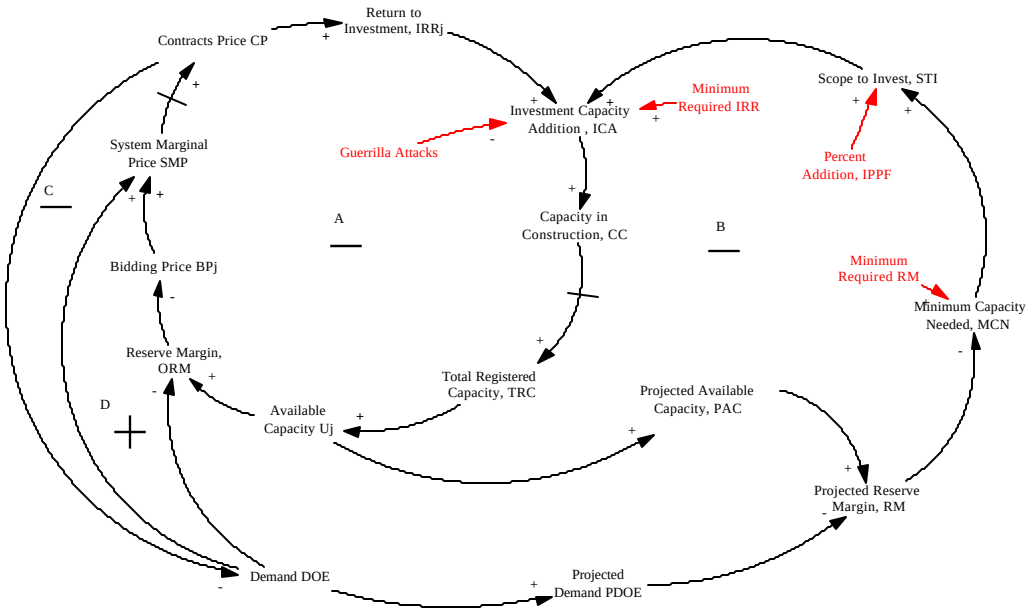
- IPPs have demonstrated to be willing to add high percentages of capacity needed if the conditions of the system are such that allow them to recover their required minimum returns to investment.
- IPPs are willing to add capacity when the expectations on rationing (or tight reserve margins) are high.
- IPPs will only invest in the most economically competitive technology (i.e. generally those with low capital costs such as combined cycle gas turbines)
- Based on the interviews conducted, it is assumed that IPPs demand on returns to investment are lower than those demanded by multinational utilities such as Endesa, but higher than those demanded by public utilities.

Figure 5 presents the loops characteristic of IPPs' behaviour. The balancing feedback loops A and C, as well as the reinforcing feedback loop D[22] denote the wholesale

[22] In this diagram it is shown that demand of electricity (DOE) not only affects the contracts price which reflects long term consumers demand elasticity, it also affects the system marginal price (SMP) since this is set through a least cost dispatching or merit order. The SMP is in fact a function of the demand (see Manual Model System Dynamics of Liberalised Colombian Power Sector as well as the powersim model at www.env.ic.ac.uk/research/epmg/GabrielaCV.html).

market. The balancing feedback loop **B** denotes the strategic decision of IPPs which leads to investment in capacity. In effect, the investment decisions of independent power producer are mainly affected by the potential returns to investment that the system can provide.

Figure 5 Loops Characteristic of IPP's Investment Behaviour



Source: Elizondo (2003)

B Investment Behaviour of Public Companies

b.1) Public Utilities (EEPPM, ISAGEN)

Although limited by capital funds and the possibility of government outflows, some public companies that have survived the process of liberalisation and that are commercially sustainable (i.e. positive cash flows) such as Empresas Publicas de

Medellin (EEPPM) or ISAGEN, will play an important role in the future capacity additions to the Colombian electricity system.

This is because although these firms have internalised commercial principles into their investment decisions to behave more like private firms competing in market-oriented schemes, they have also kept some of the social and environmental objective functions characteristic of their behaviour before the liberalisation. For instance, despite its low profitability EEPPM is in the process of building a 19.5 MW wind based power generating plant which is participating in the international carbon emissions market. Indeed, portfolio diversification is seen as an important aspect of EEPPM's long-term growth strategy.

In addition, due to their local knowledge and contacts network (i.e. which lowers information asymmetry), public firms appear to be less risk averse than international firms. Based on the interviews conducted with manager of EEPPM and ISAGEN, the behaviour of Colombian public utilities is represented with the following rules:

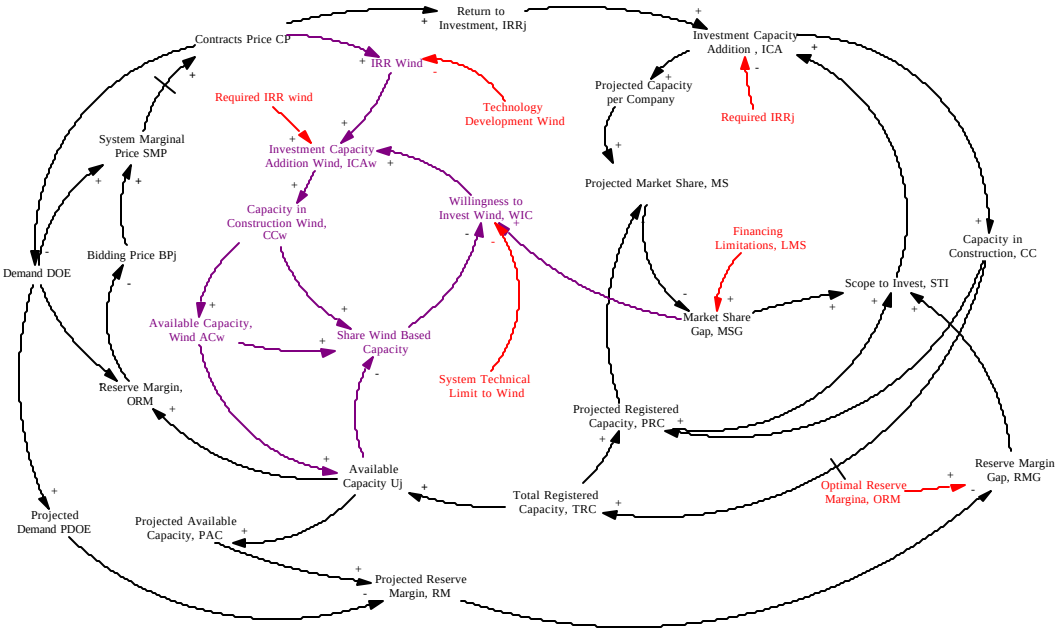
- It is assumed that PUs are more flexible than IPPs and MUs in their demands for returns to investment.
- This behaviour will however change with time, since the expectation of these public utilities is to become financially and organisationally more similar to private companies.
- For the particular case of Colombia, in which PUs have historically had portfolios with high hydroelectric shares, PUs will strive for an increase in technology diversification mainly in the form of thermal generation.
- PUs are willing to invest in renewable source based power generation even though their return to investment is not competitive but as long as the returns to investment are not lower than certain specified limit.
- PUs tend to be more concerned (and involved) with social and environmental issues, hence their more active participation in the installation of renewable based power generation and emissions trading.
- PUs in Colombia tend to add capacity as a response to a) certain degree of lowering of the system's "optimal" reserve margin (expectations), b) financing capacity

restrictions (e.g. certain public utility in Colombia could not increase its market share to more than 21% due to financing restrictions[23]).

- For its forecast, PUs consider the conservative scenarios of demand (e.g. average to worse case) provided by the planning unit to account for the fact that the UPME's reference scenario has been historically overestimated (Navarro 2002).

Figure 6 presents the loops characteristic of PUs' behaviour.

Figure 6 Loops Characteristic of PU's Investment Behaviour



Source: Elizondo (2003)

The diagram integrates the wholesale market loops (as shown in Figures 3 and 5 for MNECs and IPPs), however, the fact that their investment decisions include portfolio diversification (i.e. including wind based generation given the potential for this type of

[23] This is recorded in the form of "quotes" in the working paper Elizondo (2003), Expansion and Behaviour of Energy Companies Operating in Latin America, Imperial College of Science, Technology and Medicine, www.env.ic.ac.uk/research/epmg/GabrielaCV.html

renewable energy) makes the diagram visually more complicated. Additionally, public utilities consider the levels of reserve margin when considering long term investment.

IV Effects of Ownership on the Dynamics of Capacity Expansion

This section analyses the effect of different ownership structures on capacity expansion with a sequencing of scenarios that resembles the steps followed since the beginning of the liberalisation. These scenarios are the following:

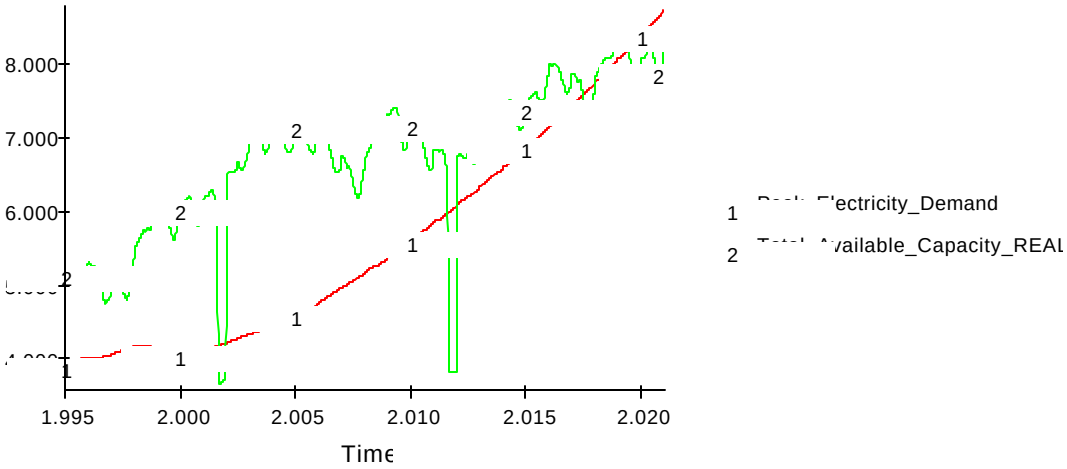
- Scenario I: Pre-Liberalisation: Participation of only Public Firms
- Scenario II: Post-Liberalisation: Participation of a mix of Public and Private Firms
- Scenario III: Post-Liberalisation: Participation of only Private Firms

All other assumption regarding exogenous variables and parameters have been kept the same for the three scenarios and have been also chosen with the criteria most conservative (e.g. most probable or conservative scenario of fuel costs rather than high cost scenarios).
The intention of the exercise is to explore how the structure of ownership affects the sustainability of the Colombian liberalised power system which is highly reliant on hydroelectric capacity and therefore highly vulnerable to seasonality.

Scenario I Pre-Liberalisation: Only Public Firms

In order to explore how would the system have evolved in terms of capacity expansion should liberalisation have not occurred, the system dynamics model was run with the participation of only Public Utilities. Indeed, in the early 1990s the government realized that public utilities alone could not ensure the long term sustainability of the system given the government's budgetary constraints.
With this scenario we would like to explore what would have happened if the Colombian government had not decided to liberalised. The results are shown in Figures 7, 8 and 9 below.

Figure 7 Evolution of Capacity Expansion (Scenario I)



Note: The scenario of rain applied delivers two extreme climatic events (i.e. severe droughts or Niño phenomena) in the years 2002 and 2012. This can be appreciated in line 2 of this graph.

Figures 7 and 8 show how public utilities would have been able to sustain minimum levels of security of supply (i.e. reserve margin above 20%) for at least up to 2010.

Figure 8 Evolution of Reserve Margin (Scenario I)

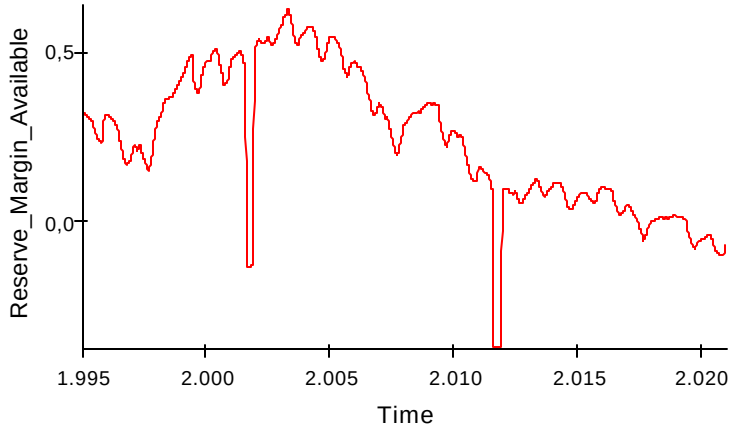
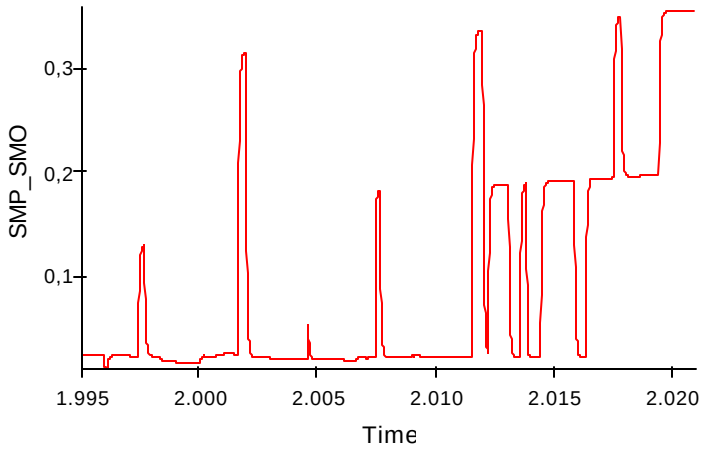


Figure 9 Evolution of Spot Electricity Price (Scenario I)

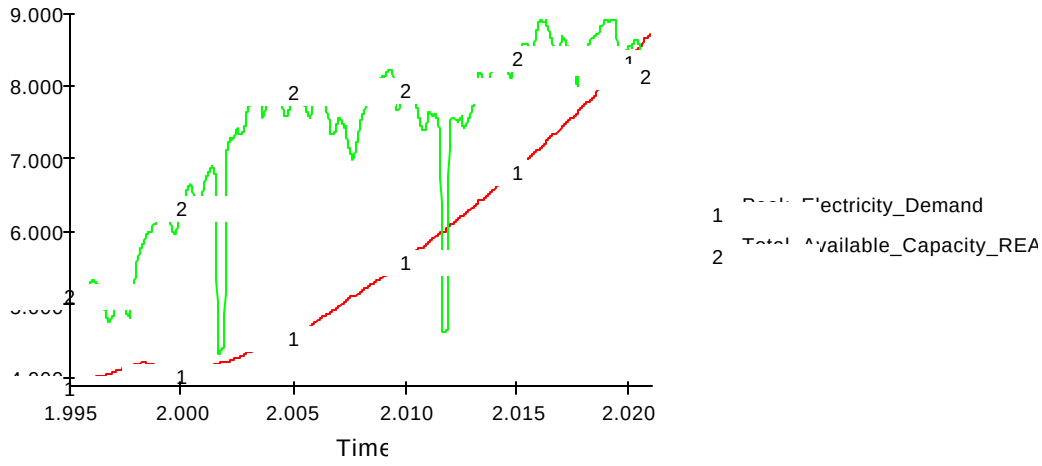


As shown in this graph, a dramatic lowering of the reserve margin is registered after 2010 with rationing events occurring only after 2017. Indeed, increased demand and the financing restrictions imposed on Public Utilities do not allow them after 2010 to maintain the optimal reserve margin for which they strive (i.e. no lower than 20%). The spot market price of electricity responds to the reduction of available hydroelectric capacity (see spikes in years 1997-98, 2002, 2007 in Figure 9) and the reduction of the reserve margin after 2012. Under this scenario (no market or monopoly) however, the market price is meaningless, in other words, the price would exhibit this degree of volatility.

Scenario II: Post-Liberalisation: Participation of both Public and Private Firms

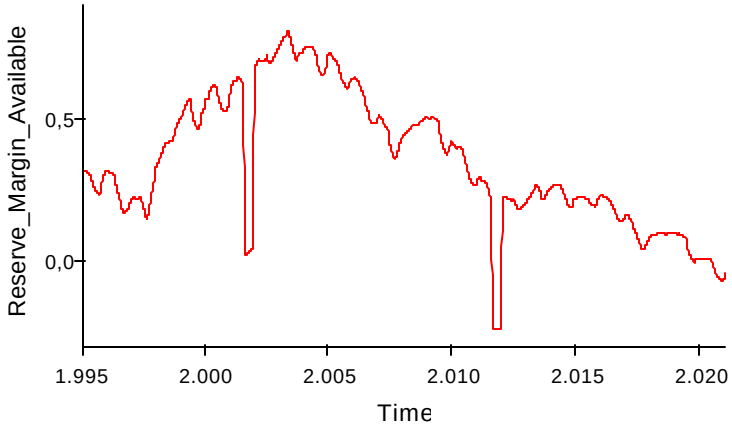
As shown in Table 1 and Figure 4, after the liberalisation in 1995, both public and private firms have secured a degree of participation in the Colombian electricity supply industry (i.e. 44.27% public and 55.73% private as of 2001).
This scenario simulates the co-existence of public utilities, independent power producers (IPPs) and multinational energy utilities. The results are show in Figures 10 to 12:

Figure 10 Evolution of Capacity Expansion (Scenario II)



Note: The scenario of rain applied delivers two extreme climatic events (i.e. severe droughts or Niño phenomena) in the years 2002 and 2012. This can be appreciated in line 2 of this graph.

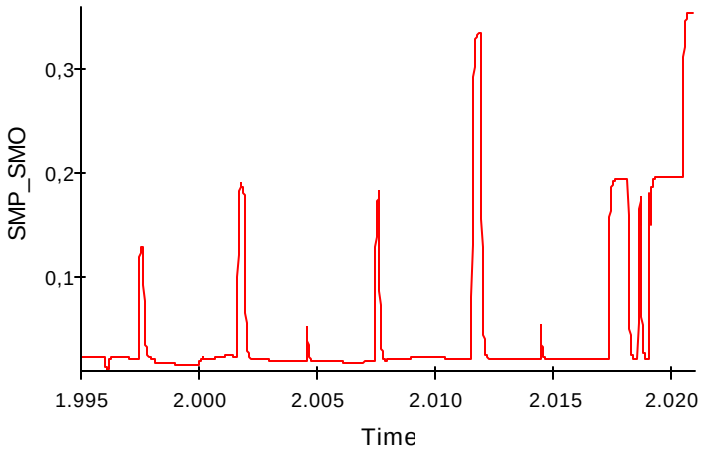
Figure 11 Evolution of Reserve Margin (Scenario II)



As shown in graphs 10 to 12, the participation of both public and private enterprises delays a possible electricity supply crises to the year 2017. The financing limitations of Public Utilities which lead to a reduce reserve margin with associated increase of

electricity spot price are complemented with private investment. Private companies however are, as explained before, also limited by their own restrictions in terms of market shares and demands on returns to investment.

Figure 12 Evolution of Spot Electricity Price (Scenario II)



The price of electricity reacts accordingly (Figure 12).

The results show that the liberalisation of the system does not ensure the long term sustainability of the system. The reserve margin lowers with time until it becomes zero at around 2017.

Scenario III: Post-Liberalisation: Participation of only Private Firms

This scenario explores weather the operation of only private companies would ensure the long term sustainability of the system.

Accordingly, in graphs 13 and 14 it is shown that under this scenario minimum levels of reserve margin are provided up until the year 2010, after which the system exhibits tight reserve margins.

Figure 13 Evolution of Capacity Expansion (Scenario III Only private Firms)

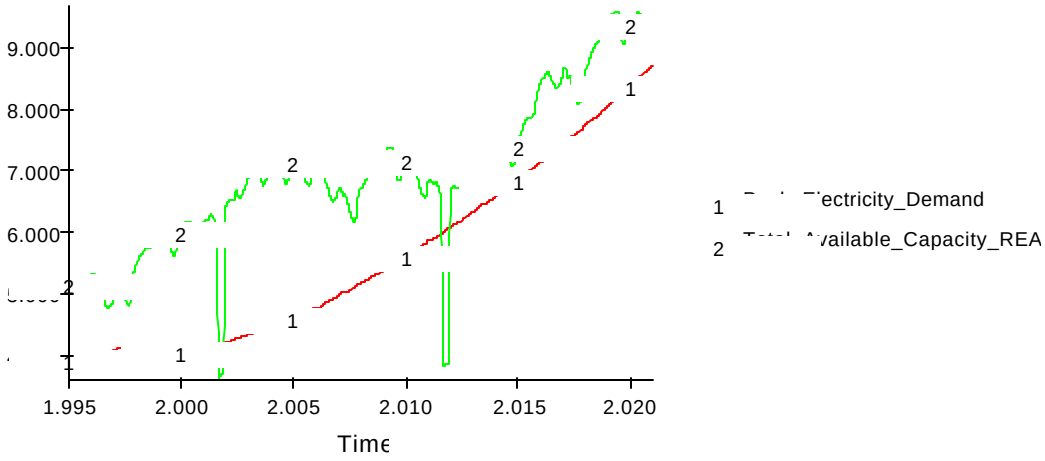
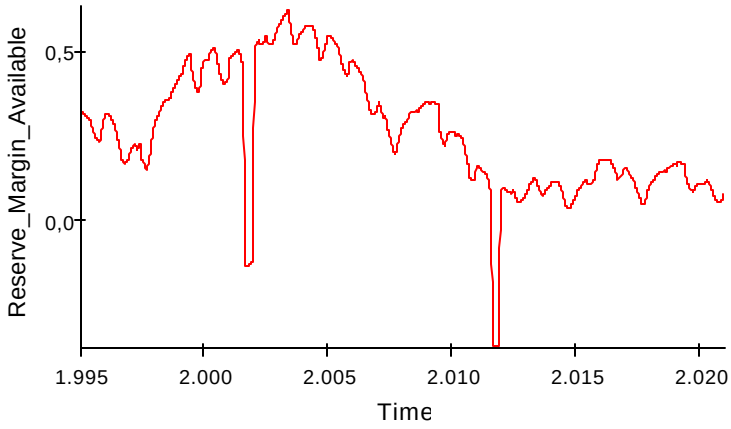
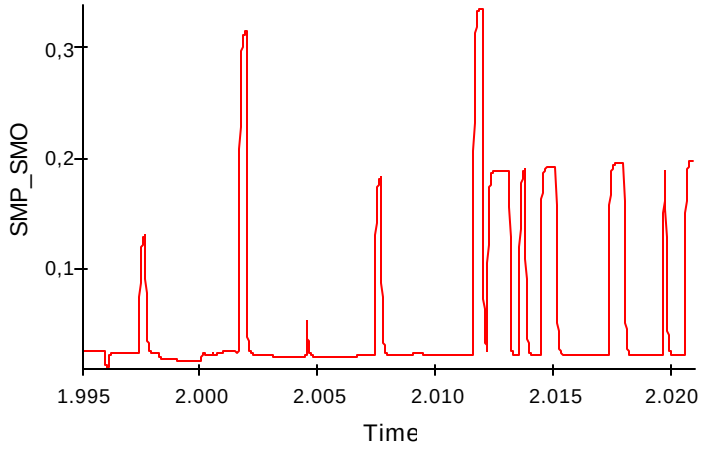


Figure 14 Evolution of reserve Margin (Scenario III Only private Companies)



The evolution of the spot price exhibits the same degree of volatility as in Scenario II.(i.e. with spikes due to either extreme hydrologic conditions or very low reserve margins).

Figure 15 Evolution of Spot Electricity Price (Scenario III, Only private Companies)



Summary of Results

The results show that the co-existence between different types of private and public firms ensures minimum levels of reliability of supply up until at least 2016. The other two scenarios (i.e. only private companies or only public companies) do not however delivers acceptable levels of reserve margin after 2010.

Table 4 Summary of Results

SCENARIOS Participating Firms	**Long Term System Sustainability (Reserve Margin)** Period of Sustained Minimum Reserve Margin	Reserve Margin Below Minimum	Negative Reserve Margin (Rationing)
I Only Public Firms	2010	2010-2017	After 2017
II Both Private and Public Firms	2016	2016-2019	After 2019
III Only Private Firms	2010	After 2010	None

Note: Public Firms are public utilities (e.g. ISAGEN, EEPPM), Private Firms are IPPS (e.g. AES, InterGen) and MNECs (e.g. Endesa).

Indeed, financing restrictions on Public Firms, regulatory restrictions on market share and the high demands on the returns to investment affect in combination the long term

sustainability of the Colombian Electricity Supply Industry, given the different strategies sought by each type of firm.

V Discussion and Conclusions

Several conclusions can be drawn from the simple analysis provided in this paper:

- It has been shown that market liberalisation do not ensures the long terms needs of the system in terms of reliability, a condition that is necessary for the maintenance of a system that has a high share of hydroelectric capacity and it is therefore highly vulnerable to seasonality.
- Public firms in Colombia however play a key role in the maintenance of a minimum reliability of supply in the system.
- Public firms alone however would not be able to maintain an optimal or even a minimal level of reliability for a long period due to budgetary constraints.
- The Colombian government should continue working on the financial independence of its public firms in order to increase their ability to invest in capacity expansion.
- The criteria for investment considered by private firms is not aligned with the long-term needs of a system such as the Colombian one . Their sole participation in the market, as shown, would not ensure the maintenance of a minimum reserve margin. Rather, private firms investment is mainly triggered at very tight or negative (rationing) reserve margins.
- Complex stochastic models such as the Super Olade Bids and the EMEPODE or those that do not consider the differences in the behaviour of companies can not capture the possibility of a crises after 2012. Rather, this models either consider an exogenous expansion plan, or assume a inversely proportional non-linear relationships between the price of electricity and the reserve margin, which might no be always consistent with the behaviour of players.
- New incentives have to be designed to increase both private and public investment (i.e. the use of innovative financial and contractual tools such as futures, options, swaps and others).

- At the macroeconomic level, the government of Colombia should seek to lower the risks associated to investing in the country through incentives that benefit or improve the financial structure of projects.
- Indeed, in order to maintain the markets without destroying them, companies have to balance investor's demands with social and environmental needs.
- Public utilities in Colombia are in fact a new type of hybrid company: they have internalised commercial principles into their investment behaviour without letting other socially and environmental considerations go. The development of this type of companies have to be studied in more depth, given their behaviour which is key to the maintenance of minimum levels of reliability.
- The model developed simply shows that the mix of ownership in a particular liberalised system matters due to the differentiated behaviour of companies. Of course, this depends very much on the conditions of the public utilities operating in the system and the incentives for investment that the system itself provides.
- For the particular case of Colombia, international interconnections (regional interconnections) will play an important role in the future. For instance, the transmission line Puebla(Mexico)-Panama can be joined to the interconnected Andean region increasing the efficiency of supply-demand balancing operations (e.g. countries in Colombia with high shares in hydroelectric capacity can be supplied by countries such as Mexico with high shares of thermal generation). The impact of the lack of capacity investment in the medium to long terms can be in part buffered by the complementarities between hydro, thermal and wind resources in the region.
- There is a need to develop in depth case studies on the behaviour of public and private firms with high shares of ownership at the regional and national levels. Indeed, their behaviour has changed after more than a decade of liberalisations in the region and they can't be categorized any more as simply private or public.

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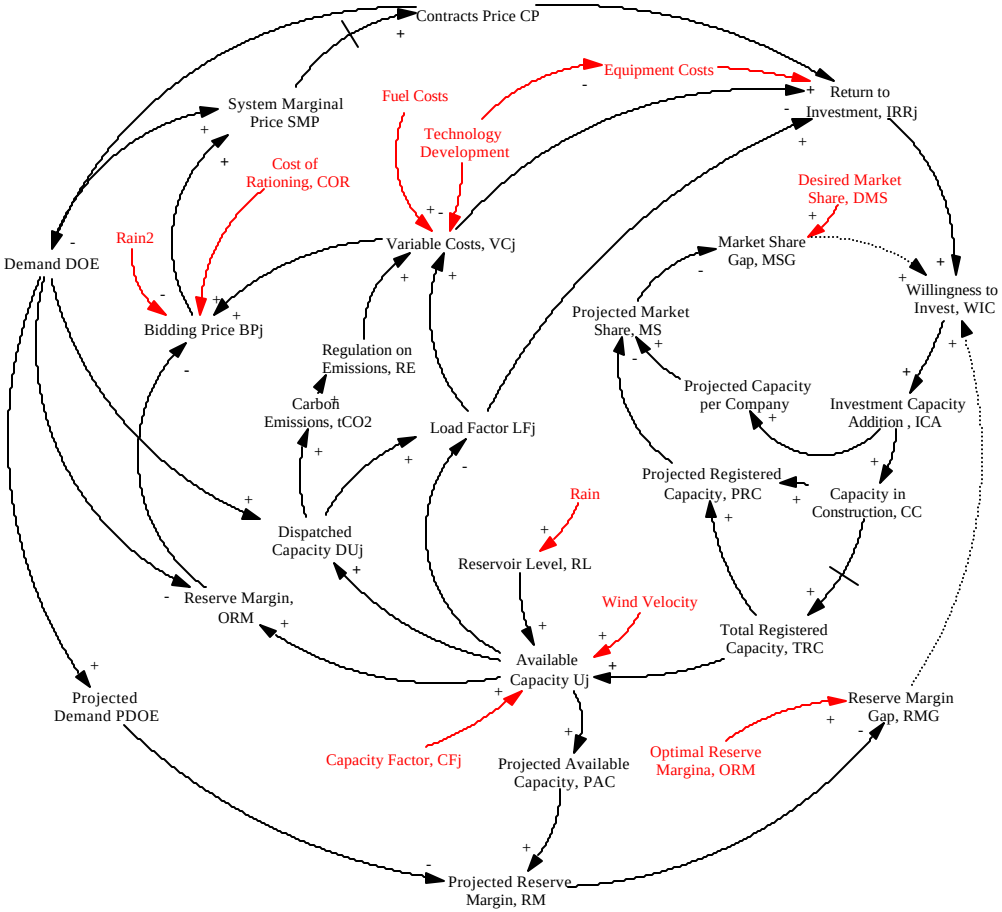
Annex I System Dynamics of the Colombian Electricity Supply Industry[24]



[24] For a detailed description of the model including equations, assumptions and diagrams, see document and powersim® model in the following web site: www.env.ic.ac.uk/research/epmg/GabrielaCV.html.

Annex II ENDESA SPAIN, INVESTMENTS IN THE PERIOD 1989-2001

	Degree of Liberalisation											
	1st Generation				2nd Generation				In Progress		Non Liberalised	
	Argentina		Chile		Peru		Colombia		Brazil		Venezuela[25]	
	Ownership (MWs) Greenfield (G) vs Divestitures/Acquisitions (D/A)											
	G	**D/A**	**G**	**D/A**	**G**	**D/A**	**G**	**D/A**	**G**	**D/A**	**G**	**D/A**
1990	-	-	-	-	-	-	-	-	-	-	-	-
1991	-	-	-	-	-	-	-	-	-	-	-	-
1992	-	211 G	-	-	-	-	-	-	-	-	-	-
1993	-	-	-	-	-	-	-	-	-	-	-	-
1994	-	-		-	-	-	-	-	-	-	-	-
1995		-	-	-	-	200 O 520.6 H 281.3 H	-	-	-	-	-	-
1996	-	-	-	-	-	161 G	-	-	-	-	-	-
1997	-	-		-	-	-	-	2,277 H 222 C	-		-	-
1998		-	-	-	-	-	-	-	-	-	-	-
1999	-	-	-	-	-	-	-	-	-	-	-	-
2000	-	-		-	-	-	-	-	-	-	-	-
2001	-	-	-	-	-	-	-	-	-	-	-	-
Total		211			-	1162.9	-	2,499	-		-	-
TOTAL	211		-		1162.9		2,499		-		-	

Note: G is gas, O is diesel/oil, C is coal and H is hydro.

[25] Endesa Spain had a 7.86% participation in Electricidad de Caracas, however in the year 2000 the Company sold these shares (http://www.endesa.sp).

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