CAN A RELIABILITY CHARGE SECURE ELECTRICITY SUPPLY?
An SD-based assessment of the Colombian power market

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ABSTRACT

The deregulation of the Colombian electricity market took place in 1994 and the pool started operation in 1995. The Colombian market adopted a *capacity charge* mechanism to increase incentives for investment in new capacity. The capacity charge proved to be weak in terms of transparency and incentives, causing negative effects on investment. Nowadays, the application of the capacity charge is over and a new mechanism is in place. The new mechanism, the *reliability charge*, intends to provide reliability to the system. We have previously used a non-standard system dynamics approach to evaluate alternative regulation schemes for the Colombian Electricity Market. In this paper, we have updated the system dynamic model, formerly built, to evaluate alternatives to the capacity charge mechanism. We have also assessed the effect that the reliability charge mechanism may have over the market and found that the proposed scheme may actually overcome some of the drawbacks of the previous scheme; however, simulations indicate that this may not have the desirable effects prompt enough to avoid blackouts.

1 Introduction

The electricity industry has been transformed worldwide since the mid 1980s. The deregulation process has replaced state-owned monopolies with open and competitive markets in those parts of the supply chain where it seemed feasible, taking advantage of experiences in other deregulated industries such as telecommunication and airlines. These have prompted a new paradigm for the activities of trading, management and delivery of energy services to final customers as well as for regulation (Armstrong *et al*, 1994). Chile in the 1980s was the first country to move ahead, followed by the UK and Norway in the early 1990s, with major innovations in market openness, privatisation schemes and regulation set-ups. In Latin American, most countries have undertaken major reforms or are in the process of transforming their electricity industries; in particular Colombia, whose pool started operations in 1995 (Arango *et al*, 2006). Both the evolution and the worldwide spread of the new industry paradigm have been very rapid.

The underlying motivations of deregulation have been to provide electricity more efficiently and reliably with higher quality, also aiming to prevent mismanagement and excessive government involvement in running utilities as was the case in some Latin American countries and in the UK (Bacon and Besant-Jones, 2001; Newberry, 1999). Progress has been observed but there is still room for improvements. On the one hand, some benefits are already being perceived in terms of technology development and price reductions (Larsen *et al*, 2004). On the other hand, the systems are still far from reaching equilibrium and major reforms are underway in many countries. Limitations in adaptation have created problems such as in California (Wolak, 2003) and Chile (Fischer and Galetovic, 2004), where major outages and extremely high electricity prices have been observed due to regulatory complications.

In this paper, we focus on the Colombian Electricity Market (CEM), where deregulation took place in 1994 (Laws 142 and 143: Congreso de la República de Colombia, 1994a; 1994b), and the short-term market started operation in July 1995. During the first years, the system developed satisfactorily in some sectors, especially regarding generation, sales to large customers, and recently the household sector (Larsen *et al*, 2004). The Colombian market adopted a British-like structure by adding a capacity charge (CC) mechanism to entice investments in new capacity. The

CC proved to be inefficient in terms of transparency and disincentives, causing a negative effect on capacity. Nowadays, the application of the capacity charge is over and a new mechanism has been implemented.

The literature considers a number of alternatives to the capacity charge mechanism (Millán, 1999; Comillas, 2000; TERA, 2001; UN-COLCIENCIAS- INTEGRAL, 2003; Larsen *et al*, 2004; Arango, 2007). However, the regulator – CREG – has adopted since mid 2006 the *reliability charge* mechanism (RC), which intends to provide reliability to the system (regulation CREG 071, 2006). In this paper we asses this mechanism through simulations. We present a model which simulates, among other factors, the behaviour of investors under such scheme.

The following section briefly describes the CEM, followed by the modelling approach chosen for analysis and the system dynamics platform for assessing this regulation alternative. Next, we explain and assess the adopted option by the CEM. Finally, we present our conclusions in light of the simulation process and results.

2 The Colombian Electricity Market (CEM)

The characteristics of the CEM are quite unique. It contains a large hydroelectricity base - around 70%. A third of which depends on a large reservoir capacity that is affected by severe weather conditions which might reduce water inflows into the system by up to 50%. As Colombia adopted the British regulatory scheme (ISA and XM, 2006), some changes where introduced to account for structural differences between these systems. A complete description and evaluation of the CEM is presented in Larsen *et al* (2004) and Arango *et al* (2006). Briefly, the results of over a decade of operations seem satisfactory in terms of wholesale price, technology evolution, and management development. However, price volatility and gains in the household sector are pending. Furthermore, black clouds are ahead with respect to the appropriate technology mix which influences price volatility and reliability of supply. Figure 1 shows the evolution of the pool and long term contract price, the aggregated water level of reservoirs, and the system margin (difference of Supply and Demand, over Demand).

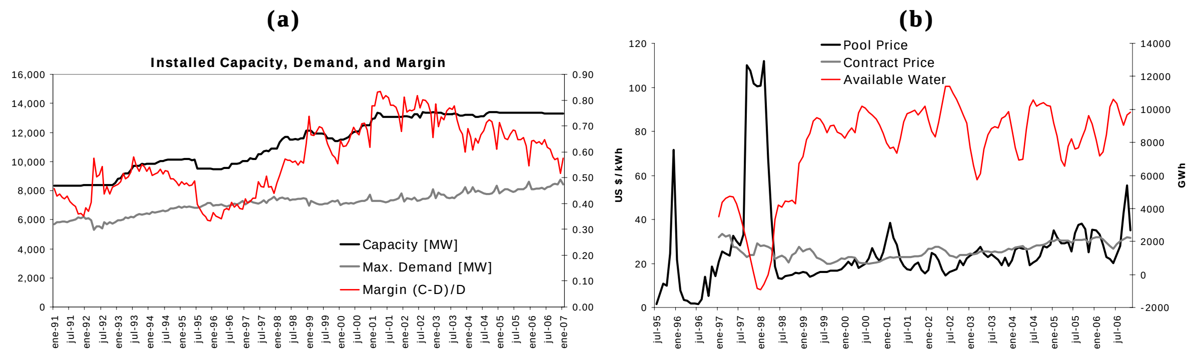

Figure 1. (a) Installed capacity and maximum monthly power demand in Colombia. (b) Evolution of pool and contract electricity prices in Colombia (Source: XM, 2007).

An important aspect in the CEM is the influence of the macroclimate phenomenon called ENSO (El Niño South Oscillation). One of its indicators is the SOI and its occurrence significantly reduces water inflow to reservoirs, as well as to many other sectors such as agriculture. The SOI index might be used to determine the occurrence of ENSO. The opposite of El Niño, “La Niña”, brings water inflows above average. Consequently, prices increase considerably under ENSO conditions, given the fact that the system is approximate 70% hydroelectricity based. In Figure 1, the effect of the ENSO over the system during 1997–1998 is clear, as pool prices reached their maximum levels and water reserves dropped considerably. Two coinciding factors have affected the CEM lately: a large fall in demand and a high water inflow after the ENSO 1997-1998.

Figure 1 shows that capacity has increased and peak demand has fallen, creating an excess-capacity situation. This drove prices down and discouraged investments in new plants, with possible undesirable long-term consequences. New plants may not seem viable now but might be required when the next ENSO (Larsen *et al*, 2004) occurs – the system may not provide clear economic signals well in advance. As can be appreciated in Figure 1(a), the system margin is now falling to levels that were observed when Colombia suffered significant blackouts between 1992 and 1993 and when there were threats of outages during 1997-1998.

The principles behind the pool in the CEM are to provide long-term economic signals for capacity expansion and service reliability. In order to satisfy these principles CREG developed the capacity charge (CC) mechanism (CREG, 1996; 1998), and reservoir interventions when water levels fall bellow certain threshold. These limits are imposed on reservoirs to secure short-term reliability. The CC is a payment given to those generators that provide, according to a predefined procedure[1], reliability to the system. The reference value for the CC is estimated as the cost of installing one kW of an open cycle gas generator. The CC has been established at 5.25 US$ per kW. It is collected in the pool and becomes the lowest pool price. The CC is allocated by using a long term model with specific conditions according to regulations: Resolutions CREG-077, CREG-082 and CREG-111 of 2000 (CREG, 2000).

The following section discusses the modelling framework that has been built to asses the effect of the new CR mechanism that has started operation since 2007.

3 The modelling framework to assess alternative regulatory options in CEM

3.1 Methodological discussion

From a regulatory perspective, the electricity industry has been dominated by a number of uncertainties at all levels, so stability has been an important objective. The regulator's task is far from simple. The regulator strives for a balance between all stakeholders and particularly between two of them: suppliers and customers. From a simplified perspective, the regulator may pursue goals to attain intensity in competition so that prices will reflect the incremental industry cost, with clear signals for effective system expansion to satisfy demand at competitive prices and good electricity quality.

Electricity markets face uncertainties and complexities which create difficulties for modelling; where optimisations seem often unfeasible alternative, behavioural methodologies are more likely to address a number of issues involved. Modelling causality and delays become an important practice to account for policy effects on the system. In particular, this modelling may indicate the need for continuous adjustment of the regulatory framework in order to attain the desired system behaviour. Modelling causality and delays also help investigating whether policies trigger instabilities which may affect system performance. System dynamics modelling is a tool which incorporates these elements.

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[1] The CC is estimated based on an indicative plan developed and executed by the Ministry of Energy and Mines. A set of the worst scenarios is run to determine the "optimal" capacity payment and distributed among those generators that provide reliable energy (Larsen *et al*, 2004).

System dynamics has been used to explore different policy issues during the last decades (Bunn and Larsen, 1992; Nail, 1992; Dyner *et al*, 1995; Bunn *et al*, 1997; Dyner and Bunn, 1997; Ford, 1997; Ford, 1999; Dyner, 2000; Ford, 2000). With a system dynamics model, it is possible to analyse and assess system behaviour under alternative regulatory options.

An electricity system depends on its generation, transport and supply characteristics. It possesses underlying dominant structures. Behaviour is influenced by physical, technological and topological considerations. Other *softer* structural aspects such as institutions, policies and regulations have both short-term effects on behaviour and a long-term impact on the physical structure of the system, which reinforce system evolution. Figure 2 indicates the main macro structure dynamics of such electricity systems. In this case, the system dynamics model takes the form of a system dynamic platform for policy analysis as explained in (Dyner, 2000).

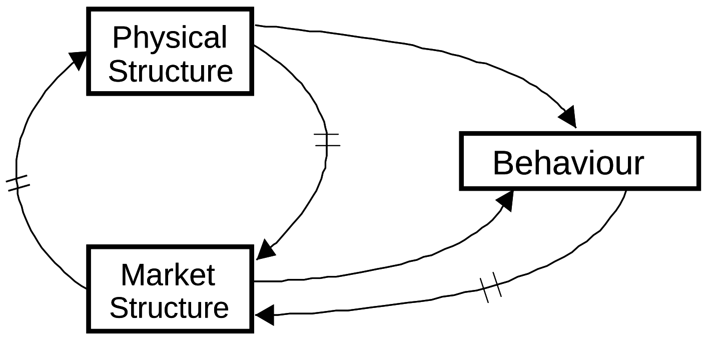

Figure 2. Macro-structure dynamics of electricity systems (Source: Dyner (2000); Arango (2007)).

3.2 The model

The model was built to address some of the problems that the Colombian Electricity Market is confronting. The main objective is to asses a regulatory option. The challenges describe before led to the development of a system dynamics model, which takes the form of a system dynamic platform (Dyner, 2000). It allows simulating the Colombian electricity market from the regulator point of view. All the parameters were estimated from public data. It was designed at a relatively high level of aggregation compared to the other detailed production simulation models (see Appendix B in Ford, 1999). For example, the simulation makes progress on monthly basis, while the market operates on hourly intervals.

The causal diagram presented in Figure 3 provides a general overview of the model. There are several feedback loops taken into account. The investment loop is the one that takes into consideration investors' behavior. It presents how investments take place in the model. The dispatch offers market prices as output and prices are signals for investment and market development. Following, there are investment decisions which will increase installed capacity after a delay. The new installed capacity changes the topology of the system and therefore the economic dispatch.

The regulator assesses the system behaviour by following the economic dispatch of the system. Consequently, the regulator adjusts in the long run the market rules and investment incentives. The market rules determine the bidding price and investment incentives influence the investors' behavior and therefore installed capacity. Note that the hydrology influences both bidding strategies and installed capacity, since it determines water availability. The hydrology is an external factor. Next, we present a more complete description of the different components of the model.

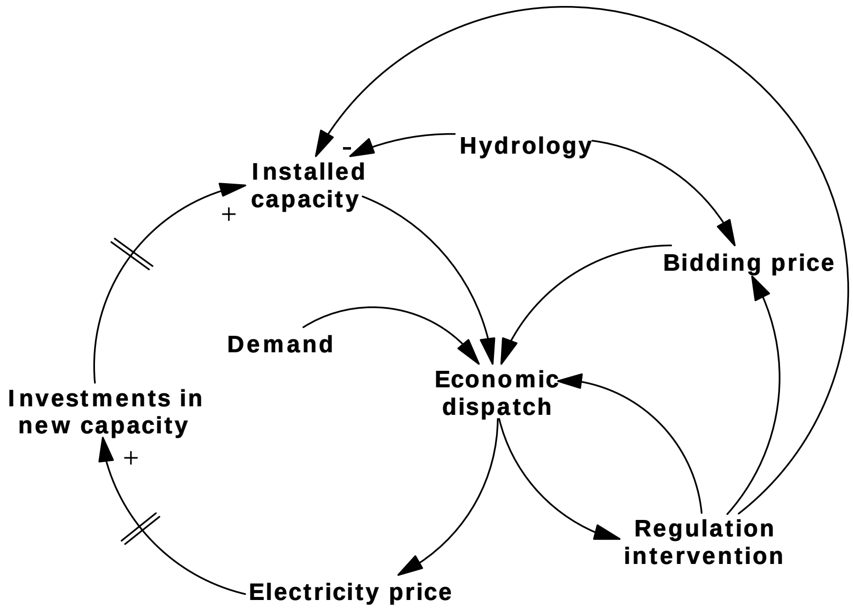

Figure 3. General causal diagram of the system dynamics platform for policy analysis in the CEM (Source: Arango (2007)).

Demand for electricity

Electricity demand is set according to the scenarios defined by UPME[2] (2006). Three scenarios have been defined: low, intermediate and high. The intermediate scenario was taken as baseline for simulations. The demand scenarios drive energy growth. The model represents the electricity demand as monthly energy requirements. Hourly and daily volatility is discarded, but the model includes seasonal variations. The model incorporates the power pool, a clearing mechanism, as it actually operates in the Colombian Electricity Market.

[2] UPME: Unidad de Planeación Minero Energético. A bureau of the Ministry of Mines and Energy in Colombia (www.upme.gov.co).

The power pool operates as a central electricity clearing-house to dispatch generation to meet electricity demand. Generators submit daily bids which are supposed to be based on their short-run variable costs. Note that there is not demand-side bidding, as demand does not actively participate in the market, in spite of its importance (Ford, 1997). If the pool cannot satisfy demand, there will be outages and contingent plans will be undertaken. This implies that the market clearing price will be set at the cost of the most expensive generating unit needed to meet total demand. Under these circumstances, the model accounts for the demand that is not satisfied and price will increase according to the maximum bid.

Power capacity

The model disaggregates installed capacity according to four technologies. These are Hydro, Thermo, Run of River and Coal. Hydro technology represents all the hydro generators with reservoir, which are modeled with their particular physical structure. Run of river are hydro generators without reservoir. Gas and Coal plants are treated similarly, assuming fuel availability. Other technologies are negligible.

The market price and economic dispatch model

The Market Price (MP) is determined by an economic dispatch that resembles the pool price mechanism of the Colombian electricity pool. Every technology has its own supply curve for each particular month, under particular macroclimatic conditions. The model takes the four supply curves and makes horizontal additions in order to get the industry aggregated supply curve. Once demand equals supply the market clears as presented in Figure 4.

Generators bid prices and quantities to the pool. It is expected that bids include not only the CC, but also the costs of generation. Supply curves were estimated as average of all generators and all bids, taken historic data since the beginning of the market. The supply curves are aggregated by technology, seasonal and macroclimatic conditions. See the reference for details (UN-COLCIENCIAS-ISA, 2000; Zuluaga and Dyner, 2007).

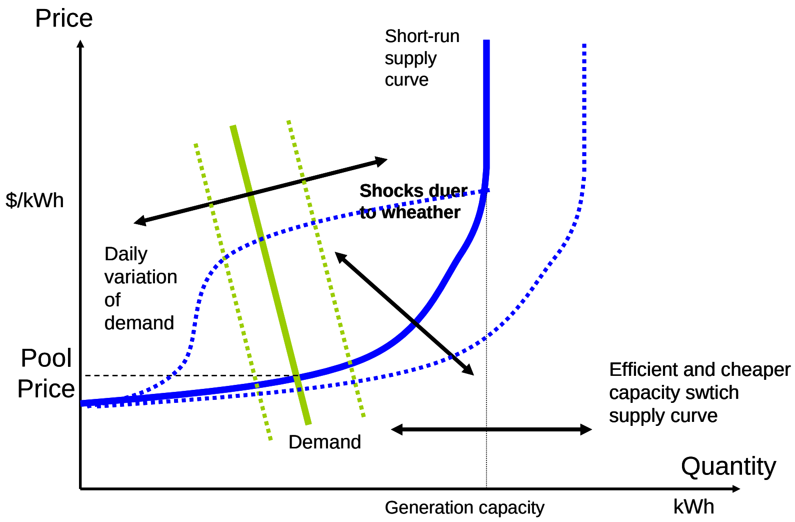

Figure 4. Market clearance and movements of *supply* and *demand* curves

An inverse process is followed to estimate the dispatch of each technology. Once MP is estimated, electricity quantities are calculated for each technology. Note that the total generation of each technology will result from the economic dispatch plus the minimum generation for the technology.

MP is given in terms of US$/MWh; it represents the hourly average electricity price during a month. The process is repeated every time step during the simulation period. This method of establishing price has been tested under a variety of conditions. Thus, a reduction in the supply leads to an increase in market price, and a gradual increase in electricity demand leads to a gradual increase in market price.

Note again that electricity demand is represented by a monthly average expressed in MW. Consequently, the model does not keep track of the hourly or daily demand variations. Thus, we must use the monthly average price as a market price.

Investment in new generation capacity

Investors may select from the projects registered by UPME. Thus varies from large scale hydro power generation projects to different sizes of OCGTs (Open-Cycle Gas Turbines). This paper focuses on OCGTs and hydroelectric projects already registered in UPME.

The investment behavior in the model takes a Real Options approach. According to the Real Options methodology, the “critical price” –P*– is the price level at which it is profitable to have a project under consideration (Dixit and Pindyck, 1994). The P* values were estimated externally (UN-COLCIENCIAS-ISA, 2003). Investors consider a number of variables, including pool prices, supply-demand balance, technology characteristics and investment incentives. We assume that these elements are computed into the Expected Price (EP). The EP is therefore interpreted as investors' expectations of market development.

The investment decision rule is a comparison between P*, the price at which the project is profitable, with the EP, the investor expected price. Thus, if P* > EP, there is an investment on the project with lower P* as long as it satisfy the minimal entry time (construction delay). Thus, the most profitable project will be the first to be constructed. The model assumes that investors are continuously monitoring market development and price behavior, and therefore the decision rule is applied monthly. The model satisfactory replicates the past investment decisions during the period between 1998 and 2004 (Zuluaga and Dyner, 2007).

Hydrology: Water Inflow and ENSO

The hydrology module contains two parts. One is the model that simulates water inflows into reservoirs. The other is a model of occurrences of the ENSO phenomena. The water inflows component uses a stochastic autoregressive model depending on the occurrence or not of the ENSO phenomena. The ENSO one is modelled by backwards sample techniques, which takes advantage of the more than 100 years of data available for the phenomena and replicates past occurrences. Both components are extensively documented in UN-COLCIENCIAS-ISA (2003).

Validation considerations

Despite the number of assumptions and constrains, the model satisfactory replicates historical market behaviour in terms of prices (Figure 5), generation, water level and investments (UN-COLCIENCIAS-ISA, 2003). Moreover, it resembles oscillatory patterns expected in electricity markets – boom and bust (Bunn and Larsen, 1992; Ford, 1999; and IEA, 1999). The model was developed in Powersim[3], which includes connections to external data. Follow up research has used this system dynamic platform at the Energy Institute at the National University of Colombia. Thus, the model has been tested in connection with other projects. Following, we turn to show simulation results of system performance under the RC mechanism.

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[3] Powersim Constructor 5.1. See the webpage for details www.powersim.com.

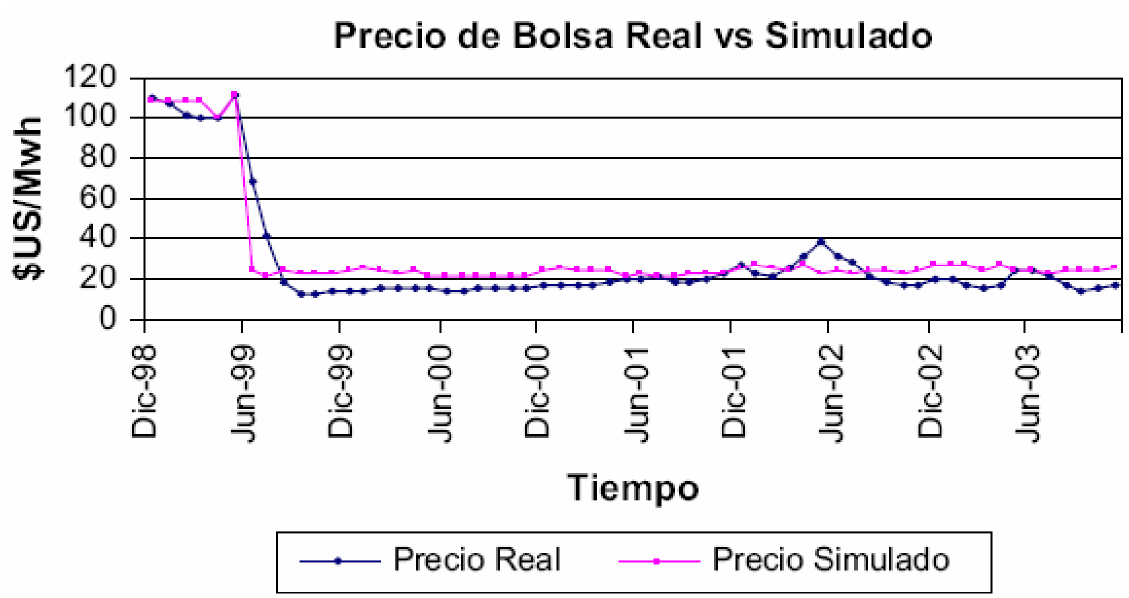

Figure 5. Simulated vs. real pool price

4 Policy analysis and simulation results

In this section we simulate possible outcomes of the *reliability charge* mechanism that has been implemented in Colombian market since the beginning of 2007. The model allows the use of different metrics for the evaluation of this regulatory option, including price variations (volatility), generation capacity according to technology, and system cost.

4.1 Simulating the *reliability charge* (RC) mechanism

This is a market oriented solution to the problem of security of supply and is based on standard financial instruments designed for financial markets. The basic idea is to create financial and a tradable instrument intended to protect buyers from sudden price increases, at the expense of a premium which the buyer pays monthly. The RC replaces the CC with a market mechanism that reflects the value set by the interactions of the interest groups involved. It includes both demand and supply, while the regulator only sets the market rules and some parameters.

The main objective of the RC is to induce supply reliability (IEA, 2002). The RC is a payment to generators for firm energy. The value is set by the regulator in the transition period, but there would be auctions after 2010. The obligation to supply firm energy works as an option, where the generator has to supply energy once the pool price is higher than the strike price. The demand to be covered with obligations is set by the regulator.

The RC is a financial instrument to be traded as *call options*, which provides the buyer the option to buy energy in the pool at a given *strike price*. In compensation, the demand (or buyer) must pay a *premium price* to the seller. The generators are the sellers and the demand is represented by buyers (distributors and traders). However, demand is not active in the process. The generator must compensate the demand in case the pool price is higher than the strike price; the generators also have a commitment to provide the electricity agreed upon in the option. The options are traded in a public auction, where all the demand must be covered. The market is expected to define the price that electricity customers are willing to pay for reliability by clearing demand and supply. Thus, the price should move up and down according to the balance of demand and supply. Note that there is no need for external models that may complicate market rules. In this case, each generator has to discover how to build a portfolio of plants to guarantee power supply to its customers. In this manner the market will find the appropriate technology mix to reduce the probability of electricity blackouts. The electricity price received by generators is:

RC = PR + min(PP,SP)

where PR is the option price or what is called the *Reliability Charge*, PP is the electricity pool price, SP is the strike price and RC is the *Reliability Charge*; all measured in US$/MW. Note that the generators receive the extra revenue due to the option price or premium (RC). As in the model we use the historical supply curves to estimate pool prices. The strike price and premium would be set by the new market.

We now present the simulation results of the base case. Figure 6 shows simulations of market prices and dispatch by technology for the coming 10 years. We observe that the option market manages to spread rewards to producers, reducing peaking prices during periods of low water inflow, as it occurs during El Niño periods. Customers benefit for the same reason, and therefore, the pool price would experience a reduction in volatility. We also observe the upward tendency of dispatching hydroelectricity plants compared to Gas and Coal ones that remain in the same range of variation. We may observe that the options market benefit customers in the long-run by smoothing the effect of El Niño, but increases the cost of electricity in the short-term.

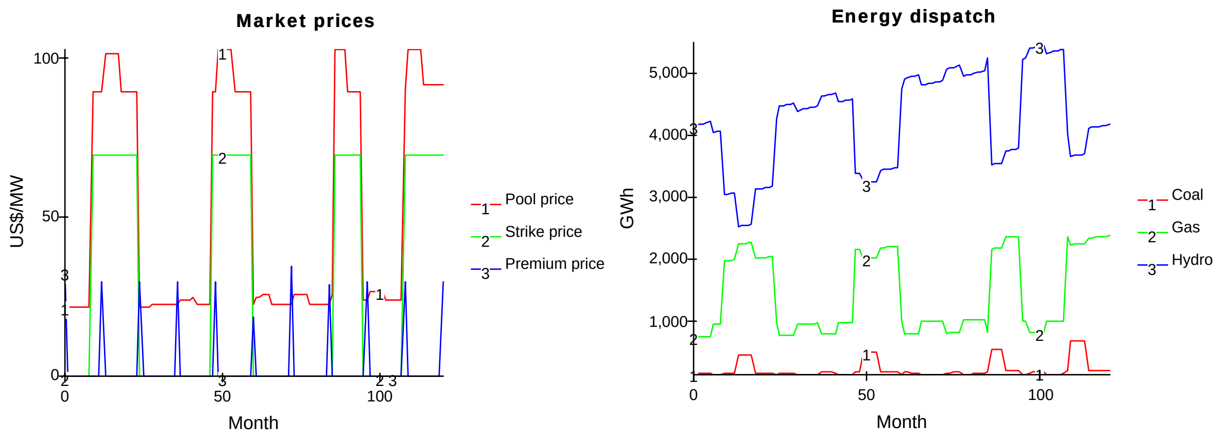

Figure 6. Market prices and dispatch by technology with the current RC.

Figure 7 shows the evolution of the installed capacity and system margin under an intermediate demand-growth scenario. We observe that investment increases, especially in gas generation. We observe an upward tendency through the simulation. The system margin increases after an initial reduction, but it begins to fall again at the end of the simulation period.

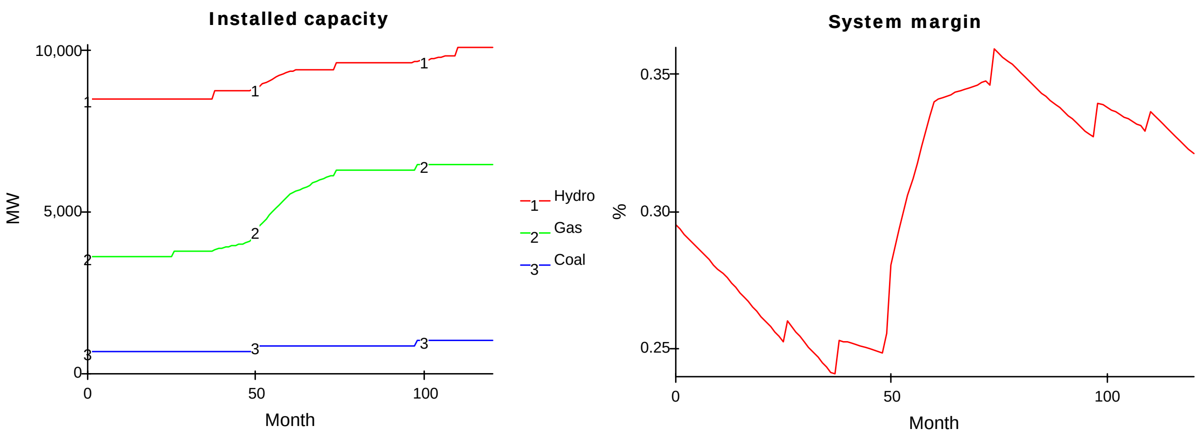

Figure 7. Installed Capacity and Margin of the system

Results suggest that the RC mechanism might be effective to induce investments. New capacity is brought on line and increases the system reliability. However, simulations indicate that the Colombian Electricity Market might rapidly reduce its margin, as the application of this regulation mechanism might be slightly late. If the system suffers an El Niño similar to the one registered during 1997-1998 blackouts may take place.

Figure 8 shows sensitivity analysis under different demand-growth scenarios. As observed, under the highest demand scenarios the likely occurrence of blackouts increase while under the slow demand-growth scenario the occurrence of outages is reduced.

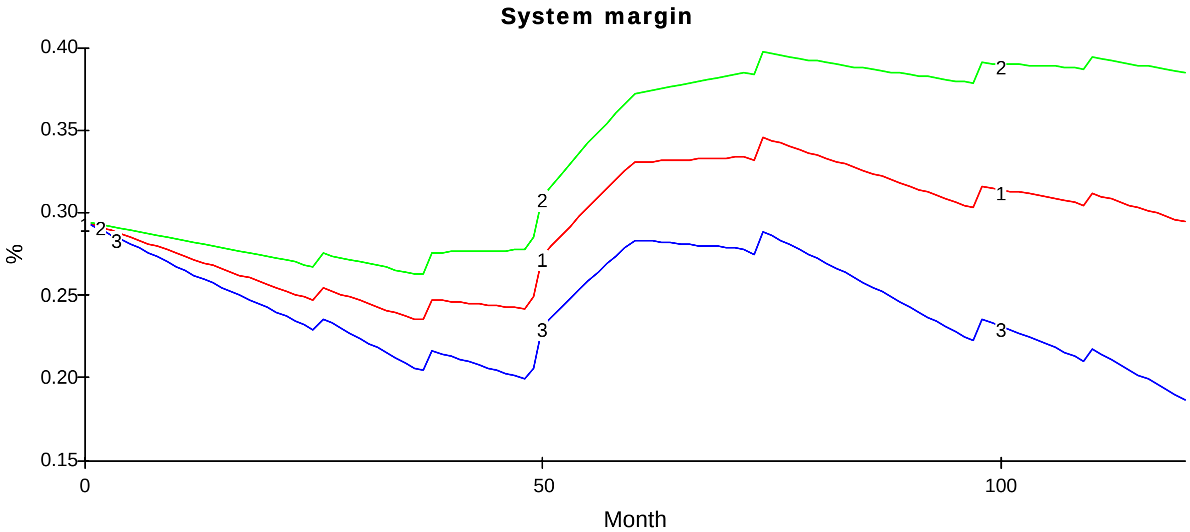

Figure 8. Installed Capacity under different demand scenarios (1. Base; 2. Low; 3. High)

New investments could unsafely cover, with some delay, what the system requires in terms of capacity. Regulators should have taken this into consideration as was suggested by analysts and consultants (TERA, 2001), institutions (Millán, 1999), and academics (UN-COLCIENCIAS-ISA, 2001). In the mean time, demand side management should be considered to reduce the possibilities of blackouts.

As expected, RC reduces volatility of pool prices. However, the yearly auction with long term contracts of the RC may reduce competition in the option market and new capacity may only come on line with some time delay.

5 Final discussion

The CC has expired in 2006 and a different alternative has been implemented. We have initially assessed the RC mechanism now in place by using a simulation platform in terms of its reliability and price to customers and volatility.

The new alternative favours thermo electricity. We have observed that the signal resolves the problem of new capacity, since new investments should become available. Nevertheless, the RC might result late in its application. New investments may come just after supply problems emerge, if one *strong* Niño occurs. Thus, the regulator should be aware of the potential problem that may emerge in case that an ENSO occurs. The ENSO is not predictable; thus, the regulator should be prepared in advance to avoid outages.

The simulation model is not intended to be a finished product. Improvements could be made by including the grid in some detail, by taking a different approach to the load curve for demand during the day, or by using a different investment behaviour model. Follow up research has used the system dynamic platform presented in this paper. The Energy Institute at the National University of Colombia has used the model in different research projects, such as the Microworld for electricity investments in Colombia (Arango *et al* 2002) and it was also adapted by some Latin-American countries (UN-COLCIENCIAS-INTEGRAL, 2000), to explore the potential of wind technology in the CEM (EPM-COLCIENCIAS-UN, 2004). Thus, the model has been tested in connection with other projects.

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