

MODELING GENERATION EXPANSION IN THE CONTEXT OF A SECURITY OF SUPPLY MECHANISM BASED ON LONG-TERM AUCTIONS. APPLICATION TO THE COLOMBIAN CASE

P. Rodilla*, C. Batlle*, J. Salazar**, J.J. Sánchez***

Abstract

In a search for providing investors in electricity generation with appropriate economic incentives so that quality of supply is maintained at socially optimal levels, a growing number of electricity market regulators have opted for implementing a security-of-supply mechanism based on long-term auctions.

In this context, being able to anticipate and analyze long-term investment dynamics is a key issue not only for market agents, but also for the regulator. In this paper, we describe a model developed to serve for this purpose. We have designed a general methodology capable of facing the analysis of these long-term auction mechanisms in the different formats already implemented. To illustrate the model capabilities we have developed a real-size simulation based on the Colombian system.

Keywords: Security of supply, long-term auctions, electricity market modeling

1 INTRODUCTION

Though motivations may differ in each specific case, the universal *leit motiv* in electric power industry reform has been the need to seek new vehicles, new regulatory models, to channel the necessary strategic expansion of electric infrastructure in general and generation facilities in particular. Since the very beginning of the power systems reform process back in the eighties, the question posed has been whether the market, of its own accord, is able to provide satisfactory security of supply at the power generation level or if any additional regulatory mechanism needs to be introduced, and in if so, which is the most suitable approach to tackle the problem. No international consensus has been reached in this regard, but as time passes, an in-depth analysis of the electric power systems worldwide, see (Batlle & Rodilla, 2009), shows that in almost every electricity market, in one way or another, the regulator has designed any kind of rule to drive or put boundaries to the natural market evolution in an attempt to guarantee supply in all terms.

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Long-Term auctions as mechanisms to ensure security of supply

The theoretical orthodox reason justifying the liberalization process at the generation level was mainly to promote efficiency at all levels: operation, planning & expansion. However, this objective cannot be fully achieved unless risks are allocated efficiently among the different agents. Power generation investment decision-making risk is high and failures¹ are likely. Risk, although to a lesser extent, also plays a key role in the resource management decision-making process.

Under the market-oriented paradigm, the new regulation must make sure that the appropriate economic incentives exist for each one of the activities so that quality of supply is maintained at socially optimal levels. Precisely in a search for providing investors in generation with these incentives (the extra income or the hedging instruments they require to proceed with investments), a growing number of electricity market regulators have opted for implementing a security-of-supply mechanism based on long-term auctions.

Although every security-of-supply mechanism presents its particularities, roughly speaking, this approach entails assuring new entrants an extra payment or hedge for some years from the time they become operational. In the particular case of the auction-based approach, the market authority buys (or orders the Load Serving Entities to buy) in a public auction on behalf of the demand all (or at least a partial hedge over) the expected consumption for a number of years. This asset/instrument/product, the so-called reliability contract, can take different formats, ranging from a fixed payment in exchange of the guarantee of producing in scarcity periods, e. g. the so-called reliability option, see (Vázquez, 2002), to a more “plain vanilla” energy supply future contract (e. g. a sort-of contract-for-differences).

Main design elements of the reliability contracts auctioned

The design of this reliability contracts conditions critically the final outcomes of the mechanism (Batlle & Pérez-Arriaga, 2008). And in this sense, two key elements can be distinguished: the time terms and the measure that allows evaluating the contract fulfillment.

- First, since the objective is to provide investors with a sufficient hedge to carry on their projects, it is of major relevance to define adequate time terms:
 - the “lag period”, i. e. the existing time duration between the moment the commitment of deliverability is signed and the moment it has to be delivered. It is a key element to give time to the investors in a new generating unit winning the auction to develop the project (e. g. four years).
 - the contract duration, i. e. the number of years the compromise resulting from the auction lasts (e. g. ten years).

¹ By investment failures we make reference to those investments that do not maximize the net social benefit as much as other available possibilities would have. The uncertainty involved in the power sector investment decision-making process is the main responsible of these suboptimal (when evaluated ex-post) investments.

- Also, regulators must define a methodology to evaluate and provide consideration for each generating unit's actual contribution to system reliability. Two very simple (and simplistic) ways to measure it would for instance be "installed capacity" [MW] or monthly energy production [MWh/month]. But this definition is usually based on a measure of the availability of units during critical periods, when the likelihood of scarcity is highest, what leads to referring to such a measure as "firm supply" which, depending on system requirements and the specific details of the incentive, is termed "firm capacity" (Spain), "firm energy" (Brazil), "adequacy capacity" (Chile) or even "efficient firm offer" (Guatemala).

These long-term auction-based mechanisms are supposed to guarantee to a large extent the investments required to maintain an adequate and stable generation reserve margin. The agents' bids, along with the defined quantity of "firm supply" the regulator deems necessary to ensure future supply, determine the resulting price of the reliability contract, i. e. the hedge that allows them to overcome their risk aversion and make the financing of their projects feasible.

As stated, mechanisms of this sort have been already implemented in a significant number of electricity systems², for instance in Brazil, Colombia, Chile, Peru in Latin America or New England and PJM in the US³.

The need for models to allow analyzing security-of-supply long-term auctions

In this context, being able to anticipate and analyze long-term investment dynamics is a key issue not only for market agents, but also for the regulator. In the case of this latter, this analysis should support the auction design process, in order to ponder the impact of the different elements that configure the reliability contract (lag period, duration contract, optionalities, penalties, etc.), since it has been fully demonstrated how the contract definition and some other characteristics of the mechanism, if not carefully designed, may sometimes lead to undesired results.

On the market agents' side, the need for tools to support the decision making-process in face of these auction mechanisms is evident. This new market framework makes simulation models a necessary tool to analyze the suitability of an investment in a new generating facility as well as to help defining the most suitable strategies to be followed in the auction.

In this paper, we describe a model developed to serve for this purpose. We have designed a general methodology capable of facing the analysis of these long-term auction mechanisms in the different formats already implemented.

The model is inspired on the system dynamics methodology (Sterman, 2000). System dynamics is one of the modelling techniques which has succeeded in analysing long-term

² See (Batlle & Rodilla, 2009) for a detail enumeration and discussion of the different mechanisms implemented worldwide.

³ No European market has yet implemented a solution of this nature, but the Directive 2005/89/EC explicitly foresees that regulators could resort to them if needed ('the possibility of imposing public service obligations on electricity undertakings, inter alia, in relation to security of supply').

dynamics of liberalised systems, particularly in representing the way the new generation capacity enters into the market. There are different approaches on how to accommodate this theory to the long-term analysis of electricity systems, see for instance (Ford, 1997), (Ford, 2002) (Bunn & Larsen, 1997). In particular, system-dynamics-based models have been proved to be useful to identify and characterize the so-called boom-and-bust investment cycles that tend to lead the generating investment decisions in the absence of any additional adequacy regulatory mechanism, and they have also been used to analyze the influence of different regulatory long-term security of supply mechanisms, see for instance (Bunn & Oliveira, 2001) and (Park *et al.*, 2007).

Next, in section 2, we describe the main features of the model design. The model is inspired by the guidelines and the basic structure of the approach described in (Sánchez, 2008). Some key additional refinements have being developed so as to be able to cope with the complexities stemming from the particular characteristics of the different electricity systems structures and market and auction designs. This way, we have for instance introduced a multi-scenario analysis tool or an approach to assess new hydro plants investments.

Then, in section 3, in order to illustrate the potential of the methodology, we present a real-size case study to analyze the long-term results obtained from the application of the model to simulate the evolution of the long-term generation expansion in the context of the Colombian Reliability Charge Auctions. The reason behind choosing the particular case lies in the fact that it constitutes the richest example available, since it gathers a market structure in which several technologies compete for entering the system (hydro, coal, gas, fuel) and the most sophisticated auction design (aimed to deal with such technology diversity).

2 METHODOLOGY DESCRIPTION

2.1 Model overview

It has been mentioned that the long-term auction-based mechanisms are supposed to ensure the investments required to maintain an adequate and stable generation reserve margin. This way, the *boom-and-bust* cycles that characterize generating investment decisions in the absence of any additional adequacy regulatory mechanism are expected to disappear. This also leads to a reduction of the price volatility, since scarcities are expected to be considerably reduced as well. However, this is far from meaning that there is no uncertainty at all.

Under this type of regulatory mechanisms it is still of the utmost importance for market agents to be able to estimate the future market functioning under the influence of the auction-based security of supply mechanism. The final objective is to anticipate the expansion portfolio structure in the future, in order to allow the regulator to envisage the future evolution of the system, and also on the market agents' side, to assess the profitability of their potential investments. It is in response to this necessity where forecasting tools can play an important role.

Therefore, we have developed a system-dynamics-inspired methodology also benefiting from a short-term game-theory model. This latter model simulates electricity market agents' interaction in the spot market, reflecting market agents' strategies, supply function

building and market clearing, and providing the future market outcomes (prices and productions).

Figure 1 gives a first and simplified conceptual overview of the model. It consists of three differentiated modules, which are mutually linked as shown in the diagram.

- First we represent the regulator's decision-making process, which serves to assess the necessity for calling an auction to sign new reliability contracts with generators so as to hedge future demand requirements. This module also determines the demand curve, i. e. the price-quantity curve that the regulator calculates on behalf of the demand to reflect the utility function (the maximum value/prices of the contracts to be bought).
- The second module is aimed at calculating the curves the generating companies (or GenCos) bid in the auction. This second module comprehends the core of the model. As shown in the figure, the game-theory spot market model, used to simulate the short-term market functioning, is embedded as a part of this module.
- Finally, the last module calculates the long-term auction matching and updates all the relevant variables involved (new generating units entering in the system as a result of the auction, new debt issued by the GenCos, etc.).

These modules are executed sequentially on a year-by-year basis. This way the cyclical process simulated includes the determination of the demand requirements, the assessment of new potential investments and the calculation of their bids in the auction, and finally the clearing.

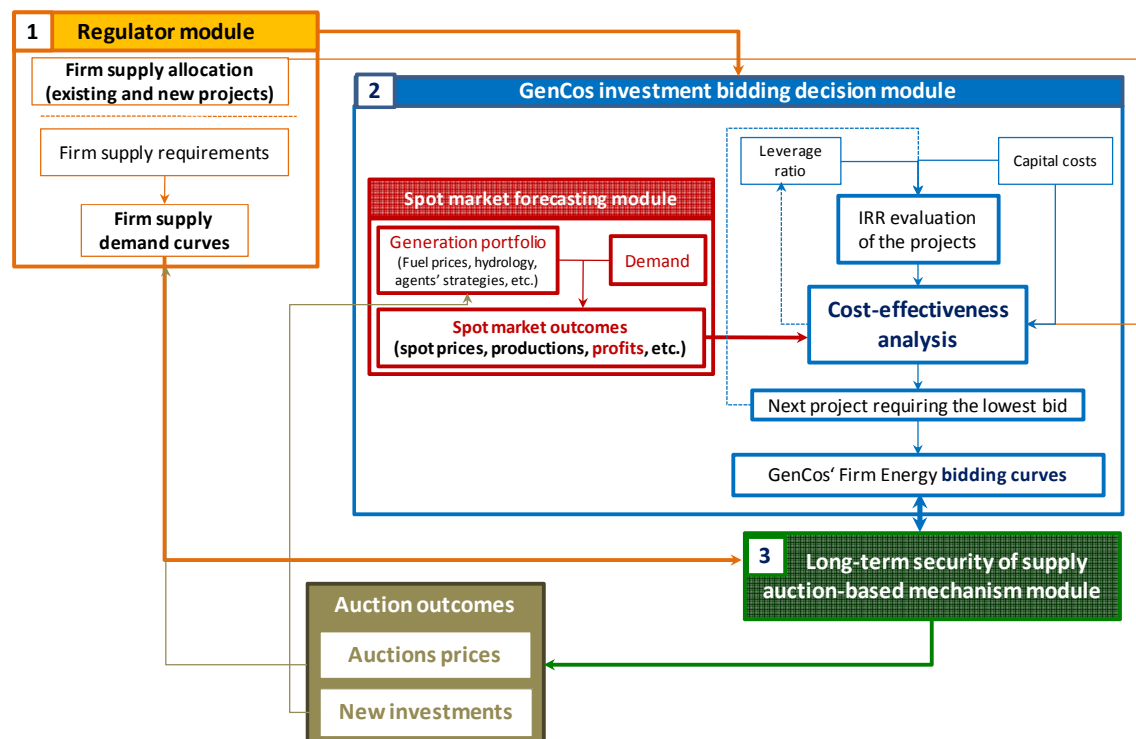


Figure 1. Model diagram

Next we delve into a more detailed description of these three components.

2.2 The regulator module

The condition to call an auction

The model performs this assessment annually (as regulators do in real life); taking into account the lag period defined in the contracts. The regulator calls a long-term auction with the objective of acquiring enough contracts of the reliability product (for instance energy swaps or financial options or any other long-term instrument) so as to hedge the future supply of electricity. Therefore, these auctions only make sense when there is a negative imbalance between the quantity of reliability contracts already contracted (in former auctions) and the expected future requirements, in other words, if at one point in time the regulator considers that the market, left to its own devices, is able to provide sufficient generation availability when needed, there is no need to implement an auction.

Firm supply allocation criteria

The firm supply assigned to each plant represents the amount of the reliability contract⁴ that the regulator considers, according to historical values or future estimations, that each unit is capable of providing under scarcity conditions.

For instance, in the Peruvian case, hydraulic units are allocated the 95% percentile of the production the unit is capable of producing during the critical period (considering that the unit produces at full capacity seven hours every day).

The reliability product demand curve

Once the regulator has estimated the future needs, i. e. the quantity to be purchased in the forthcoming auction, the next step consists in calculating the demand curve.

In some systems (Colombia, NE, PJM, etc.) the curve representing this requirement is expressed as a piecewise linear function. A particular case of the demand curve, indeed the simplest one, consists in just determining the requirements and the so-called reserve price of the auction, as is it the case of the long-term auctions implemented in the Peruvian case.

2.3 Investment bidding decision module

Prior to the description of the algorithm used to simulate the generators' bids building process, we briefly outline four major assumptions that have been considered:

- First, from the generators perspective only two sources of income have been considered: the spot market and the long-term security of supply auction. Thus, we do not take into account other possible sources of income such as markets for ancillary services.
- Second, in the simulation it is implicitly considered that a new generating plant is only able to enter the system after winning a long-term auction. Even though under certain conditions a plant may be profitable by just perceiving the spot market income, it does

⁴ For instance, energy produced in an hour in which the spot price exceeds a certain threshold, as it is the case of NE-ISO, or in a whole day in the Colombian case.

not seem plausible that investors will lose the opportunity of receiving the stable additional payment provided by the security-of-supply mechanism.

- Third, the bids of the generators are calculated so as to obtain the so-called break-even position, in other words, bids are computed in such a way that the full recovery of the cost of capital plus an adequate rate of return is ensured. Therefore, no strategic bidding (as withdrawing potential investments in new capacity) is considered in the long-term auction⁵.
- Fourth, all the investment costs associated to a new project are assumed to be completely financed by issuing new debt.

When modeling long-term dynamics under an energy-only market scheme⁶, the main criterion driving the generation investments has been usually based on the expected profitability of each project, typically measured by means of the Internal Rate of Return (IRR in the following). Under such approach, it is obviously necessary to analyze in each case the expected cash flows along its life span. Under the long-term auction scheme, this approach is no longer valid, since the cash flows cannot be determined until the auction has been cleared. Here we have opted for inverting the traditional methodology, by first determining the IRR required by a new project and later calculating the bid that would ensure such profitability.

The internal rate of return (IRR) required to a new project

The profitability that each agent requires to a new potential project is calculated by means of an empirical function relating the IRR required and the leverage ratio of the company (the IIR function hereafter).

The IRR functions used within the model present the characteristics shown in Figure 2, in which the rate of return required grows as the company's leverage ratio increases. In the figure it can be observed that there exists a leverage ratio saturation level that cannot be surpassed⁷. The function has to be adjusted for each agent independently, so as to capture the existing differences with respect to their investment possibilities (due to their size and their financial structure). The advantage of using empirical functions lies on their

⁵ In the context of a long-term auction there are three major effects derived from the strategic withdrawal of the possible new investments: first, the price in the auction rises, second the price in the spot market is also higher since scarcity periods are more likely to happen, and third, this price increases may encourage in the end other competitors to invest. The latter effect tends to compensate to some degree the benefits that could be achieved by just the mere price increases observed in the short-term and long-term markets. The reason is clear: those with the ability of benefiting directly from withdrawing some investments see how their market share can be seriously reduced, and consequently its former capacity to exercise market power (Sánchez, 2008).

⁶ Although the term "energy only market" is a little vague, it is commonly used to refer to those markets in which no mechanism is imposed by the regulator to guarantee a reliable supply.

⁷ There is a strong theoretical support for such dependence that can be explained by means of credit risk theory, see (Sánchez, 2008).

ability to represent most of the variables influencing companies' decisions in a very compact and simple way.

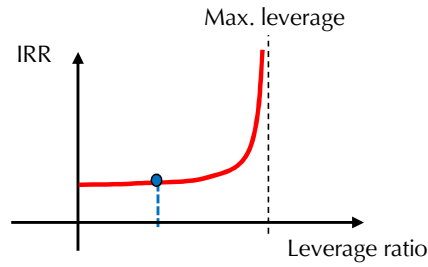


Figure 2. IRR function of a new project

In the simulation model this function is continuously updated, so as to allow every company assigning a different IRR to each one of the projects being bid within the same auction, since entering into a new project alters the financial structure of the company.

New projects representation

Each new potential project has been characterized by several parameters, among others: its maximum capacity (MW), its variable cost (\$/MWh) throughout the whole simulation scope, the firm supply value assigned by the regulator (MWh or MW, depending on each particular case), its capital costs, its construction period and life span and its unforced failure rate.

In the particular case of new hydraulic projects, it is also necessary to introduce as an input data the energy (MWh) expected to be produced in each month. This production is expressed as a linear function of the energy produced by those hydro plants which were already installed at the present time. The reason to make this approach is that it is easier to find data regarding historical hydrology conditions of existing units, and this information is essential when computing future scenarios. In the model, several scenarios of energy availability can be considered within the same simulation execution.

The algorithm to determine bidding curves

To build bidding curves of the generators we follow the iterative procedure represented in Figure 3, which consist of the following steps:

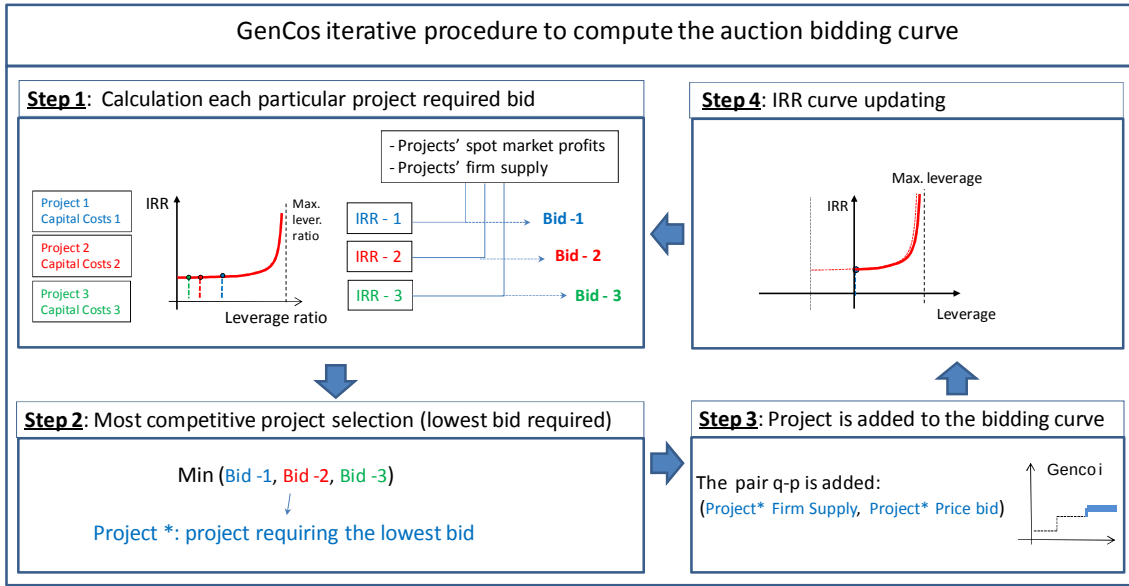


Figure 3. Iterative procedure to compute the auction bidding curves

- Step 1: calculate the individual bids that ensure the break-even position of the potential new projects.

For each firm, considering the financial structure, we calculate the IRR of the new potential projects being evaluated by the firm. This is carried out by making use of the IRR function already introduced. Based on this IRR and also on the expected cash flow resulting from the spot market (computed using the game-theory simulation model described next) we determine the bids for the reliability contract.

- Step 2: identify the project with the lowest bid.

The most competitive project is considered to be the one requiring the lowest bid. This is the next project to be included in the bidding curve.

- Step 3: add these latter project to the bidding curve.

The firm supply of the most competitive project and its corresponding price bid represents the next pair quantity-price of the generator's bidding curve.

- Step 4: update the IRR function.

The IRR function is updated to take into consideration that if the company invests in another project, the new IRR increases.

Next we go back to the first step and repeat all the process considering the previous project until either we have run out of potential new projects⁸ or we have reached the investment saturation level (the maximum leverage ratio allowed to each company in the simulation).

⁸ It is possible to limit the number of projects in which a firm can invest in the same year. These limits can be imposed on a technology by technology basis.

Short-term market income forecasting: spot market price module

To represent the spot market price evolution we made use of the model SPCM (Strategic Production Costing Model), described in (Batlle & Barquín, 2005). This model extends the classic Production Costing Model approach to allow for a better simulation of agents strategies under a liberalized context, by considering the slope of the residual demand functions in the bids building.

Compared with other oligopolistic models, the main advantage of the SPCM lies on the side of its computational speed. This has been considered as a key feature in the long-term modeling for very long simulations are required when computing the different scenarios. We summarize the three main characteristics of the SPCM model next:

- The expected demand in each period (e. g. a week or a month) is represented by means of its load-duration curve.
- The energy to be dispatched by the hydro units in each period is determined by an exogenous model that provides hydro production scenarios. The production profiles of the plants within each period are calculated by means of an algorithm that peak shaves the demand monotone⁹.

Although this hydraulic dispatch represents the perfect competitive behavior, the hydraulic production is latter taken into account (on a company by company basis) as inframarginal production when calculating the strategic (oligopolistic) bids of the thermal plants.

The maximum and minimum output of the hydro plants are determined based on historical data, as a function of the energy produced during each week.

- The thermal units are scheduled along the monotone following a merit order given by their price bids. These bids are calculated internalizing the slope of the residual demand faced by each agent, considered as exogenous variables by the SPCM model.

The market model is executed considering different scenarios of hydrological conditions and thermal plants availabilities (using Monte Carlo), two uncertain variables that play a key role in the price formation of hydro-thermal systems market.

2.4 Auction module

Once we have calculated both the demand curve and the bid curves corresponding of the generating companies, we proceed to clear the auction. The main outcomes resulting from this module are on one hand the price to be paid (the auction marginal price) and on the other hand the winners of the auctions, i. e. new investments that enter the system.

⁹ Indeed, the peak shave algorithm is applied to the equivalent demand monotone. This equivalent demand is calculated by adding to the energy demand consumption the energy corresponding to non available units submitting bid prices below the resulting system's marginal price. This serve us to represent that identical load levels could lead to different marginal prices due to thermal plants failures. The availability of the units is computed on a time block by time block basis (where each time block represents 10 hours of similar demand over the monotone).

After simulating the auction, the leverage ratio of each GenCo is to be updated. This way, the IRR curve is modified so as to allow future assessments. The new plants have to be introduced into the system's generation mix with the corresponding lag period established in the regulation.

3 LONG-TERM SIMULATION OF THE COLOMBIAN SECURITY OF SUPPLY AUCTION-BASED MECHANISM

In this section, a real-size simulation aimed at studying the expected evolution of the Colombian generation expansion trend in the following decades in the context of a security of supply auction-based mechanism. First we briefly present the main elements of the regulatory design, then we describe the input data defining the scenario considered, and finally we discuss the results and the major conclusions obtained.

3.1 Ensuring long-term resource adequacy in the Colombian system: a brief description of the Reliability Charge Auctions

The so-called Reliability Charge Auctions were implemented in Colombia back in 2006 (the first auction was called on May 2008). The mechanism provides generators a fixed payment in exchange for producing in the critical periods (also known as scarcity periods) at a predetermined price (or strike price). Since a period is declared critical every time the spot price exceeds the strike price, the reliability contract (called Firm Energy Obligation) implies a commitment that takes exactly the form of a financial call option.

If the generator fails to comply with the committed production in such periods, it has to acquire energy in the spot market (so as to replace the shortage that avoids the fulfillment of the commitment acquired). Thus, the incentive to be available during tight conditions is high, since an implicit penalization for non compliance does exist.

Both the generators that receive such payments and the payments themselves are determined by market forces in a public auction. The quantity (the total amount of Firm Energy Obligations) to be purchased in the auction, that is, the energy that could be required to be produced every time a critical period is declared, is determined by the regulator (who acts on behalf of the regulated demand).

Prior to the auction, the regulator certifies the maximum quantity that each unit is entitled to offer in it, and thus, to commit through contracts. This upper limit, which we named previously as firm supply, called in this case Firm Energy for the Reliability Charge¹⁰, is calculated by means of some predetermined rules and algorithms that are set by the regulator.

The auction is carried out four years before the energy obligation could be exercised by the regulator (the lag period). The Regulatory Energy and Gas Commission (CREG) has to calculate whether or not there is an imbalance between the Firm Energy already contracted (in former auctions) and the expected demand consumption for the year being evaluated. Should this imbalance be negative, the Regulatory Commission communicates the decision of calling an auction.

¹⁰ In Spanish "Energía Firme para el Cargo por Confiabilidad" (ENFICC)

Different conditions apply to the different units depending on their characteristics:

- Existing plants: those plants already in operation at the time of the auction. The contract duration in this case is just one year, and these plants neither can set the price nor can be withdrawn in the auction (unless the auction price goes below a predefined threshold).
- New plants: those plants whose construction has not started at the time of the auction. The duration of the contract can be up to 20 years. These units are the ones presenting a quantity-price bid in the auction, and thus, they are the ones determining marginal clearing price of the auction.

In the Colombian case, most of new large-scale hydraulic projects require more than four years until they can be considered to be fully operational. To allow this type of projects (known as GPPS projects) participating in the mechanism as new entrants, special conditions are applied to them. After celebrating a standard auction, an additional auction is called for these GPPS projects, which can enjoy a lag period up to eight years. This auction presents the peculiarity that there is a reserve price (a price cap) that is set as the previous standard auction clearing price.¹¹

For further details about the rules governing the Reliability Charge mechanism, a comprehensive description can be found in (CREG, 2006), (XM, 2008) or (XM & BBVA, 2007).

3.2 Scenario definition

The simulation studies the spot market and the Reliability Charge Auctions evolution along a 25 years horizon, starting in 2010. It is assumed that the periodicity to call the auctions remains fixed, and thus, all standard auctions are to be called annually.

The Firm Energy demand function (see Figure 4) is based on definition of two parameters M1 and M2, considered constant all along the simulation time scope. The CONE (Cost of the New Entrant) is updated after each auction is cleared according to the formula provided in the regulation, that is, as the pondered value of the last CONE considered and the auction clearing price.

¹¹ In the simulation we considered the sequential nature of these two auctions, in order to incorporate all the information resulting from the standard auction (new investments and resulting price) in the GPPS auction. Some simplifications with respect these auctions were considered: all the potential GPPS entrants are offered the same lag period (8 years) and the same contract duration (20 years).

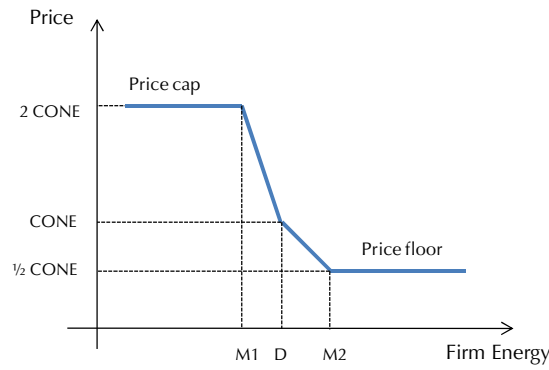


Figure 4. Firm Energy demand

It has been assumed that the demand growth follows the forecasting values provided by the report of the Mining and Energy Planning Unit (UPME, 2008). As shown in Figure 5, it has also been considered that the objective demand for Firm Energy Obligations follows a similar trend.

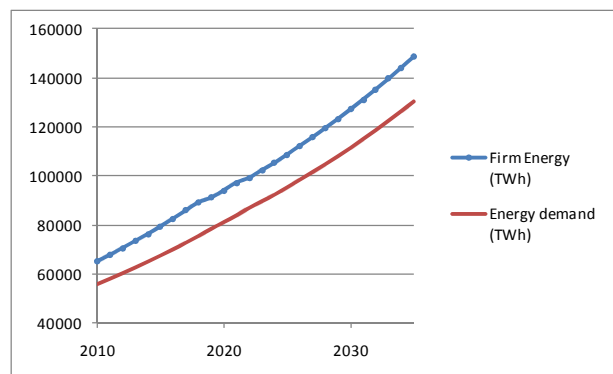


Figure 5. Expected evolution of the energy demand and the reference values of the Firm Energy Obligations to be purchased by the regulator

The evolution of the relation between the maximum demand and the average demand has been considered to take a constant yearly increment of 3%.

The series of the fuel prices follows the baseline scenario provided in the report of the Energy Information Administration (EIA, 2008). In Figure 6 it has been represented the fuel price evolution. Throughout the whole simulation scope it has not been considered any additional cost motivated by environmental reasons.

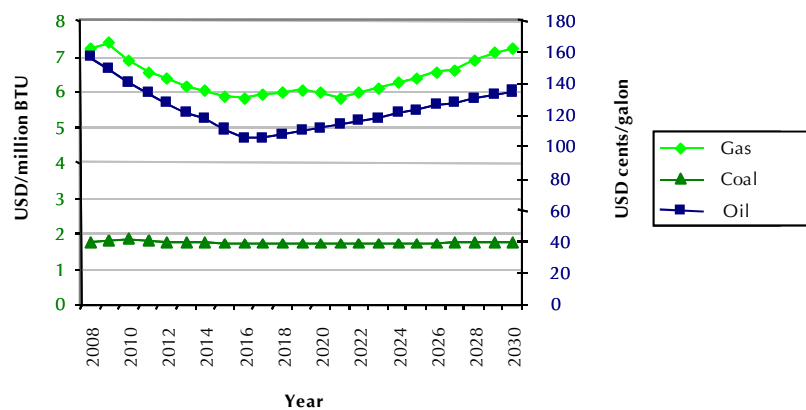


Figure 6. Fuel pricing forecasting scenario (source: base scenario of the EIA report)

When modeling the Colombian electricity market, it is of the utmost importance to represent the high dependency of the system on hydraulic resources. Moreover, the presence of severe (and difficult to predict) dry periods that occur during phenomena like the El Niño Southern Oscillation, plays a relevant role in the investment decision-making process. In order to introduce this hydraulic variability, three different scenarios of hydro resources have been considered.

The evolution of the yearly production corresponding to the hydro plants already installed in 2010 in the different scenarios considered, has been represented in Figure 7.

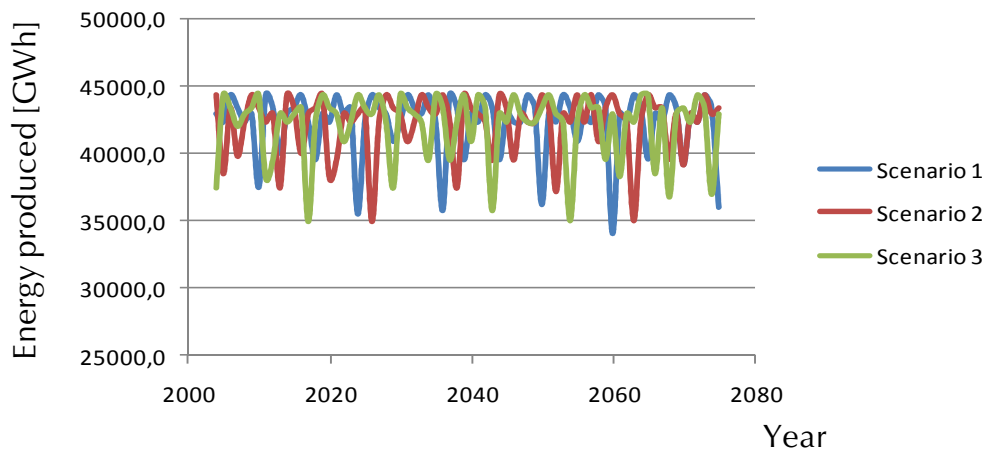


Figure 7. Hydrology data used in the simulation

The annual production corresponding to hydro power plants being installed after 2010, has been expressed as a linear function of the production of those plants already installed in the first year contained in the simulation (see Table i).

Table i. Coefficients of the linear function determining new investments production

	ALBAN	BETANIA	CHIVOR	CALIMA	GUATAPE	GUATRON	GUAVIO	MIEL	JAGUAS	TASAJERA	PAGUA	PLAYAS	PORCE II	PRADO	SALVAJINA	SAN CARLOS	URRA	Constant
Medium size project	0	0	0	0	0.030	0.030	0	0	0.030	0.030	0	0.030	0.030	0	0	0.030	0	0
Amoya	0.051	0	0.019	-0.047	-0.020	0	0	0	0	0	0.126	0	0.014	0	0	0	0	-15,860
Sogamoso	1,386	0	0.192	0	-0.951	0	0	0	-2,164	0	0	0	0	-3,021	0	0.858	0	47,120
Pescadero	3,078	0	0.398	0	0	0	0	0	0	0	0	0	0	0	3,020	0	0	269,800
Químbo	-0.191	0.507	0.024	0	0	0.106	0	0	0	0	0	0	0	0	0	0	0.161	-18,816
Cucuna	0.124	0	0.021	-0.060	-0.022	0	0.008	0	0	0	0	0	0	-0.152	0	0	0	-0.508
Porce4	0	0	0	0	0.097	0	0	0	0	-0.043	0.308	0	0.722	1,466	0	-0.102	0	-27,115
Miel2	0.346	0	0	0	-0.054	-0.093	0.019	0	0	0	0	0.206	0	0	0	0	0	-0.131
Andaquí	0	0	0.159	0	-0.236	0.860	0.099	0	0	0	0	0	0	0	0	0.144	0	-22,720
El Neme	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fonce	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cabrera	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Porce3	0	0	-0.036	0	0.2019	0.718	0	0	0	0.319	0	-1.052	1,155	0	0	0	0	3,010

The model calculates short-term spot market prices for a 40-year-long time horizon. The first 10 years are directly computed by the spot market model, and the rest are approximated by means of an interpolation function that makes prices converge into the very long-term system prices. These very long-term prices have been also calculated with the short-term model, assuming a perfect competitive environment and the structure of the generating mix presented in Figure 8.

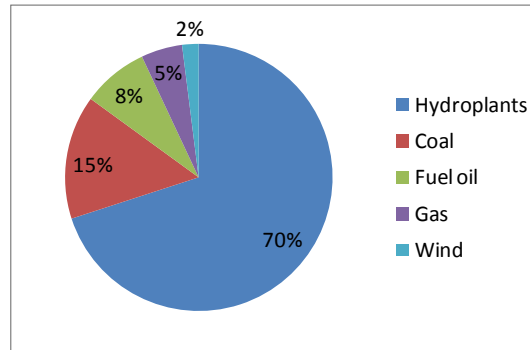


Figure 8 Generating mix structure in the very long term

When computing the spot market simulation, it is also necessary to conjecture the expected expansion of the generating mix. This conjecture has been assumed to be shared by all market participants. The expected expansion hypothesis is updated after each auction is celebrated, so as to include the preferences on the latest investments.

New projects being evaluated include coal, fuel-oil, wind and hydro plants (of different sizes and in different geographical locations¹²). The information regarding plausible future investments were taken from (UPME, 2008) as well as from some firms' expansion plans. The data corresponding to the small-scaled projects is presented in Table ii.

Table ii. Small-scaled projects characteristics

Project	Construction period	Life Span	Capacity (MW)	Investment cost (M€/MW)	Variable cost (€/MWh)	Average availability factor	ENFICC (GWh/Year)
Fuel-oil	3	20	200	140	59	0,85	1577
Coal	3	20	325	400	22	0,95	2800
Medium size hydro plant	3	40	120	122	0	0,55	250
Wind	3	30	150	290	0	0,4	262

We did not consider the potential entry of new generating companies in the business. Nowadays, several small companies with growth potential are already in place, and their characteristics are close to the ones that would represent a new entrant. Each firm is modeled with its own function relating the IRR required to a new investment and its financial structure (debt and equity proportion).

3.3 Calibration of the spot market model

The parameters used in the spot market model were adjusted using historical market data. The agents' strategic behaviour was calibrated so as to match market data from 2007. The average monthly prices obtained from the model (once it was calibrated) and those actually resulting in the market are represented in Figure 9.

¹² The geographical location affects the hydro inflows.

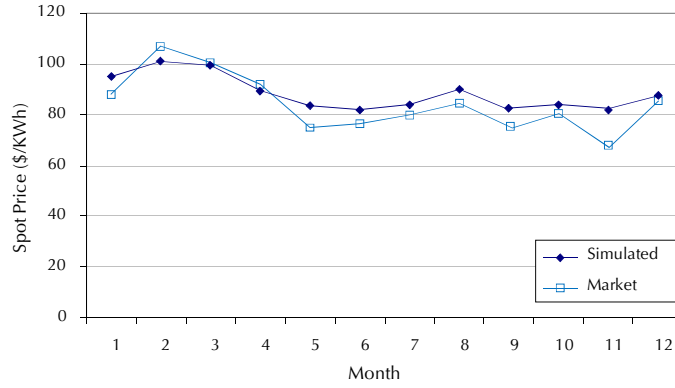


Figure 9. Simulated average prices and market average prices for 2007

We also checked the suitability of modelling hydro plants dispatch by means of a peak shaving algorithm. In Figure 10 we represent the simulated dispatch and the actual dispatch for two different months. It can be seen that the accuracy of the approach may differ from one period to another, but the trend is always reasonably properly captured.

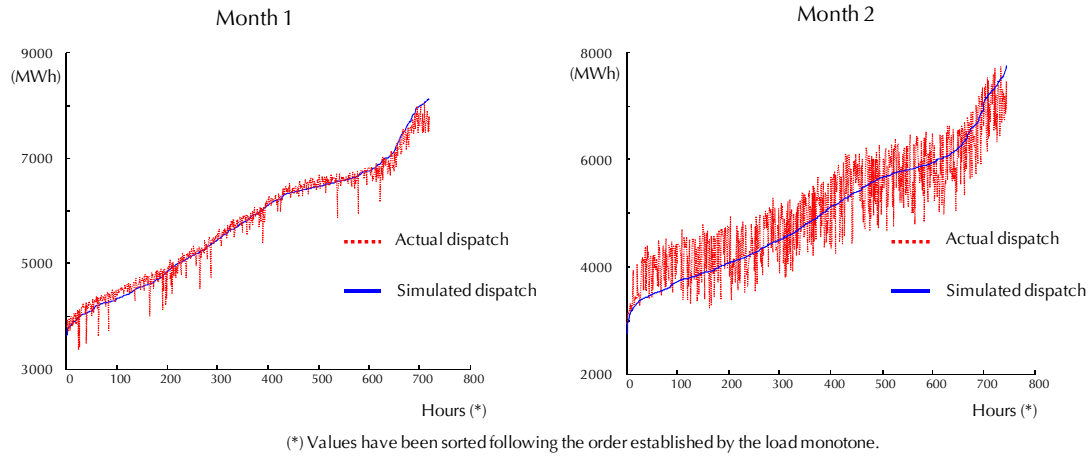


Figure 10. Checking the suitability of the hypothesis followed to dispatch hydro plants

3.4 Simulation results

The evolution of the agents' investment decisions has been represented in Figure 11. Since the negative deviations from the Firm Energy objectives set by the regulator are relatively small (see the figure on the right), it is clear that the mechanism fulfils its main objective, i.e. it ensures enough generating available resources in the long term.

This way, the mechanism provides a more stable investment scenario in which the boom-and-bust cycles are almost non-existent. Nevertheless, by analyzing the technologies entering into the system in each of the simulated years (figure on the left), we observe technology investment cycles. In other words, the most profitable technology varies throughout the simulation time scope.

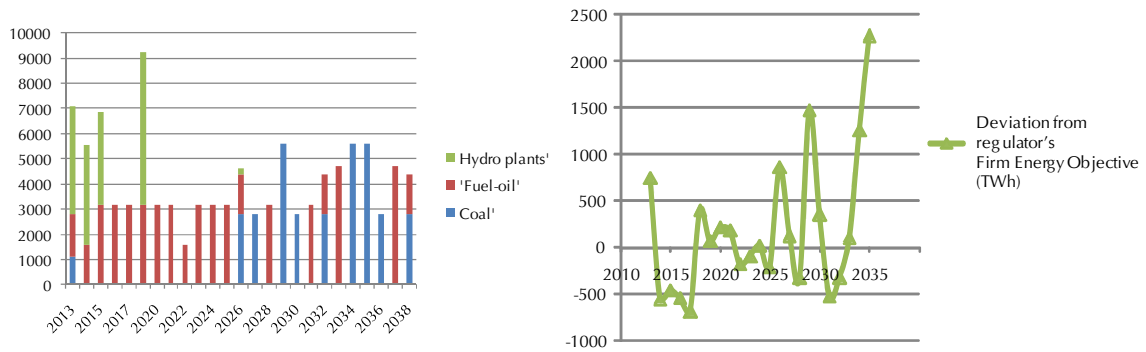


Figure 11. Evolution of the entry of new investments

The effect the entry of the new plants has on both the market prices and on the financial structure of the different companies is the main reason behind these cyclical investment trends.

Investment cycles

In order to better illustrate the long-term dynamics simulated by the investment decision module, we show next the computations carried out by the model in some of the simulated years. The objective is to show how the expected market income and the required IRR (which depends on the company's financial structure) determine the optimal investment.

Once the expected market cash flow of a certain plant has been determined, we can calculate the annualized payment (the premium representing the price bid) required to fully recover their investment costs. For some of the simulated years, and for each one of the technologies being considered, this premium (expressed in \$ per MWh of Firm Energy) has been represented as a function of the IRR required (see Figure 12).

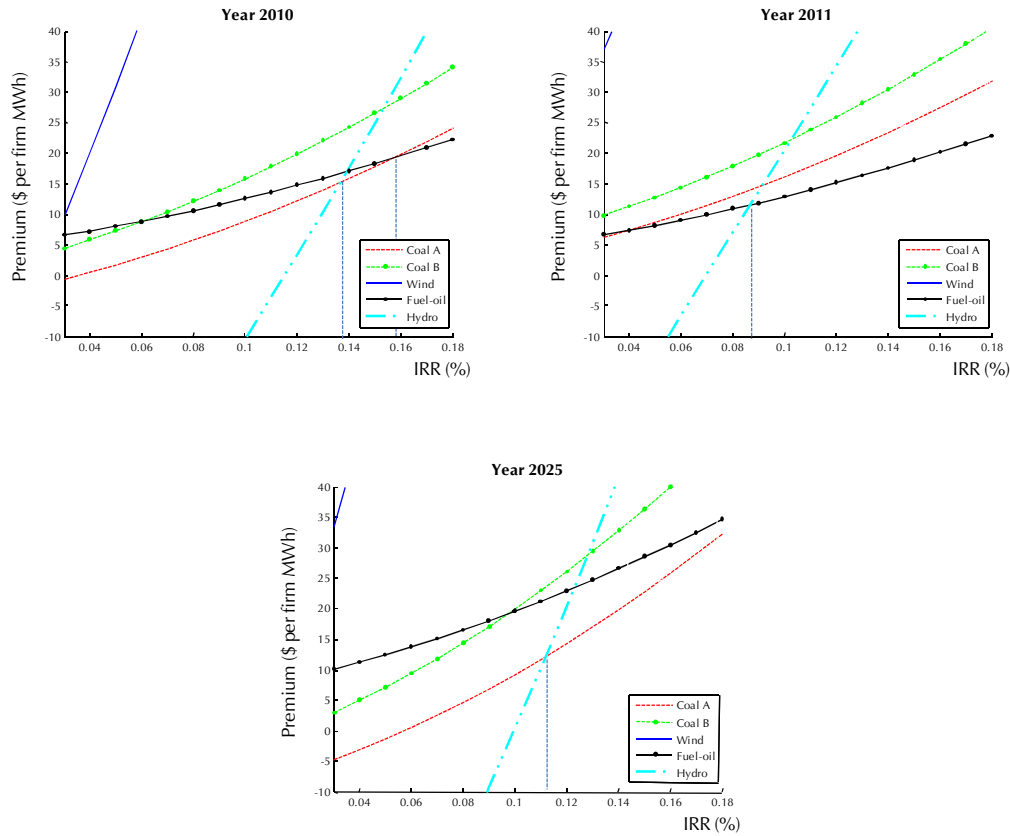


Figure 12. Premium by technology as a function of the IRR

Although the required IRR ranges typically, depending on the company and its leverage ratio, from 10% to 14,5%, it is clear that in the first simulated year (upper-left chart of Figure 12) the hydraulic plant represents the most profitably investment for most of the firms considered (followed by coal fire plants and then by fuel-oil plants). Indeed, it is remarkable that for certain values of the IRR the spot market prices would ensure the full recovery of investment costs.

Since a considerable amount of new hydro energy is committed in the first auction, spot prices are expected to decrease in the forthcoming periods. This leads us to a whole new situation the next year (see the upper-right chart of the same figure). It can be observed how coal-fired plants cannot be the most profitable technology, no matter which the internal rate of return being required to a new project is, and fuel-oil represents the optimal technology for almost the whole range of IRR values.

The entry in the following years of fuel-oil plants makes spot prices rise in the future, and as a consequence, the investment curves revert to the initial situation (see the lower chart of the figure). In this latter case, the expected evolution of fuel prices, coupled with the expected prices in the spot market, makes coal-fire plants the most competitive technology along the relevant range of IRR values.

The regulatory intervention

Although this market-based mechanism has been claimed to leave completely in the agents' hands the decision of determining the most profitable technology, it is obvious that some regulatory decisions condition to great extent the final results¹³.

Here, we just show how the previous results may be significantly modified if the criteria to allocate the ENFICC would be slightly different in the case of the hydraulic plants. Thus, we increment the ENFICC allocated to the medium-size hydro plant new projects from 250 GWh to 350 GWh, a value that is still well below the average expected production of the plant. The entry of the new Firm Energy (GWh) under this new hypothesis has been represented in Figure 13, where it can be seen how the amounts the share of hydro power plants increases with respect to the base line scenario presented above.

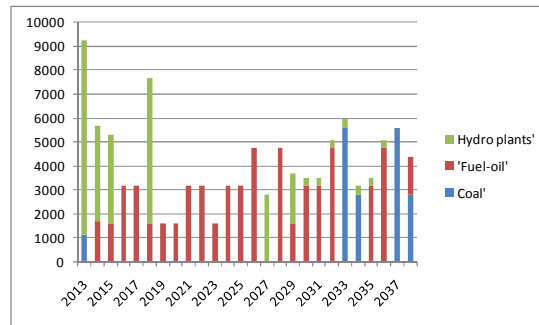


Figure 13. Evolution of the entry of new investments in terms of Firm Energy

4 CONCLUSIONS

After providing a brief description of the security of supply mechanism based on long-term auctions, a methodology to simulate the dynamics in generation expansion under such context has been presented.

The simulation tool developed can be considered as a system-dynamics-inspired model, which makes use of a strategic production cost model (Batlle and Barquín, 2005) in order to better represent agents' interaction in the short-term spot market.

To illustrate the model capabilities we have developed a real-size simulation based on the Colombian system. The Colombian electricity system is a hydro-dominated system with uncertain hydraulic resources (due to the presence of difficult-to-forecast cyclical climate phenomena like El Niño).

The calibration of the short-term model was carried out with historical data, and a 25 years' time scope was analyzed. The results obtained allowed us to draw some interesting conclusions:

- The present mechanism, the so-called Reliability Charge, clearly fulfils the objective of bringing new investment resources in generation. Indeed, the Firm Energy installed

¹³ For a general discussion on this issue see (Batlle & Rodilla, 2009), where several examples are provided in a wider context.

along the period studied, follows closely the regulator's objectives. The price cap and the definition of the demand curve do not suppose any entry barrier to the necessary investments in terms of Firm Energy.

- The mechanism ensures a more stable environment. However, there are some clear technology investment cycles. These cycles are motivated by the late response that usually characterizes long-term investments dynamics. For example, high spot prices are a magnet for hydro plants, what leads to a spot market decrease in the following years, and thus the long-term signal provided by the mechanism changes.
- Although this market-based mechanism has been considered to leave the decision of the most profitable technology completely in the agents' hands, it is obvious that some regulatory decisions condition to great extent the final results. As an example, we have shown here how the results obtained may be significantly different if the criteria to allocate the ENFICC would be less strict with hydro plants.

Electric power systems regulation is currently looking for the right equilibrium between free market initiative and centralized (sometimes called indicative) planning, see (Pérez-Arriaga & Linares, 2008). In this context, security of supply mechanisms are enlarging their scope, aiming to allow regulators recovering part of the control over the future development of their electricity systems. Thus, simulation tools as the one we have presented in this paper, able to represent jointly financial criteria, economic dispatch and regulatory design and real-size case examples are going to be of a major significance in the near future.

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