SYSTEM DYNAMIC MODEL TO ANALIZE INVESTMETS IN POWER GENERATION IN COLOMBIA

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ABSTRACT

The Colombian electricity sector was restructured in 1994. Under the new legal framework, investment decisions for building new capacity need to incorporate elements of risk and uncertainty. In these circumstances it results advantageous for agents to learn about market risks for assessing the implications of their decisions. Microworlds or simulators, as the one presented in this paper, intend to help investors for better understanding uncertainty and its implications over their decision-making processes.

The authors developed a micro world, supported on a System Dynamics model, in which it is possible for the decision maker to assess his/her investments in capacity under simulated conditions. The developed microworld for the Colombian electricity market is described in some detail and applications are presented.

Key words: Investment, Electricity, Simulation, System Dynamics, Microworlds

1 INTRODUCTION

The electricity sector in Colombia was restructured in 1994, where new markets elements were incorporated in the system. During the last decade, the scheme has changed from a central planning structure towards free markets, seeking efficiency and better use of resources.

In this context, the criteria for investment decisions of new power plant need to incorporate risk and uncertainty analysis. In these circumstances, it results advantageous for agents to learn about market risks in order to assess the implications of their decisions as, a consequence of competition, we have observed trends towards improvements in efficiency and reductions in electricity prices.

It is important to note that these newly engineered markets have exacerbated different sources of uncertainty in variables such as: electricity price, regulation, demand growth, and technology development, among others.

However, it is difficult to assess the evolution of such variables, which makes even more complicated to evaluate investment decision on power plant. This is why, the authors developed a tool, supported on a System Dynamics model, in which it is possible for the decision maker to assess his/her investment in capacity under simulated conditions. The methodology and the developed tool are described next.

2 METODOLOGY APPROACH

There is a tradition in the electricity sector to support investment decisions on simulation models. It seems even more reasonable today to continue this trend of though because of the ever increasing interactions among the multiple factors that are involved in the created markets, which include the economy, energy technology, normative policies, conservation and environmental legislation, company strategy and privatisation policies (Bunn y Larsen, 1997).

Econometric simulation and optimisation have been the most common tools under central planning. The main criticism regarding the use of these tools, under market conditions, have pointed out issues related to the modelling process, the way that uncertainty is incorporated and model credibility, among others (Lee et al., 1990; Dyner and Larsen, 2001).

Complexity and market forces generate new methodological requirements. Such requirements represent a challenge for the modelling approach with respect to the incorporation of feedback thinking and uncertainties, among others (Dyner, 2000) - System Dynamics seems to be appropriate for these purposes (Nail, 1992; Bunn and Larsen, 1992; Ford, 1997; Dyner, 1995; Montoya, 1997; INTEGRAL – UN – COLCIENCIAS, 1999).

Under the current market conditions, the chosen tool to support decision-making processes should take into account at least some of the uncertainties that characterize the sector. Hydrology, demand, fuel supply, prices and bids incorporate significant uncertainties. This market characteristic creates the need for focusing on the behaviour analysis of the system rather than on the search for an “optimal solution” that does not exist.

In order to address this issue, a system dynamics microworld was developed. The purpose is to create an environment that facilitates learning about the problem of investment in new generation capacity. In this paper, we exhibit a model that has been built with the purpose of assessing the economic impact of the electricity market over investments in new power plant. In the following sections we present the model that has been built for this purpose.

3 MODEL DESCRIPTIONS

The developed tool is supported by a system dynamic model, which allows analysing the system evolution under any scenario created by the potential investor. The main purpose of the model is the estimation of cash flows and other financial indicators.

The model was built using components of related models that have been developed under the framework of the Energy Institute at the National University of Colombia (UN-COLCIENCIAS-INTEGRAL, 2000; UN-COLCIENCIAS-ISA, 2000; Montoya, 1996). We now turn to present the general model structure and its corresponding modules.

The developed model has been based on a general causal loop that explains the dynamic of electricity markets (Bunn and Larsen, 1997), which is shown in Figure 1. In this figure, on the one hand, one can appreciate that a high margin (difference between Capacity and Demand) tends to reduce low electricity prices. Also, an increase in the electricity price implies incentives to investment, as investors should obtain larger revenues. When there are more investments, the capacity of the systems increases and hence the margin increases, closing a balanced loop. On the other hand, a high price tends to reduce electricity demand, because of price elasticity. The demand is affected also by external variables such as the population and the gross domestic product. And finally, to close the other cycle, the higher demand the lower price, due to the margin's definition.

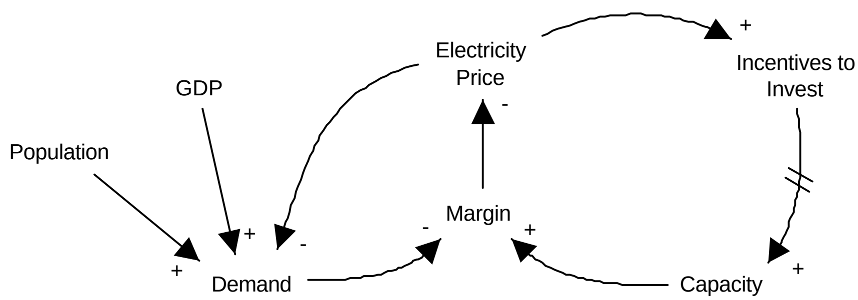

Figure 1. General scheme of the dynamics of the Colombian Electricity Market

There are other relevant elements, which are not accounted in the diagram, such as: the availability of the power plant to generate electricity, which is influenced by the hydrology, fuels availability, and installed capacity; and investments incentives, which depend on financial indicators and regulatory incentives are important.

The model was created in a modular architecture as can be appreciated in Figure 2. The main modules in the model are: market, expansion, demand, hydrology and finances.

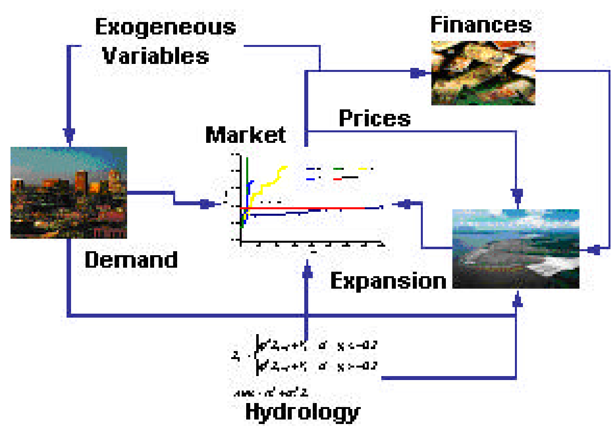

Figure 2. Modular structure of the SD model

Following we present a brief description of each component of the model, and some elements related to the validation of the model.

Market

The main purpose of this module is to establish the price setting mechanism, which basically depends upon supply and demand. The market module incorporates some sort of economic equilibrium criteria to adjust the supply and demand curves. In this way, electricity prices and plant dispatch are determined taking into account hydrology conditions and technology composition.

According to the electricity market in Colombia, price formation is represented as shown in Figure 3. The supply curve is obtained by adding the supply curves of all generation technologies involved. The pool price (PB) is found at the intersection of the supply and demand curves.

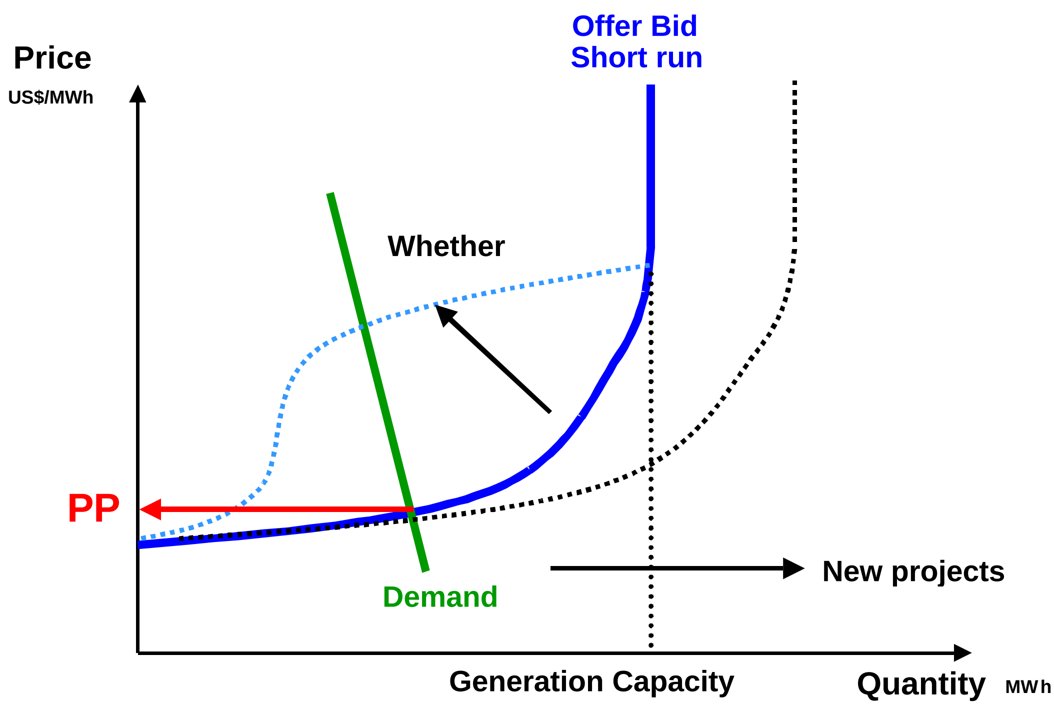

Figure 3. Price process formation

Supply functions have been estimated by technology - hydroelectric with reservoir, river plant, gas plant and coal technologies (UN-COLCIENCIAS-ISA, 2000). Different sets of supply functions have been estimated according to the season (whether it is a raining season or not), and also depending on the macro climatic condition (whether a Niño occurs or not). A typical supply function is shown in Figure 4.

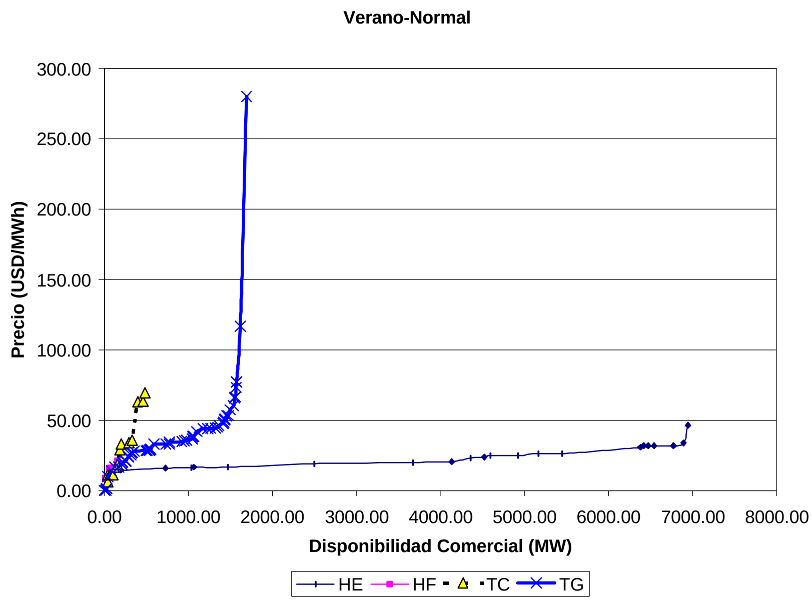

Figure 4. A typical Supply functions per technology.

In addition, the supply functions are modified depending on the entrance of a new project. Those projects extend the supply functions to the right, which assumes that the new projects are more efficient than the old ones. The availability of the hydro plants is estimated according to water inflows into the reservoir and the reservoir level. Price volatility is estimated as an indicator of the price variability.

Expansion

The expansion module is an abstraction of what actually happens in reality, with the purpose of providing insights into the capacity evolution of the system. The transitions from highly regulated systems to competitive structures may create problems in terms of the required capacity to attend demand (Hirst y Hanley, 1999) because of the inappropriate financial instruments used by investors. The model uses two alternative mechanisms describe below: an adapted "real options" approach and minimum average cost.

For the real options approach, the fundamental idea is to compare the "critical price" (estimated theoretically), P*, for each project with the expected electricity price, Pe. A new project will enter to the system if it satisfies:

- $Pe \geq P_i^*$, i represents the projects
- $t \geq t_{mi}$ (t_{mi}: minimal time to entry)

P* is estimated according to the optimal rule to entrance in a real option model (Dixit and Pindyck, 1994; Osorio, 2000). The estimated values for the model are taken from INTEGRAL–COLCIENCIAS–UN (2000). Pe is calculated as follows:

$$P_e^k = PM(t^k)^* \prod_i F_i^k$$

Where the P_e^k is the expected price for the technology k, PM (t^k) is the move average of the pool price and F_i^k: is a factor which involves others aspects such as technology, incentives, etc, represented by i. For details of the model, see UN-COLCIENCIAS-ISA (2000).

Hydrology

The hydrology module contains two components: one is the occurrence of the ENSO (El Niño South Oscillation) and the other is a stochastic model, RAR(1), for the representation of inflows (Salazar, 1994). Due to the fact that there are two kinds of hydro plants, it is necessary to calculate water inflows. For this target we selected a RAR (1) model (more details see 1994), which include the influence of the ENSO phenomenon and the monthly dependence of the inflows. To see more details in the parameters estimations and validation of this model see Arango (2000).

Finally, the evolution and occurrence of the ENSO phenomenon, we used a model based on re-sample techniques available in the project INTEGRAL-COLCIENCIAS-UN, 2000.). With this model, we picked up 5 hydrologic scenarios of the ENSO phenomenon, in order to have a wide range of possibilities, in addition to a random one.

Demand

Demand is modelled according to the forecasts of the Unit of Energy Planning in Colombia (UPME, 1999), which includes variables such as population, and GDP, among others. Those are time series, which can be modified if the user wants to have a personalized demand scenario.

Finance

Finally, a finance module takes into account the new plant being evaluated according to indicators such as net present value, profits, cash flow, etc. This module takes into account the investment decisions and evaluates its implications on the system.

The investment is made in certain period of time. It is done in terms of capacity of the project, technology, availability conditions (hydrology or gas availability), costs and debt capacity, among others.

According to the investment decision, the microworld estimates cash flows. With these cash flows, the model estimates some finance indicators such as Net Present Value, Internal Return Rate and Recuperation Period of Capital.

4 VALIDATION

The model validation was undertaken using the data available for the period January 1996 to December 1999. Using this data, we observe how in general, the model represents system behaviour, despite not only the small amount of data available but also because of the quality of the data. The data does not have significant measure error; the problem is that this is a market in an infantile stage, where elements such as the learning process within the market, transitional problems and the high risk aversion that is taking place.

The behaviour of the systems, in terms of the gas and hydro generation, is well represented as shown in Figure 5. In addition, in terms of price behaviour, the model closely follows historical data as shown in Figure 6 (especially during the occurrence of the ENSO phenomena during 1997 – 1998). To see more details of the validation process, see Arango (2000).

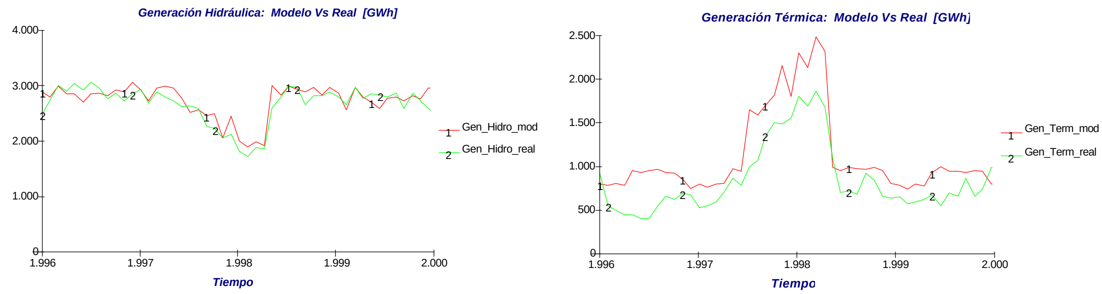

Figure 5. Simulated and Real generation. Hydro to the rigth, and thermo to the left.

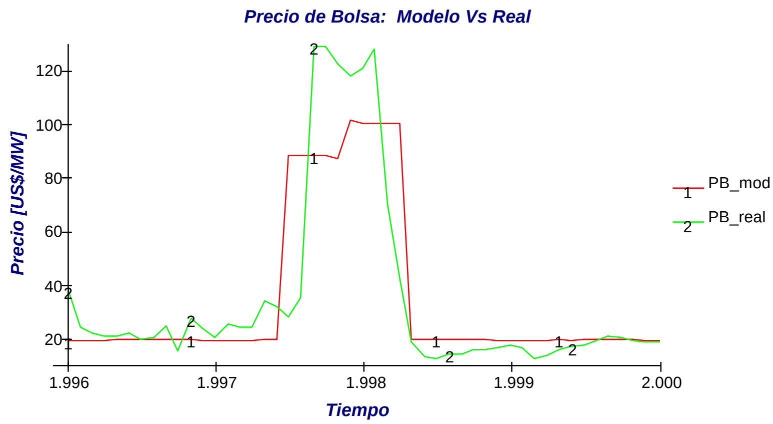

Figure 6. Simulated and Real pool price

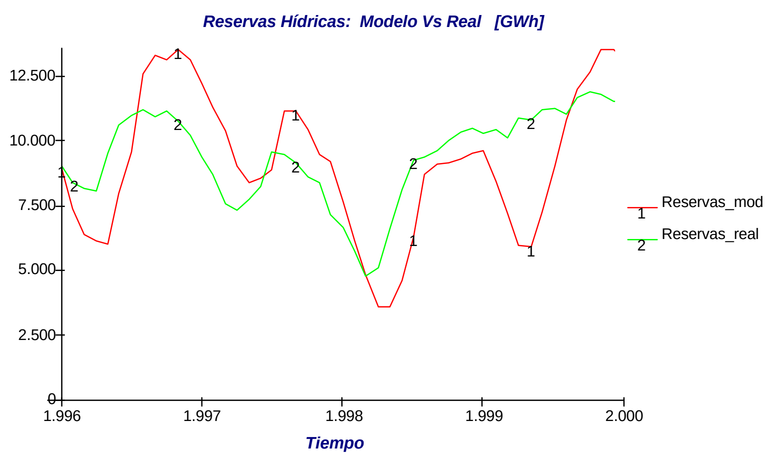

Figure 7. Water in reservoirs: modelled and real

5 DESCRIPTION OF THE TOOL

The microworld was developed as learning and analysis tool applied to the Colombia Electricity Sector. It allows the user to invest in a simulated project, under a risky and uncertain market, where the user can assess the performance of his/her investment. The tool allows the analysis of several expansion criteria, understanding the investment context, valuing the consequences of the decisions, and defining investment strategies in power generation in Colombia. Moreover, the users can also improve skills such as scenarios analysis, work group, and mental model revaluation about the Colombian electricity market, among others.

The tool has two general functions: as an analysis platform, where the user decides its investment at the beginning of the simulation period; and as an analysis tool of the evolution of the system and investment performance, where the user can make decisions about electricity trading.

5.1 The tool as a Platform for Investment analysis

With the platform for Investment analysis, the user provides some initial condition of the system, defines some features of the scenario and decides about his/her investment. The decisions are made by pressing buttons of the main window and, at the end of simulation, it is possible to appreciate the system evolution and the performance of investments. The main window is shown in Figure 7.

Figure 7. Main window of the tool

The main components are the following:

- *Condiciones de modelamiento* (model setup): As is shown in Figure 8, this windows allows setting-up some of the main variables of the system, such as hydrology conditions, demand, discount rate, and expansion criterion, etc.
- *Descripción del modelo* (model description): display a general view of the system dynamic model.
- *Decisiones de inversión* (Investment decision): it is the input of all data needs for the investment, such as investment and operation costs, capacity, location, entrance date, etc.

- *Indicadores del proyecto* (project's indicators): this button show the financial indicator not only of the project but also of the investor. See Figure 9.
- *Estado del sistema* (State of the system): This button allows the view of the system. Variables such as pool price, demand, margin, expansion, and hydrology are displayed.

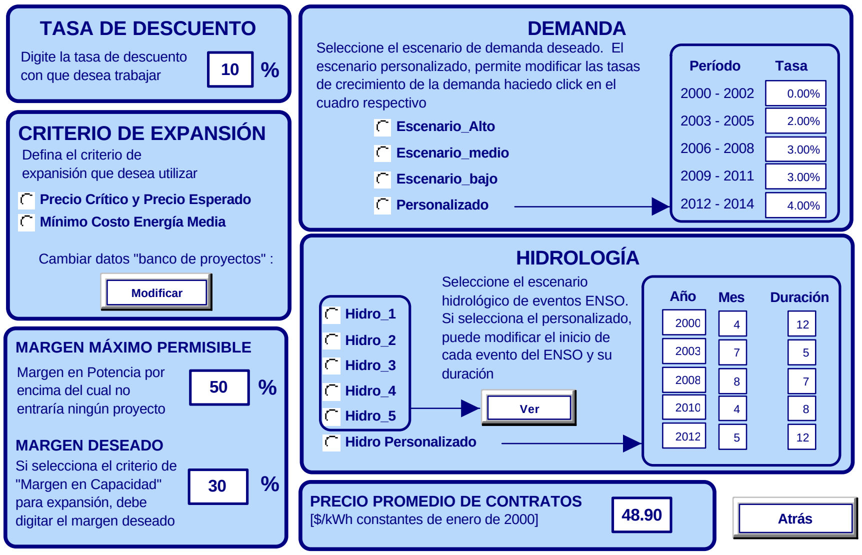

Figure 8. Model conditions in the investment platform

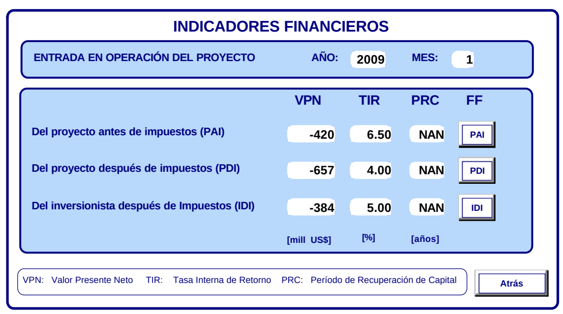

Figure 9. Financial indicator of the investment's performance

In addition, the platform allows appreciating the evolution of the system and the cash flow of the project continuously.

5.2 Micro world to invest in the Colombia electricity sector

The micro world is an interactive game, where the potential investor makes periodic decisions under a defined scenario. From time to time, the user can observe the evolution of the system and decide whether to carry out or defer the investment in power generation. Some of the main features are:

- The occurrence of an ENSO event is a random variable. It is chosen from a database of events ENSO (there is not possibility to define an hydrologic scenario).
- The step-time is a semester.
- Each semester the user decides about his/her investment, the selling profile (contracts and pool), demand growth, availability of the project, among others.

The decision making windows is shown in Figure 10. This illustration presents the buttons "*Indicadores del proyecto*" and "*estado del sistema*", which have similar functionalities as in the platform.

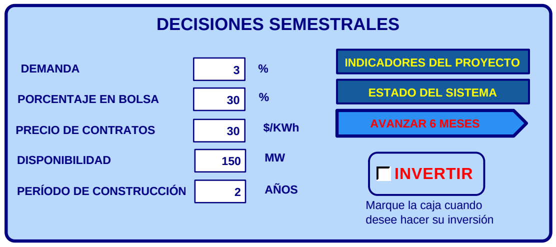

Figure 10. Decision making window of the microworld.

The user can observe the system evolution and decide whether to invest in the project at any time. Once the decision to invest is made, the user can define his/her strategy to improve the performance of the investment. Decisions about selling profile and contracting prices should be made after investment.

The microworld shows the simulation system evolution. As an example, the following section shows the behaviour of the system under de baseline scenario[1], and the evaluation of a standard 150 MW CCGT (Combined Cycle Gas Turbine) under this scenario.

6 APLICATION

The tool has not been tested with real investors; nevertheless some experiments have been initially conducted as indicated in this section. Next, the baseline scenario is presented and the performance of a hypothetical investment in a small CCGT of 150 MW CCGT. A complete report of these cases and additional cases are presented in Arango (2000).

6.1 Baseline Scenario

It could be considered as an intermediate scenario, called the baseline scenario1. This case has the hydrologic conditions shown in Figure 11. In this figure, there are 4 events ENSO, with different periods and durations, each one has associated a reduction in the aggregated inflows to the system. This inflow allows calculating the availability of hydroelectricity, and the occurrence of the ENSO determines mainly the bid curves. Due to the fact of the topology of the Colombian System (70% Hydro and 30% Thermo), these variables give some of the main features of the scenario.

[1] Baseline scenario: low demand growth (UPME, 1999), expansion made using the criterion of critic and expected price, defined hydrologic scenario, annual discount rate of 11%, and selling profile of 30% in pool and 70% in contracts, among others.

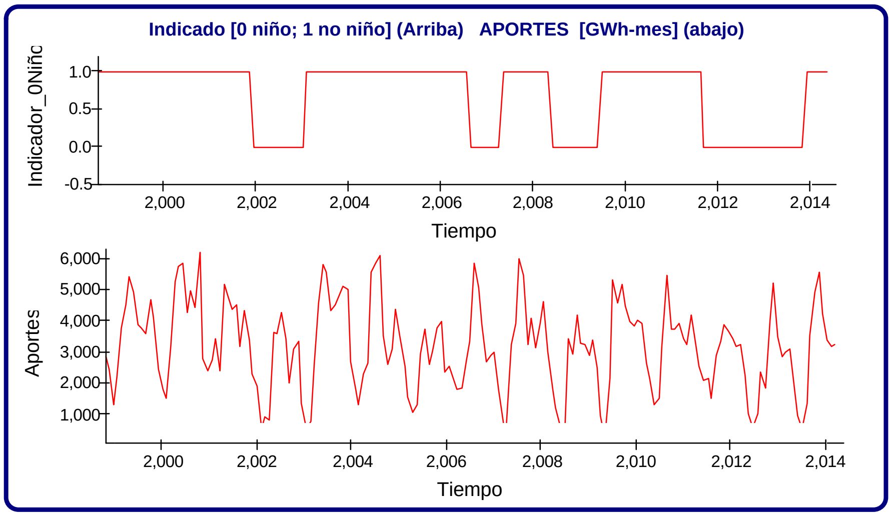

Figure 11. Occurrences of the ENSO phenomenon (top) and aggregated inflows of the system (bottom). Baseline scenario.

Figure 12 shows the pool price, not only monthly but also the average (the historical prices are included to calculate the average). It is show the influence of the phenomenon ENSO over the prices, where the occurrence of the ENSO means a considerable increases in the prices. However, the increase in the prices is higher or lower according to the difference between the offer and the demand.

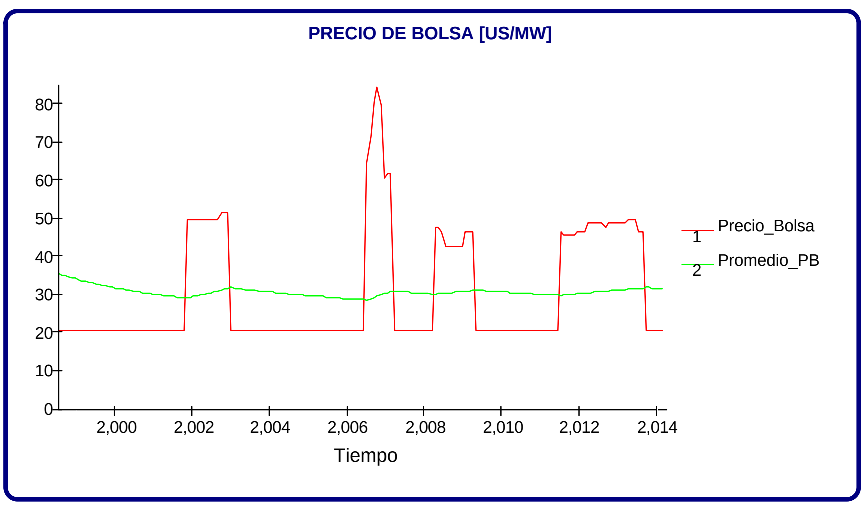

Figure 12. Monthly and average pool price,. Baseline scenario.

The feedback in the module of expansion establishes that the higher the price implies higher incentives to invest. Many investors can observe the signal of high prices and decide to invest. These investments increase the installed capacity and a reduction in prices is perceived with a delay. This dynamic is show in Figure 13, where the installed capacity, the demand and the margin (ration between the difference of capacity minus demand over demand) are presented. Here, there are some cycles of sub and over installation, which agrees with the economy theory. First, from 2000 to 2003, some projects under construction are finished, hence are part of the installed capacity. However, the demand growth is not as large as was expected, which means over capacity in the system and low prices, inclusive during the occurrence of the ENSO. It is not attractive to investors and the entrance of new projects is stopped.

During the ENSO between 2006 and 2008 the price increases considerable, which is observed by the investors as a market signal. It means that there are new power plants in the system, but the investment makes again a reduction in the prices and the cycles are continued during the rest of the simulation period.

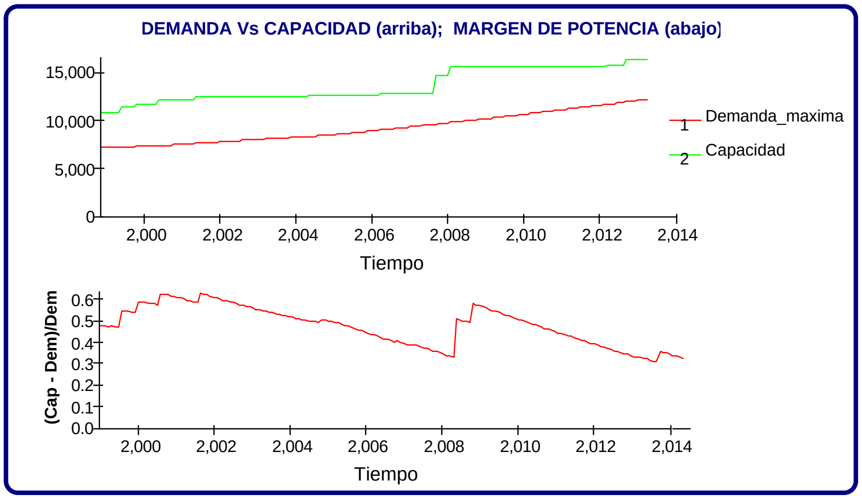

Figure 13. Demand and installed capacity (top), margin (bottom). Baseline scenario.

Figure 14 shows the technology composition of the system, no only the capacity but also the percentage. In general, the initial composition is conserved (aprox. 70% hydro and 30% thermo), despite of some differences in a few periods. In addition, the model shows the new projects in the system and the entrance date (see Figure 15).

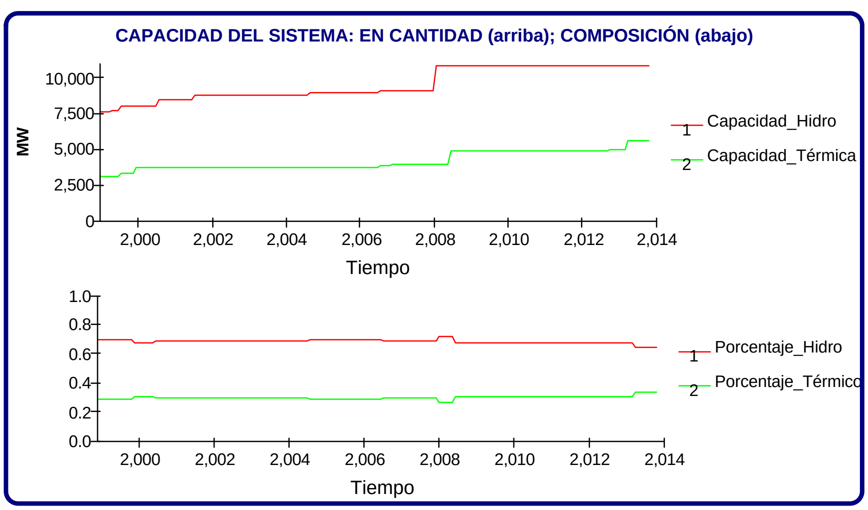

Figure 14. Technology composition of the system, capacity (top) and percentage (bottom). Baseline scenario.

Figure 15. New power plants in the system, name and entrance year. Baseline case.

An investor in the Colombian electricity market is exposed to different risks; one of them is the price volatility. The model calculates the risk associated to the price using volatility. The volatility is an indicator of the price's variability. It is presented in Figure 16, where the total accumulated monthly volatility is 113%.

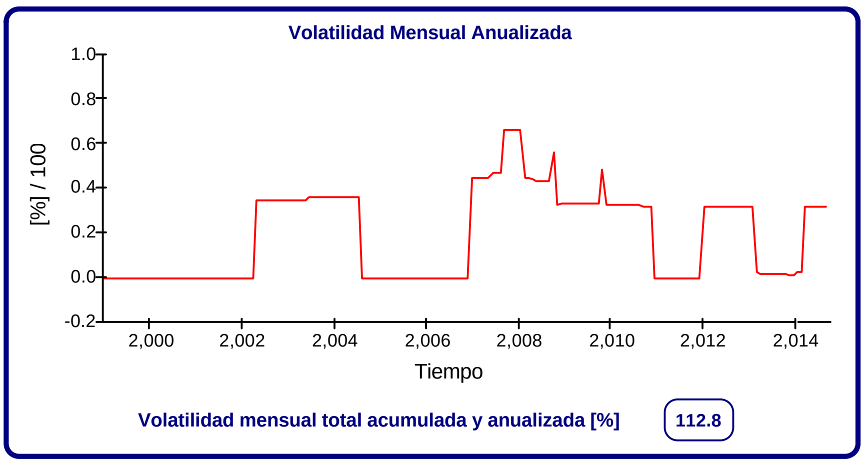

Figure 16. Monthly volatility, annualized and total. Baseline scenario.

6.2 Case: an standard 150 MW CCGT under the baseline scenario

The analysis of a standard 150 MW CCGT is an example of the use of the investment analysis platform. The project is located in the region of Magdalena Medio in Colombia. The main features of the project are summarized in the Table 1, and some details are in UPME (1999).

Table 1. Main information about the project: 150 MW CCGT.

Project	CCGT

Location	Magdalena Medio
Capacity	150 [MW]
Investment (without taxes)*	121.82 $*10^6$ [US$]
Investment (with taxes)*	126.74 $*10^6$ [US$]
Average Energy Cost (with taxes)*	37.53 [US$/MWh]

*Constant US Dollar of December (1997), own calculus using 2% of deflation rate (ANIF, 2000)
Source: UPME (1999)

Assuming that the period of construction of the project is 3 years, the investor decides that the project will operate in July, 2007 (it implies that he decides to invest in July, 2004). Some other aspects about the investment are in Arango (2000). Using the platform we get the indicators of the project, which are shown in Figure 17. This figure presents the net present value, the return interest rate, the capital recuperation period and the cash flow, according either the project with or without taxes or the investor (after taxes). The project without taxes has a net present value of MUSD 30 and the return interest rate of 14%; but, after taxes, it is reduce to 10% of return interest rate and MUSD 1 of net present value. Finally, the investor has a better net present value after taxes than the project by itself, it is because of the debt that the investor can have.

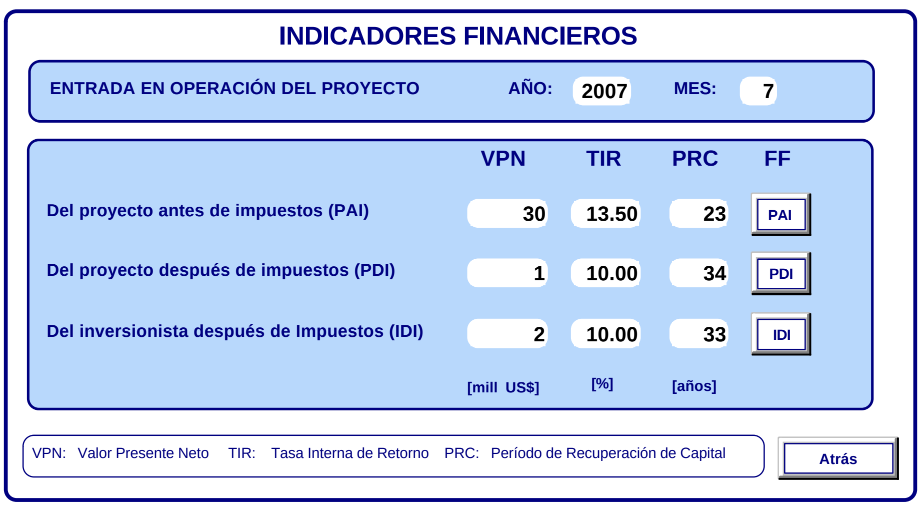

Figure 17. Financial indicators of a CCGT of 150 MW in the Magdalena Medio, Colombia. Baseline scenario.

Each indicator is estimated using its corresponding cash flow, according either is of the project with or without taxes or the investor. The buttons in the right hand allows the view of the annual cash flow. For example, the Figure 18 shows the cash flow of the project after taxes, during the commercial life of the project.

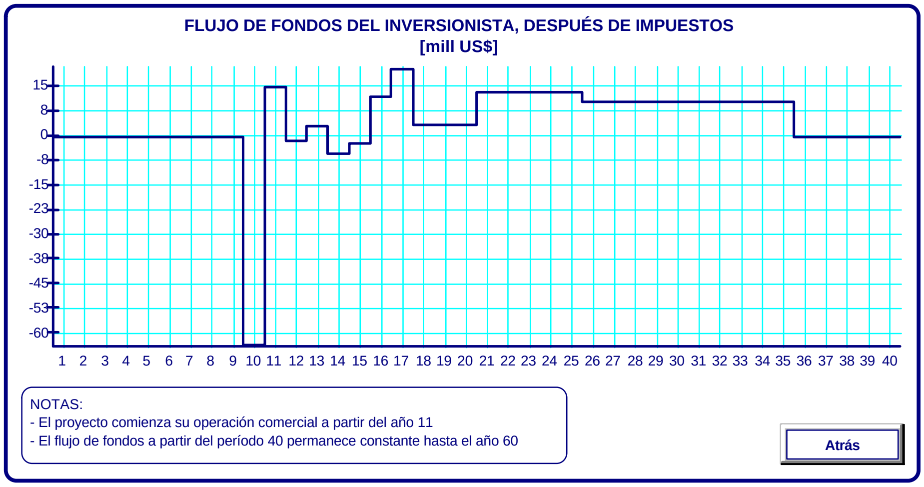

Figure 18. Cash flow of the investor after taxes of a 150 MW CCGT. Baseline scenario.

The user has to be careful about results because of the context. In this example, the risk associated to the price is the total accumulated monthly volatility (113%). He/she should have seen that the project started to operate while the system has high prices, then the user should also ask what has happed if the project starts operation one year later (before). Indeed, he/she has to know the risk and the uncertainty associated to the scenario. He/she has to check the robustness of the investment under different scenarios.

7 FINAL COMMENTS

The outcome of the project is a microworld that focuses on investments in electricity generation in Colombia. Its basic function is to estimate the project cash flow. The analysis is carried out through a System Dynamics model that simulates the evolution of the most representative system variables and their relationships. The model, properly validated, is supporting the microworld in which the user has the possibility to "play" and be "trained" for better understanding risk and power investment.

This tool is totally new in the Colombian electricity market, and it provides the bases for the coming project to extend this modelling approach to some Latin-Americans electricity markets. The next steps are the use of it with real subjects and evaluate the useful of the microworld.

The model properly represents cycles of under and over capacity. They depend on variables such as demand, hydrologic expectations and investment incentives, among others. The model confirms, once again, the importance of hydrology issues in the Colombian Electricity Sector. This fact is reflected in the consequences of water inflows over investment decisions.

The basic problem behind the developed tool is investment in new capacity. This problem has more components involved that the ones being included in the model, such as:

– Restrictions of the transmission network

- The fuels market
- Impacts of possible new regulation
- Influence of the load curve over dispatch

This is an undergoing project which is now focusing on further validation and on developing more user-friendly interfaces. Research is also focusing on the generalization of the tool to other Latin-American countries.

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