A SYSTEM DYNAMICS MICROWORLD FOR THE INVESTMENT IN ELECTRICAL GENERATION CAPACITY IN LATIN AMERICA

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ABSTRACT

The restructuring of several Latin American Electric Sectors raises the necessity of developing analysis tools focused on the understanding of the new electric energy trading structure. In this work two Microworlds were developed for the two main market schemes in actual use in Latin America: dispatch by prices and by cost. The main tool used in the microworlds was System Dynamics. Both intend to facilitate learning processes of the complex mechanism that characterize the investments in Latin American electricity markets. The developed system can also be used to analyze possible investments in electricity capacity in Latin America. An effort has been made to introduce risk and uncertainty criteria to analyze possible decisions. Some results are presented by applying the developed tools to Colombian and Panama Electric Markets.

Key Words: Microworlds, Investment decisions, Electric Generation, Latin America, Learning, System Dynamics

1. INTRODUCTION

In the last two decades, several countries of Europe and America had restructured the public services sector, including the electric energy sector, by introducing market structures. As a result several Latin American countries has today electricity energy market schemes with ample participation of several agents such as generators, traders, consumers and distributors. The different market agents trade energy in two basic forms: by long or middle term energy contracts or by participating in a short term energy interchange mechanism where energy is traded every day. The electric market schemes generates opportunities for investments in different aspects of the power chain. Potential investors has to make decisions in a complex environment that includes the consideration of aspects such as: future electric energy demand growth, macroeconomic conditions, market regulatory policies, technological developments and the penetration of energy substitutes, among others, many of which are generally not known by the investors.

The electricity energy market has several risk and uncertainty sources that has to be properly considered in investments decision analysis. The traditional financial evaluation of power capacity projects presents several problems, specially in aspects related to the appropriate evaluation of the project benefits in a market scheme. New risk analysis methodologies have been introduced to evaluate the option to invest, considering investments as a time opportunity, and by evaluating the involved risk and the uncertainty.

There are then complex markets schemes where investments decisions has to be made that involves several risk and uncertainty sources. Most of the agents participating in the electricity energy markets in Latin America are not well prepared to face this kind of decisions. Learning tools are needed to build up decision capacity in those markets related to several aspects, including capacity investment decisions. Microwolds are a interactive learning mechanism that allows the users to learn how to participate in those markets through a virtual environment. Several specially design market conditions are included in the microworld to teach de users how decisions should be made.

The developed tool has two components: the microworld for learning how to invest in Latin American electricity markets, and a decision support system to analyze particular investments in those markets. Both components were developed using a System Dynamic model to represent the market interchanges. The analysis of the electrical markets in Latin American countries, lead to the identification of two typical structures for the transaction of energy, corresponding to two different criterion of how markets are operated: in the first one generators are dispatched according to a system based on the prices of the amounts offered by the agents, and in the second one the dispatch is defined using a minimum cost operating criteria. Following these two criteria two microworlds or simulators were developed for the investment in generation, as learning tools or as a decision support tool in the investment decision making.

In the following sections a description of the developed microworlds is presented. Results and discussion of two applications in two different countries are presented, followed by some conclusions and recommendations.

2. MICROWORLDS AND THE ELECTRIC ENERGY MARKET

The Microworlds or simulators are tools based on the system approach stated by Senge (1993), and that facilitates the learning of their users. These applications consist of structuring models to explain the interrelations that exist between the variables of the system, saving time and costs that otherwise the user would incur in real life. As an analysis and learning tools, the development of Microworlds for investments in new electric energy generation capacity, help to understand the evolution of the market under different investments forms and criteria. In addition, it allows to understand the market environment to make investments and to support the decision making process.

The conceptual structure of Microworlds responds to the methodologic requirements necessary to face the complexity and the new elements introduced in the analysis of power systems. In addition they allow to consider some special modeling characteristics (delays and back feeding) encountered in those systems, and must satisfy the following methodologic requirements (Dyner, 2000):

<u>Modularity</u>: It allows to understand the system through its components. It gives the possibility of developing modules without losing the system vision of the problem.

<u>Back feeding and continuous adjustments</u>: It allows the updating of the model, not only with the information, but also through back feeding mechanisms.

<u>Transportability</u>: It incorporates modeling structures with the respective adjustments to take advantage of the modeling advances already made.

<u>Transferbility</u>: It allows the user to know the model, from the assumptions to the results.

<u>Handling of Uncertainty</u>: It is necessary to have a suitable treatment of uncertainty, since it is one of the most important factors in the new structures of electrical systems markets.

3. GENERAL SCHEME OF MICROWORLDS FOR INVESTMENT IN GENERATION

The modeling platform developed in this work is based on the structure proposed to study the dynamics of modern electrical markets (Bunn et all, 1997). In Figure 1 it can be noticed that the difference between available generation capacity and electricity demand (the system margin), affects the electricity price and this as well affects the demand, due to the existing elasticity between these variables, forming a back feeding cycle. On the other hand, the electricity price and the system margin generate incentives to invest (including not investing), which affect the available generation capacity and another back feeding cycle is closed.

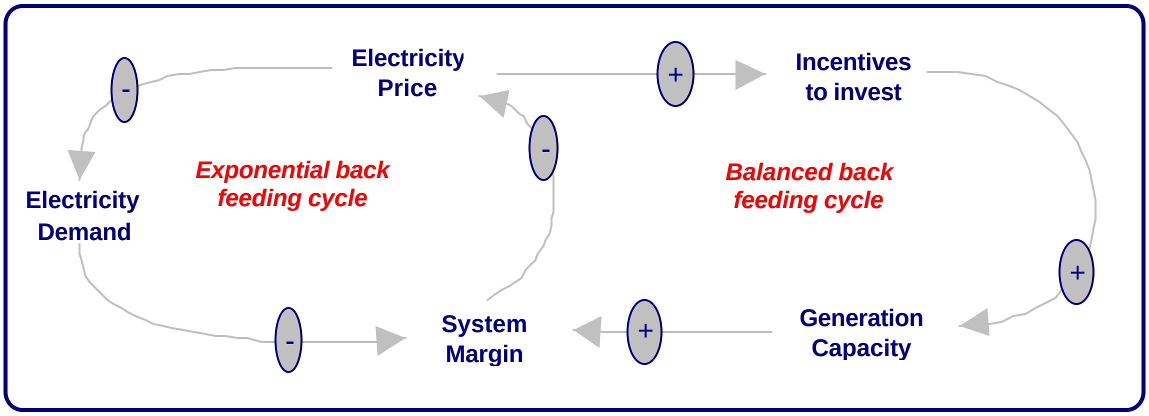

Figure 1. Example of electrical energy markets dynamics.

The modular structure constructed to relate the mentioned variables allows to represent the systemic structure of electricity markets and it is conformed by the modules of demand, hydrology, market, capacity expansion and financial, as it is described below.

An important effect caused by the introduction of competition in the electric sector is the technological diversification that occurred in most of the countries, and that respond to the construction of more efficient power plants, in order to obtain a better performance in a competitive market.

4. MARKET SCHEMES IN LATIN AMERICAN COUNTRIES

The selected Latin American countries for the conceptual development of Microworlds were Argentina, Chile, Colombia, Costa Rica, Ecuador, El Salvador, Panama and Peru.

In conceptual terms, the modeling of the investment in generation capacity in the analyzed countries, was based in the following basic characteristics of the electrical sector restructuring introduced in those countries:

- The market structure as far as the number of generation agents (effective competition), the coverage and dead lines of energy contracts (new participants), tendency and level of activity of the demand (capacity expansion signals)

- The transmission network: coverage and quality of the transmission system (real competitiveness between energy producers and importance of the network constraints).

- The generators: technological diversity as a function of energy sources availability and the capacity generation property structure (effective competition).

Based in the study of the regulatory frameworks and in the structures of operation of the electrical sectors of these Latin American countries, two types of schemes were identified. It was then decided to develop a different Microworld for each one of those schemes which are:

- Latin American countries whose electrical sector has a dispatch scheme of transactions based on a price offers by the electrical generators, such as Colombia and El Salvador. For simplicity, in this report this scheme will be called "Price Dispatch".

- Latin American countries whose electrical sector has a dispatch scheme of transactions based on the short term economical costs of the generators energy resources. Countries such as Argentina, Chile, Costa Rica, Ecuador, Panama and Peru uses this kind of dispatch. For simplicity, in this report this scheme will be called "Cost Dispatch".

The simplifications and desaggregations made on the dynamics of the electrical systems for the accomplishment of the microworlds were the following ones:

- A monthly aggregation level.

- In the microworld based on Price Dispatch the power generating units were added according to the type of technology and the regulatory capacity of hydropower projects. The power generation units were then added into the following technologies: Long Term Regulatory Hydropower Plants (HE), Run of the River Power Plants (HF), Coal Power Plants (TC), Natural Gas Power Plants (TG). Also, in the Cost Dispatch microworld, the generation units were aggregated in: Long Term Regulatory Hydropower Plants (HE), Run of the River Power Plants (HF), Natural Gas Power Plants (TG), Diesel fuel Power Plants (TD), Bunker fuel Power Plants (TB) and Fuel Plants with combined cycle (TC).

- In order to consider the inside–of-the-year (monthly) hydrologic variability, the year was divided in two climatic periods: one with abundant rainfalls (winter) and another one with moderate rainfalls (summer).

- In order to consider the ENSO (El Niño Southern Oscillation phenomena) effect on the hydrologic conditions, the years were classified according to the occurrence of the warm phase of this phenomenon (El Niño), the occurrence of the cold phase (La Niña) or the occurrence of normal conditions.

5. BASIC OPERATION OF MICROWORLDS

The developed microworlds offers two possible uses. The first one is composed by several games, and its intention is to teach the user (investor) about the mechanisms of how electrical markets operates under certain specifically design conditions (demand, hydrology and capacity expansion). These conditions are designed so that the user will learn about possible situations that can occur in the market and that can put him in a difficult position. By playing in the market under these conditions he learns how to invest in the electric market. Its intention is to illustrate the most appropriate moment to make the investment.

The second Microworlds use allows the user to analyze a specific investment under uncertainty considerations. In this case the user has the option to determine the number of simulations that he wishes to make, being able to define a predetermined macroclimate condition or to use synthetically generated hydrologic conditions using a stochastic model. If a single simulation is made, the model computes a series of financial indicators of common use within the financial practice. If a number of simulations are made, the model also provides some risk and uncertainty indicators.

The model offers as results, beside the financial indicators, the temporal evolution of variables such as the river discharges (in energy) into hydropower projects, the energy pool prices, the energy margin, the dispatched energy by technology and for the project being analyzed, and others. The user could implement the model for any of the selected countries as long as he has the required information.

6. GENERAL STRUCTURE OF MICROWORLDS

The Price Dispatch microworld was developed based on some previous modeling work of the Colombian market (National University and Integral, 2000; National University and ISA, 2000). The Cost Dispatch microworld was based on the structure and operational rules of the Latin American markets with Cost Dispatch schemes (Argentina, Chile, Costa Rica, Ecuador, Panama and Peru). Both microworlds were developed so that both have the same modular and operational structure. The modules that conform the two developed microworlds are structured as shown below (Pineda, 2003).

Demand Module

In the microworlds the user has the possibility of selecting a demand growth scenario with which he wants to perform the simulations. He has the possibility of using the official national demand projections of each country or to use a demand scenario defined by himself. In any case the demand projections to be used in the microworld represent information to be given to the model.

Hydrology Module

The hydrologic simulation model considers the relationships between the river discharges and the occurrence of the ENSO (El Niño Southern Oscillation) phenomena. Additionally the inside of the year persistence is considered as a determinant factor in the behavior of the mean river discharges in a region. The hydrologic model separately estimates the discharges into the runoff the river plants and the reservoir hydropower plants, considering the hydrologic regime and the existing macroclimatic conditions. The river discharges are modeled using a regime dependent stochastic model. In order to use this kind of models the macroclimatic condition has to be previously defined. In this case the users has several options to define the macroclimatic conditions: to use a dependent on the regime first order autoregresive mode, to use a re-sampling technique or to introduce a hydrologic scenario defined by the user.

The results obtained in this module are used in the market module to determine the dispatch by technology and particularly in the project being evaluated with the aid of this microworld. Thus, the river discharges into the hydropower plants (run of the river (HF) and reservoirs hydropower plants (HE)) are used to calculate the energy availability associated to these two technologies. The probable scenarios of ENSO occurrences are considered when selecting for each technology the supply curve associated to such conditions in order to define the global electric energy dispatch.

Market Module

In the market module the pool price formation process is modeled and the energy dispatch is made by technology and for the project being evaluated, based on the results from other modules that previously defined the hydrologic conditions, the energy demand and the capacity expansion.

The pool price in a Price Dispatch scheme is obtained by ordering the different amounts of energy offers (availability) by the price at which they are offered until demand is satisfied. In a Cost Dispatch scheme the energy price in the Occasional Market is defined as the short term marginal cost, and it is calculated as the cost of supplying the last unit of demand in the system load curve, including the necessary reserve for the wanted quality and reliability for the system.

The supply curves represent the energy amounts (availability) and the price at which it is offered to generate that amount of energy. These curves are constructed using the electric market historical information. The supply curves are defined for each energy generation technology that compose the system. The supply curves are dynamically modified with the entrance in operation of a new project. When a new project enter the system, the supply curve of the corresponding technology moves to the right a magnitude equal to its availability.

For both microworlds the pool price formation is obtained by horizontally adding the supply curves of the different technologies until demand is satisfied. The pool price or the marginal cost, depending on the market scheme, is then defined as the price at which the horizontal aggregation of the supply curves (specifically the amounts of energy available by technology) becomes equal to the demand. The amounts of energy associated to each technology conform the system dispatch. Microworlds also handle long term electric energy contracts and agreements, whose prices are an exogenous variable for the model.

The module uses annualized monthly volatility as an indicator of the system risk. The volatility is computed period by period as the standard deviation of the difference of the logarithms of the pool prices for the last twelve months and the monthly volatility defined in the same way but for all the simulation period (Jorion, 1997).

The results of this module (the project dispatch, the pool price and the long term contract price) are used in the financial module to calculate some investment performance indicators.

Expansion Module

The basic result of this module is a sequence of new projects to enter the electric energy generation system, which is used in the market module to modify the supply curves. In the expansion model two criteria can be used to define the expansion of the electric generation system: Minimum Cost of Mean Energy and the Availability Margin, or the Critical and the Expected Prices.

The criterion of minimum cost of mean energy and availability margin is simulated by estimating first the system availability margin and then it is compared with a minimum allowed value. When the margin is lower than that value the system is in a critical situation and it has to be expanded by entering new generation capacity. In this case the new projects are selected form a group of available projects, selecting the project that has the smaller Mean Energy Cost (MEC). The new project is entered into the system as long as its minimum time for design, construction and being ready for operation is less to the simulation time in which the model is.

In the criterion of Critical and Expected Prices (Dixit and Pindyck, 1994; Osorio, 2000) the investor decides to invest, through the comparison of a project characteristic (Critical Price), and a particular system characteristic in a given time period (Market Expected Price). The model assumes that the prices have a tendency to increase and they follow a Brownian Motion stochastic process. When the Market Expected Price is greater than the Critical Price the project enters the electric generation system, and the expansion of the system occurs. Like in the previous criterion, if in certain period several projects satisfies the Critical Price condition for entering the system, only the project that has the smallest Critical Price value will enter.

Financial Module

This module integrates the investments decisions taken by the user with the other moduls calculations such as hydrologic simulations, dispatch and capacity expansion, in order to evaluate the effect that the system conditions and their evolution would have on the project financial behavior. In this sense the user, acting as a potential investor, has the opportunity to evaluate the financial consequences of his decision by using the indicators and results of the financial module, throughout the simulation process and in the longer term (the useful life of the project).

The module simulates the financial statements of the project throughout its life (preoperative and operative), considering the possible financial and repayment conditions. With this base it computes several yield indicators to evaluate the project expected returns, for the project and for the investor, before and after taxes. Additionally, and for the case in which several simulations are carried out, the model provides several risk indicators. To perform this evaluations the model needs several elements that depend on the economic context of the country in which the project is located, such as the discount rates, the foreign exchange rates, or the tax and tributary regime.

Microworlds defines the project cash flow. The project benefits results from energy sales in the market at pool prices, and from energy sales through long term contracts at its corresponding prices. Additional benefits that the project could receive such as stand by power or available capacity offered to the system, are mechanisms existing in several countries to guarantee the system reliability and the adequate demand supply. The costs in which the project incurs are caused by operational and investment costs, and by the purchases of energy in the market to supply the contracts commitments that cannot be taken care with its own generation.

The used financial indicators are Net Present Value (NPV), the Internal Rate of Return (TIR), the Capital Recovery Period (CRP) and the Solvency Indicator, that allows to analyze the number of periods in which the project behave adequately (financially).

Vulnerability and robustness are the decision criteria used under risk and uncertainty. In the case of several simulations the model gives indicators such as the maximum, minimum, and mean values, several percentiles, distance to an ideal value provided by the user, etc., for each one of the return criteria series obtained as a result of computing the financial indicators for each simulation. The envelopment of the maximum and minimum values of the annual cash flow is also defined by the microworld. Several figures related to the obtained results are also presented including graphs of the indicators distribution.

7. MICROWORLDS APPLICATION CASES

Colombia was used as the case application for the Price Dispatch microworld and Panama for the Cost Dispatch microworld.

Price Dispatch Case: COLOMBIA

For the Colombian case information processed until year 1999 was used, the simulation was done using as a initial date of simulation December 1999. In the selected macroclimatic scenario (customized option) five ENSO events were defined, using the same starting date of December 1999. The used demand scenario corresponds to the Medium Energy Demand Scenario defined by the National Energy Planning Unit (UPME in Spanish).

The main characteristics of investment project to be analyzed are: a run of the river hydropower project with a installed capacity of 50 MW, with a mean plan factor of 0.85, and an annual mean energy of 372.3 GWh. The project can be finished and be in operation in a minimum time period of 24 months. The mean energy generation unit cost is 33 USD$/MWh, the expansion criterion to be used is the Critical and the Expected Prices assuming a expected market price of 50 USD$/MWh. The financial conditions considered for the simulations are: a 50% indebtedness capacity, a debt payment period of 12 years, an annual real interest rate on the loan of 8%, a rate of discount of 12%, costs of operation, administration and maintenance of 5 USD$/kW-year, investment costs of USD$ 42 millions, long term contracts representing 40% of the mean annual energy, and income taxes of 35%.

As a result of the application described above, Figure 2 presents the evolution of the system in terms of the supply and demand behavior. For the hydrologic and demand conditions previously defined, the system was always able to supply the demand requirements.

Figure 3, presents the dispatch for each technology during the simulation period. In the figure it can be noticed that hydropower and gas fueled plants are used more frequently than the other technologies. The gas fueled power plants increases its dispatch just before the ENSO phenomenon occurrence since in those periods the dispatch of hydropower reservoir projects are significantly reduced.

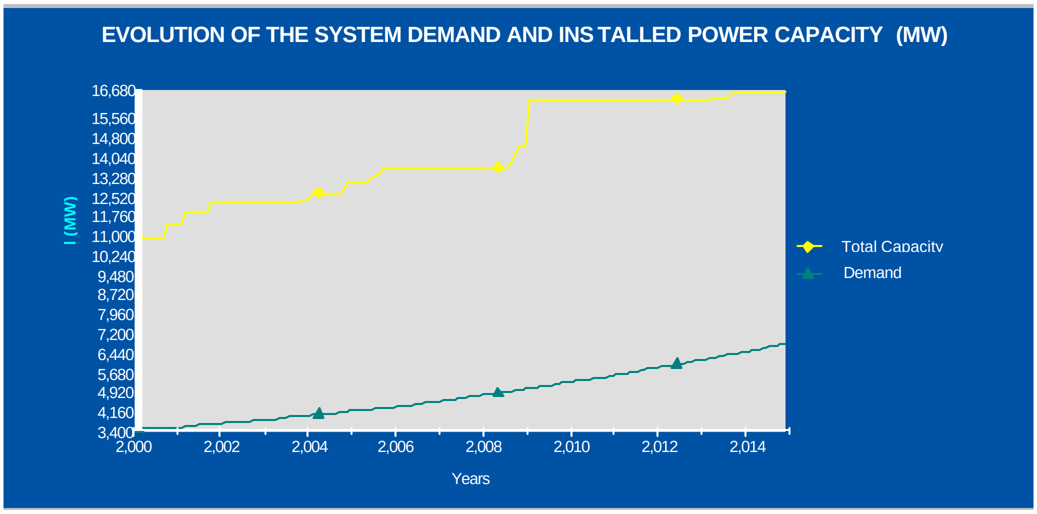

Figure 2. Evolution of the system demand and installed power capacity. Colombian Case.

Figure 4 shows the evolution of the market pool price obtained in the simulation. The pool price envelopment of the maximum , mean and minimum values are shown in that figure. In this graph it can be noticed the effect of the ENSO phenomenon on the pool prices. When ENSO occurs pool prices are significantly higher than in normal conditions.

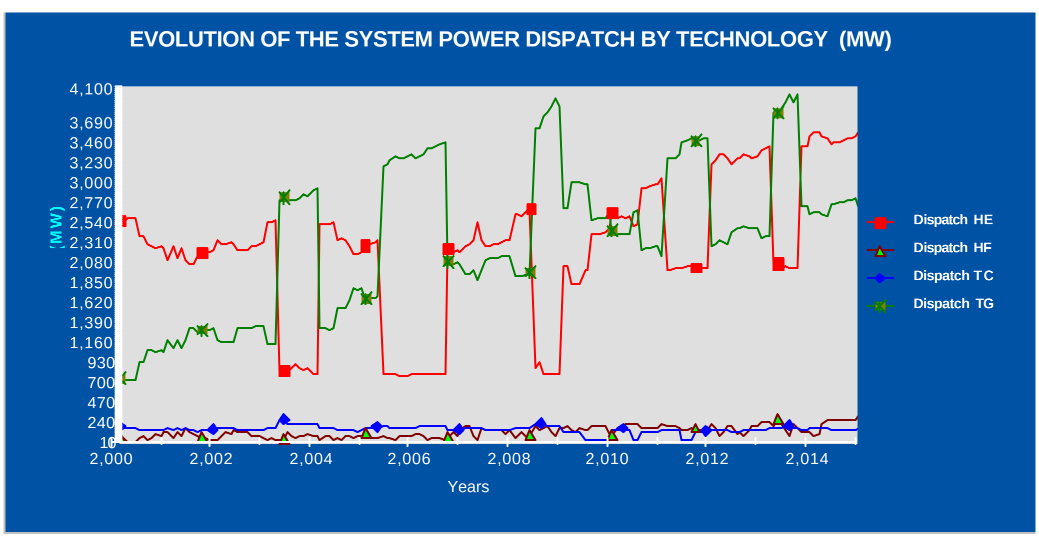

Figure 3. System power dispatch by technology. Colombian Case.

The obtained financial indicators and the cash flows, for the project and for the investor, before and after taxes, are shown in Figure 5. The results shows that the proposed investment is just acceptable. The obtained Net Present Values are positive before taxes, but the value before the financial leverage and after taxes is negative. This means that for the investor the project can be developed, specially taking into account that the solvency indicator is zero, meaning that under the assumed conditions the cash flow is always positive. Nevertheless, and even though that the Internal Rate of Return for the investor after taxes presents a value grater than 12%, the capital recovery period is quite long (from a private investor point of view). This would indicate to the investor the necessity to optimize the project, reducing investment costs or increasing the generated energy.

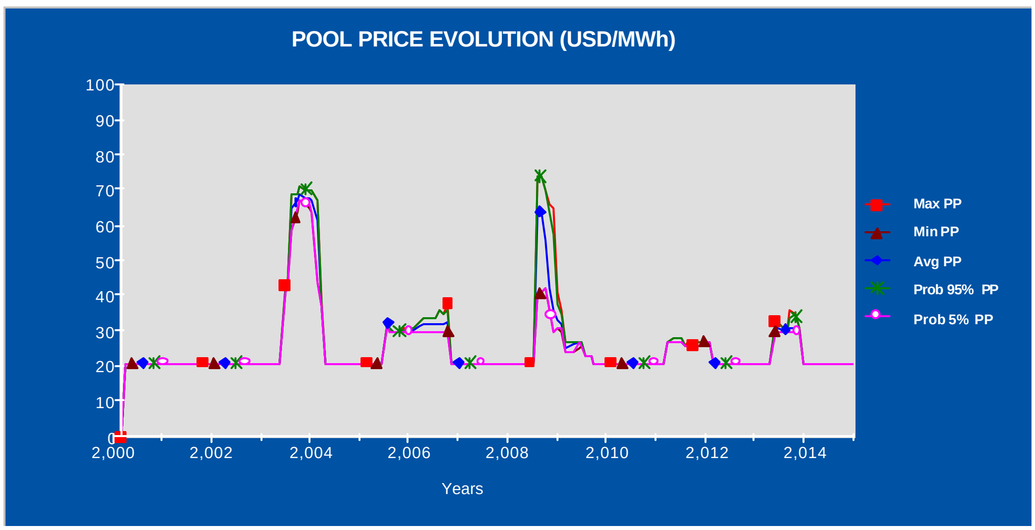

Figure 4. Pool price evolution. Colombian Case.

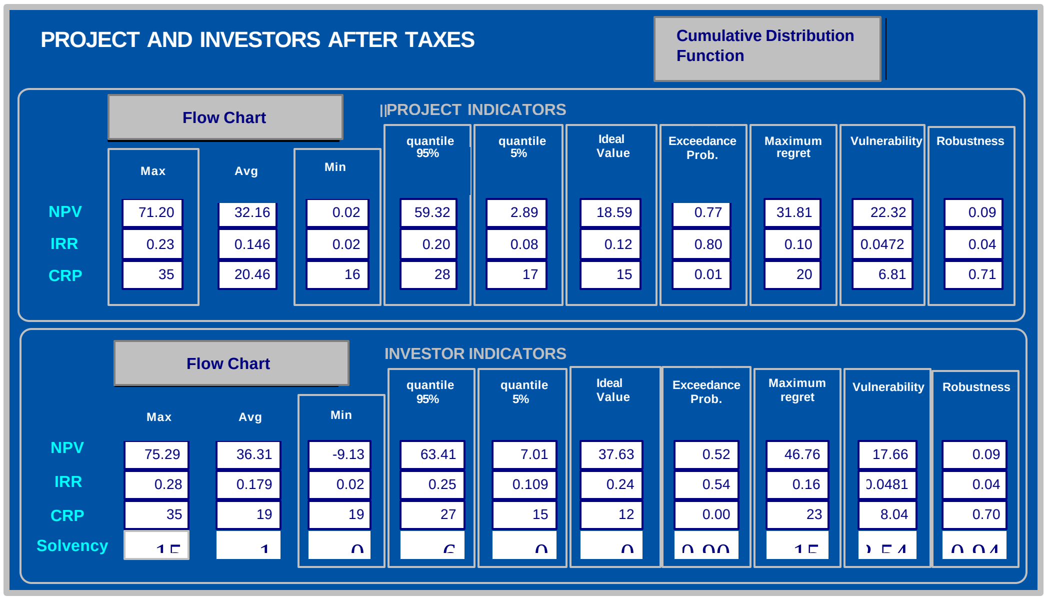

Figure 5. Financial Indicators of the proposed project. Colombian Case.

Cost Dispatch Case: PANAMA

For the application to Panama, and in general in the case of the countries with Cost Dispatch schemes, the construction of the supply curves requires information of the historical behavior of the declared energy availability for all the plants and its respective marginal costs, which are obtained from the dispatches made when carrying out the system operation optimization. The initial date of simulation of the model for Panama is January 2001.

In the Panamanian energy market some of the fuel power plants have already several years of operation, which is reflected in the energy prices (high operational costs). Usually, when thermo generation plants has a important participation in the energy market, market prices are significantly higher than in the normal condition case. Panama climatic variability has a important effect in the energy cost since the two most important plants are hydropower plants. One of them is located in the Pacific Ocean side of the country and the other one in the Atlantic Ocean area, looking for a reduction of the seasonal variability over the country.

For Panama the simulation conditions correspond to specific macroclimatic scenarios with the customized module of hydrology defining five ENSO events. The used energy demand scenario corresponds to the higher one during a summer period, which is proposed by company ETESA (The Panamanian National Energy Utility).

The main characteristics of the project to be analyzed are as follow: a run of the river hydropower project with 42.5 MW power capacity, a mean plant factor of 0.85, and a mean annual energy of 316.5 GWh. The project can be finished and be in operation in a minimum time period of 24 months. The mean energy generation unit cost is 33 USD$/MWh, the expansion criterion to be used is the Critical and the Expected Prices assuming a expected market price of 50 USD$/MWh. The financial conditions considered for the simulations are: a 50% indebtedness capacity, a debt payment period of 12 years, an annual real interest rate on the loan of 8%, a rate of discount of 12%, costs of operation, administration and maintenance of 5 USD$/kW-year, investment costs of USD$ 42 millions, long term contracts representing 40% of the mean annual energy, and income taxes of 25%.

In general, the Panamanian system presents as a dispatch characteristic a cost increase of the reservoir hydropower technology under ENSO conditions, until almost reaching the cost of thermal power plants. In Figure 8 the financial indicators of the evaluated project are presented.

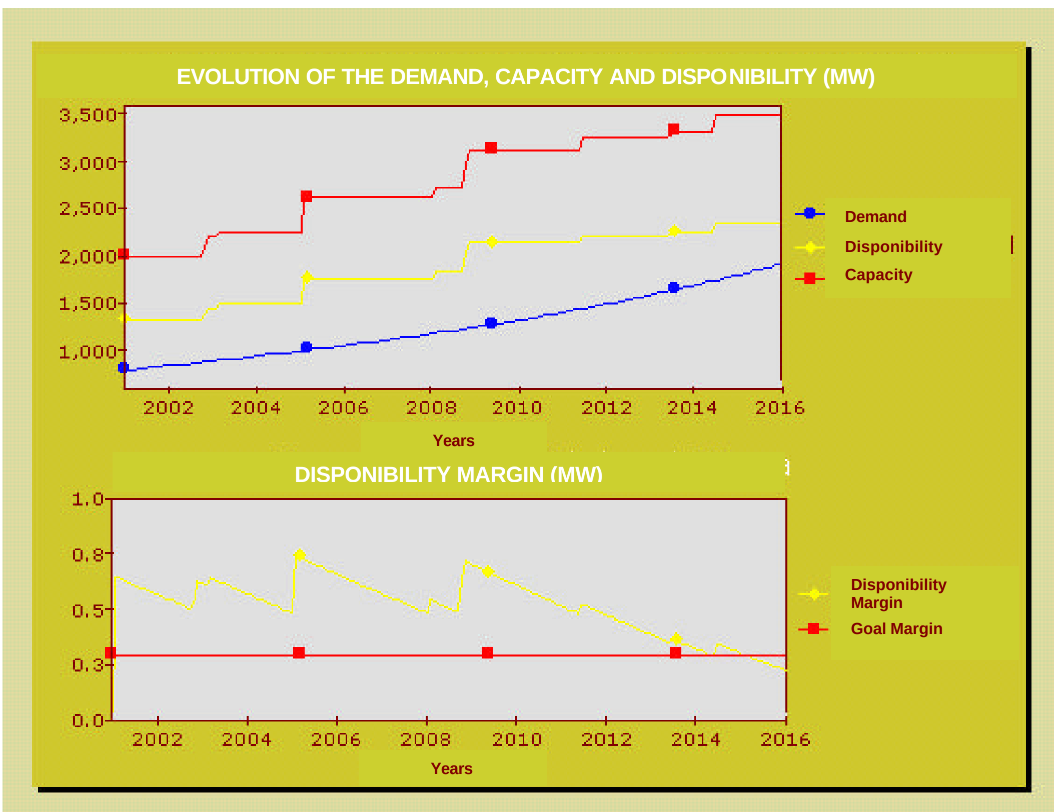

Figure 6. Electric system evolution. Panama Case.

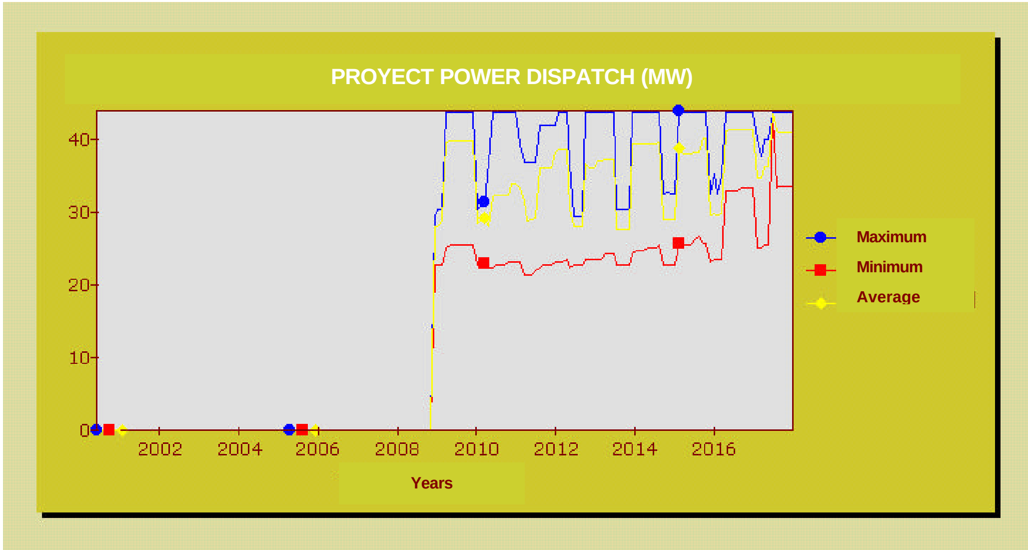

Figure 7. Project power dispatch. Panama Case.

FINANCIAL INDICATORS

Project Before Taxes

	Maximum	Minimun	Average
NPV	17.27	17.24	17.26
IRR	17.00	17.00	17.00
CRP	21.00	21.00	21.00

Project After Taxes

	Maximum	Minimun	Average
NPV	7.28	4.53	4.57
IRR	14.00	13.00	13.01
CRP	27.00	27.00	27.00

Investor Before Taxes

	Maximum	Minimun	Average
NPV	19.91	16.25	16.30
IRR	20.00	20.00	20.00
CRP	20.00	20.00	20.00

Investor After Taxes

	Maximum	Minimun	Average
NPV	10.74	7.98	8.03
IRR	16.00	16.00	16.00
CRP	24.00	24.00	24.00

Figure 8. Financial indicators for the project and the investor. Panama Case.

8. CONCLUSIONS AND RECOMMENDATIONS

- Both developed Microworlds are directed to investors in electric energy generation and other people interested in the industry. In this sense a tool was developed for learning and to analyze complex problems associated with the investments decision making in electric energy generation markets. The user can modify the different parameters and make decisions while observing how the system evolves and the effect of his decision over the system.

- System Dynamics was used to represent the market interactions in both microworlds. It is a powerful tool for the modeling of market systems with complex dynamics.

- Both microworlds behave properly when applied to Colombia (Price Dispatch case) and Panama (Cost Dispatch case). The obtained results are acceptable and in concordance with what can be expected.

- The implemented Microworlds can also be used to analyze others aspects of the electric energy markets such as: the impact of regulatory alternatives for the market being analyzed, risk and uncertainty analysis of some variables like demand and capacity expansion, and the analysis of the integrated Latin American electrical sector.

- It is expected to develop microworlds for other sectors with market structures to support learning or decision processes such as the water supply sector, telecommunications, waste management, and others.

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