Small hydro power stations, a way to secure electricity supply in Colombia. A policy evaluation using a system dynamics model

by

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Abstract

After its deregulation in 1994, the Colombian Electricity Market (CEM) has developed satisfactorily in some sectors, especially in terms of generation and sales to large costumers and to household sector. However, around 70 % of its production capacity is based on hydroelectric power stations that are built using one or more dams. The available water in the dam (considered potential electricity) is from time to time affected by severe weather conditions which might reduce the water inflow by up to 50 %. The macroclimate phenomenon called ENSO (El Niño South Oscillation) is a strong dry season or drought that occurs randomly. Therefore, to secure electricity supply, additional power stations might be required in the face of the upcoming severe weather conditions. Over the last years, and according to expected demand, the Colombian planning unit, UPME, has developed a capacity expansion plan which includes the power stations that should come into operation in the near future. The construction of two main power stations with dams was, however, canceled due to social and environmental concerns.

The main objective of this thesis is to evaluate whether these larger projects can be replaced through the construction of small hydro power stations that, each, has a lower generation capacity, but in total have less social and environmental impact. In this thesis, we present a System Dynamics model of the CEM including the supply from various competing technologies; hydro and thermal. The thermal fired power plants are used sparsely due to their high costs causing the electricity price to rise. Therefore, they will only generate electricity in order to satisfy the demand that is unmet after the hydro scheduling. The future market development will be evaluated under different scenarios that combine variations in the paths of investment in small hydro power stations, expected electricity demand, gas and coal prices, and weather conditions.

Key words: hydro power stations, thermal power stations, investment, electricity price, weather conditions.

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Introduction

Until the early nineties, the Colombian Electricity Market (CEM) was formed by thirty companies; all of them were state owned. The deregulation of the CEM was decided in 1993 by the Colombian Government due to reasons such as:

- The electricity sector's debt turned into a macroeconomic problem because it built up, and constituted 40% of the foreign debt.
- Two major blackout periods, the former in 1983 and the latter in 1992 – 1993, that caused a high increased in the electricity price.

After evaluating the situation and considering some policies, the Colombian Government concluded that increasing the capacity of the Colombian electricity system is one way of decreasing the likelihood of a new blackout, and increasing the efficiency of existing capacity is the second way of improving the electricity system. However, and due to a tight budget and the poverty eradication as a priority, the government was aware of its inability to finance this expansion of capacity. So non-government intervention was needed, i.e. private and/or foreign investment.

In 1994, laws number 142 –on residential public services- and 143 – on electricity- passed and defined the initial design of the Colombian deregulation. A year later the electricity pool was created, permitting deregulation to take place and the new electricity market to operate. The English framework was adapted considering the difference of structure and technologies in Colombia compared to England. The electricity market was deregulated and a mixed ownership structure was allowed (i.e. private and public). A new regulatory institution was created and named as CREG (Regulatory Commission for Electricity and Gas). So generators and suppliers are limited to a market share of no more than 25 % of the total. A 24-hour-ahead pool was designed and within it electricity demand and electricity supply are balanced in the short term. A second notable institution was set up, UPME, a planning unit that is entrusted with undertaking the long term capacity expansion plan, the short term transmission expansion plan and policies on rational energy use.

After its deregulation in 1994, the CEM has developed satisfactorily in some sectors, especially in terms of generation and sales to large costumers and to household sector. However, around 70 % of its production capacity is based on hydroelectric power stations that are built using one or more dams. The available water in the dam (considered potential electricity) is from time to time affected by severe weather conditions which might reduce the water inflow by up to 50 %. The macroclimate phenomenon called ENSO (El Niño South Oscillation) is a strong dry season or drought that occurs randomly. Therefore, to secure electricity supply, additional power stations might be required in the face of the upcoming severe weather conditions.

Over the last years, and according to expected demand, the Colombian planning unit, UPME, has developed a capacity expansion plan which includes the power stations that should come into operation in the near future. The construction of two main power stations with dams was, however, canceled due to social and environmental concerns. The main objective of this thesis is to evaluate whether these larger projects can be replaced through the construction of small hydro power stations that, each, has a lower generation capacity, but in total have less social and environmental impact.

In this thesis, we present a System Dynamics model of the CEM including the supply from various competing technologies; hydro and thermal. The thermal fired power plants are used sparsely due to their high costs causing the electricity price to rise. Therefore, they will only generate electricity in order to satisfy the demand that is unmet after the hydro scheduling. The future market development will be evaluated under different scenarios that combine variations in the paths of investment in small hydro power stations, expected electricity demand, gas and coal prices, and weather conditions.

We conclude that the electricity price will rise significantly under the high and moderate demand scenarios. Therefore, the small hydro power plants, that were taken into consideration in the density distribution of capacity with the aim of replacing the canceled projects, must come on line under those scenarios. However, these additional small hydro power stations will not get the desired profits in the case of a low demand, due to the forecasted electricity price is below their critical price.

We also conclude that the electricity price will rise in the upcoming years, regardless to the expected weather conditions, under a high or moderate electricity demand. However, the projects that are already registered before UPME, and the small hydro power plants (assumed in the investment behavior) will reduce the electricity price when coming online. Therefore, oscillations will be a constant in the electricity price in the future. The electricity price trend will portray a linear or exponential growth depending on the electricity demand scenario that is considered. In the case of a drought and under a high electricity demand scenario, the CEM might face some blackouts.

Additionally, we conclude that the trend of a generation capacity mainly based on hydro power stations in Colombia seems not likely to change. The gas fired thermal plants must not be considered as feasible due to the expected increase in the gas price after 2019. The new investments are focused on hydro power stations as seen in the projects already registered before UPME.

This paper is organized as follows. The first chapter presents a general description of the CEM, and the reference modes. The second section defines the problem that is studied in this thesis. In addition, the second section reviews previous researches related to the electricity sector (in general), and also regarding to the CEM. The third chapter presents the system dynamics model use to represent the operation of the CEM. The fourth section describes the tests that were conducted in order to validate the model. The fifth section presents the expectations of several variables that are important for forecasting the development of the CEM. In addition we explain the resulting simulation. Finally, conclusions are presented.

1. The Colombian Electricity Market (CEM)

1.1. Description of the CEM

1.1.1. Previous to deregulation

Until the early nineties, the electricity sector in Colombia was formed by thirty companies; all of them were state owned. The three main cities –Bogota, Medellin and Cali- had their own companies which operated all the activities along electricity supply chain. The national grid worked properly since the seventies. Generation assets were properties of five companies –EPM, EEB, ISA, Corelca and CVC-. ISA was the largest generator and also the owner of the transmission grid and was responsible for the operation of the system. At that time, the capacity expansion was made in accordance with a generation and transmission plan with the aim of satisfying domestic demand. Investments were financed through loans granted by international banking, but guaranteed by the state. electricity sector's debt turned into a macroeconomic problem because it built up.

Finally, it constituted 40% of the foreign debt. (Velez, 2012)

Additionally, the three main reasons why deregulation was decided on in 1993 by the Colombian Government were (Larsen et al 2004):

- *Two major blackout periods,* the former in 1983 and the latter in 1992 – 1993. These blackouts impacted the political life significantly and forced the government to find a way to avoiding that this would happen once more.
- *Increasing the capacity of the Colombian electricity system is one way of decreasing the likelihood of a new blackout:* Due to a tight budget and poverty eradication as a priority, the government was aware of its inability to finance this expansion of capacity. So non-government intervention was needed, i.e. private and/or foreign investment.
- *Increasing the efficiency of existing capacity is the second way of improving the electricity system:* This would be feasible predominantly by means of deregulation and promoting incentives for the private sector.

1.1.2. Legal framework for deregulation

In 1994, laws number 142 –on residential public services- and 143 – on electricity- passed and defined the initial design of the Colombian deregulation. A year later the electricity pool was created, permitting deregulation to take place and the new electricity market to operate.

The English framework was adapted considering the difference of structure and technologies in Colombia compared to England. The electricity market was deregulated and a mixed ownership structure was allowed (i.e. private and public regardless of its types, central or regional government), instead of a full privatization that was implemented in England. Low income consumers kept their subsidies from customers with a higher income, from commercial consumers and also from state subsidies. These subsidies are financed by increasing prices (i. e. cross subsidies).

A new regulatory institution was created and named as CREG (Regulatory Commission for Electricity and Gas). So generators and suppliers are limited to a market share of no more than 25 % of the total. A 24-hour-ahead pool was designed and within it electricity demand and electricity supply are balanced in the short term. A second notable institution was set up: UPME is a planning unit that is entrusted with undertaking the long term capacity expansion plan, the short term transmission expansion plan and policies on rational energy use (Larsen et al, 2004).

1.1.3. The evolution of electricity sector since 1995 and its current operation

During the following years the State sold the most of its participation in generation assets and, afterwards, almost the total of distribution companies as well. EEB –Empresa de energía de Bogota- was split into a generation firm -EMGESA- and a distribution one -CODENSA-; both of them were partially sold to the private sector. New agents have come and introduced many changes in the ownership. Currently, the sector consists as more than forty generation companies, seventy traders, thirty grid operators or distributors and ten owners of transmission grids. XM, ISA's subsidiary (ISA is the largest transmitter in Colombia), is the company that manages the system. More than 4600 major customers represent 30 % of the total demand and they are allowed to purchase their electricity by means of long term agreements. These clients are considered the unregulated ones. (Velez, 2012)

The operation of the electricity sector in Colombia is described with the help of Fig. 0, in which green lines represent cash-flow. Consumers are classified into regulated and unregulated.

Unregulated consumers must demand at least 0.1 MW a month or 55 MWh/month. They are allowed to purchase their supply by means of financial bilateral contracts with traders. In those contracts, they can agree to a price and the amount of electricity to be delivered. On the other hand, regulated consumers pay their consumed electricity according to a tariff formula established by the regulator.

Traders collect consumers' payments and discount their margins. Then, traders pay the electricity that was agreed upon in their long term agreements with the generators and they also pay the use of the grid to distributors. Distribution system covers voltages below 220 KV. These networks are known as local distribution grid, LDG, and regional distribution grid, RDG.

The electricity that is purchased on the stock exchange, the use of the national transmission grid (NTG, voltage above 220 KV), and the operational cost of the system are transferred to the company that operates the system and manages the market, XM. Finally, XM pays generators for electricity sales that were agreed on the stock exchange and also pays for the use of grid to transmitters.

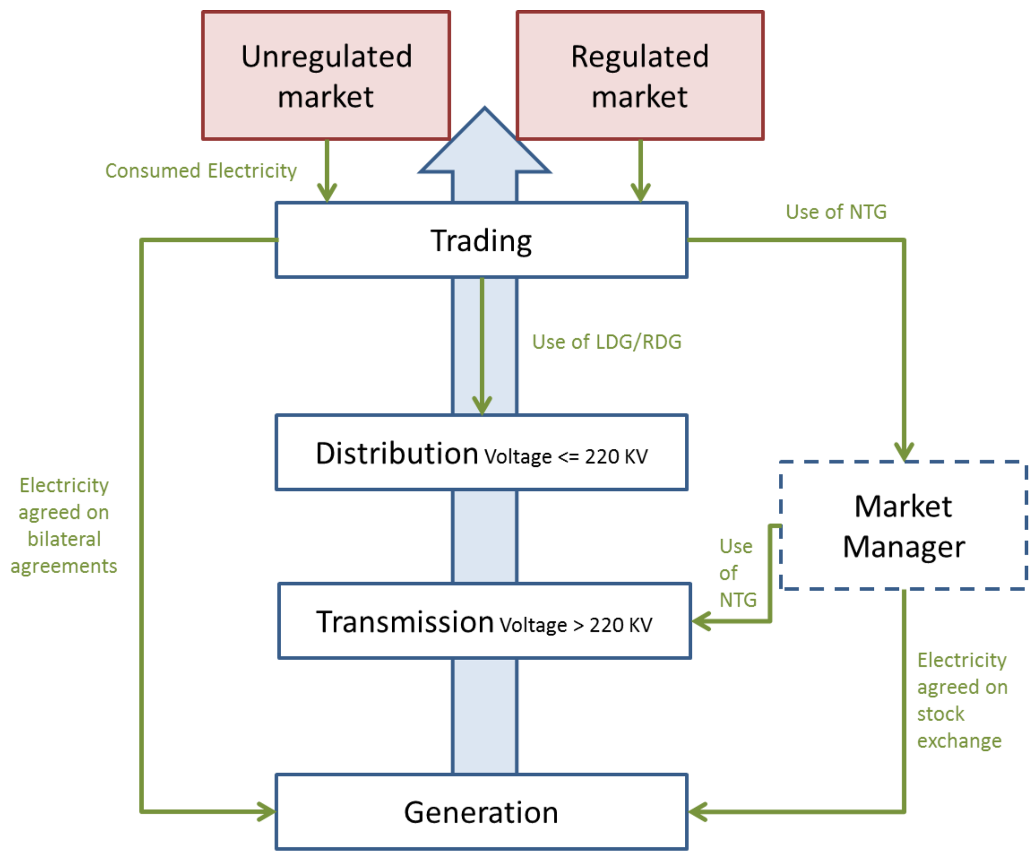

Figure 0: Operation of electricity sector in Colombia **(Velez, 2012)**

1.1.4. Wholesale market

Generation and trading are under a regime of free competition. However, transmission and distribution are regulated as monopolies. Generators, traders and unregulated consumers are the main agents on the electricity wholesale market. It has two components, the short term market and long term market. The former is also named electricity stock exchange which is exclusive to generators and traders. The latter is a market for bilateral agreements in the long term in which all the main agents can participate.

1.1.5. Short term market: energy stock exchange

The energy stock exchange has been in operation since 1995; it is a daily auction that determines which power stations will generate electricity the day after. Each generator offers its power stations with a unique price for the next 24 hours and it also declares time availability and inflexibilities. These prices must include the variable cost of fuels for thermal power stations and the water opportunity cost for hydroelectric power stations.

The market manager organizes the offers according to their merit (from lowest price to highest) until covering the projected demand for each hour. Total supply is determined at the price offered by the last power station required to satisfy demand, i.e. the highest price offered by those generators that will supply. This price is named the marginal price of the system (MPS).

The sum of each generator production plus its purchases on long term agreements is compared to its sales on long term contracts: the difference is its net purchases or sales on the stock exchange. These are liquidated at the corresponding MPS each hour. For example, see Fig. 1: “A generator” dispatches 230 MW and it had sold 180 MW, so it sold 50 MW on the stock exchange. “B Generator” dispatches 150 MW and it had sold 180 MW, so that it must buy 30 MW on the stock exchange. Finally, “C trader” has sold contracts for 200 MW and purchase agreements for 180 MW, so it must purchase 20 MW on the stock exchange. Differences arising between projected production and real supply can be due to unforeseen events. (Velez, 2012)

1.1.6. Long term market: forward market

Generators, traders and unregulated consumers take part in this market. They freely agree on price and quantities of energy to be supplied. The unique requirement from the state is that the contracts have to exhibit the quantities to be delivered per hour in such a way that agreements can be liquidated against the real supply.

Traders, who supply regulated customers, must agree supply according to the lowest price on auctions. All the contracts have to be registered with the market manager because it is in charge of liquidating the contracts.

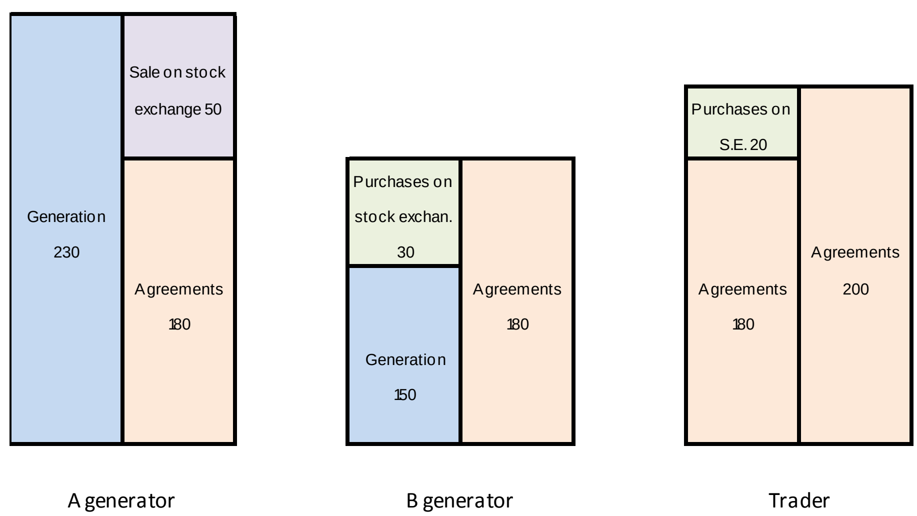

Figure 1: Liquidation of Electricity contracts (modified from Velez, 2012)

1.1.7. The reliability charge

Guaranteeing the investments in new generation capacity is one of the main problems of deregulated electricity markets. Theoretically, there is an efficient and competitive spot market, where the prices reach the equilibrium. When the demand is close to the supply, the electricity price will reflect the marginal cost of supply. When approaching a situation characterized by frequent shortages, the electricity price will increase and benefit the marginal power stations that satisfy peaks of demand and generate electricity for a few hours in the entire year. This market mechanism involves the implicit acceptance by all the agents involved, including the government as regulator, of an increase in electricity price above its average value (reflecting a normal supply demand ratio) with the aim of activating those marginal power stations. (Velez, 2012)

As electricity demand is considered inelastic in the short term, the marginal power stations can be considered as monopolies during that same period of time. Hence, it is the necessary to set a maximum value for the spot price. The basic idea is to create a financial instrument intended to protect the regulated consumers from sudden price increases, yet at the expense of a premium which is paid monthly. In the Colombian case, this reliability charge is the mechanism that encourages investment in new generation capacity and ensures the reliability of the long term supply of electricity in Colombia. (Velez, 2012)

The reliability charge is a premium that is paid to those generators that have accepted the obligation to supply the firm energy (ENFICC, in Spanish). A firm energy obligation is an amount of electricity that the generators are committed to supply during the validity of the contract when the marginal price of the system (MPS) is higher than a pre-determined scarcity price. This firm energy shall be supplied to a fixed price that is called the scarcity price and is set by the regulator. The firm energy of any plant is the maximum constant electricity that a generator can produce under low hydrologic conditions during a year. There is a method to estimate the ENFICC according to the power station technology. The reliability charge is a mechanism that operates as a call option. (Dyner at el, 2008, Harbord & Pagnozzi, 2008)

Generators supplying energy under an ENFICC are paid the scarcity price for the amounts of energy supplied up to their committed quantities, and receive the spot price or marginal price of the system on any additional quantities: (Harbord & Pagnozzi, 2008, Dyner at el, 2007)

$$PFM = RC + \min(MPS, SP)$$

Where PFM is the price of the delivered electricity that was committed on ENFICC, RC is the option price or premium that is called the reliability charge; MPS is the marginal price of the system or electricity pool price and SP is the scarcity price.

1.2. Reference mode

Fig. 2 portrays the most significant variables of the Colombian Electricity Market. These variables will be assumed as reference mode when designing and validating our model. Fig 2.a. shows the installed generation capacity (in MW) that is mainly constituted by hydro power stations (blue line). As a consequence of a large hydro installed capacity, the electricity generation is also dominated by hydro generation. However, Fig. 2.b. reveals that the thermal power stations (blue and orange lines) gain a large relevance in the electricity generation, when the hydro generation decreases; see the periods 1998 and 2009. As the thermal generation increases the electricity price sharply rise as a consequence, as shown in Fig. 2.c.

Figure 2: Reference Modes

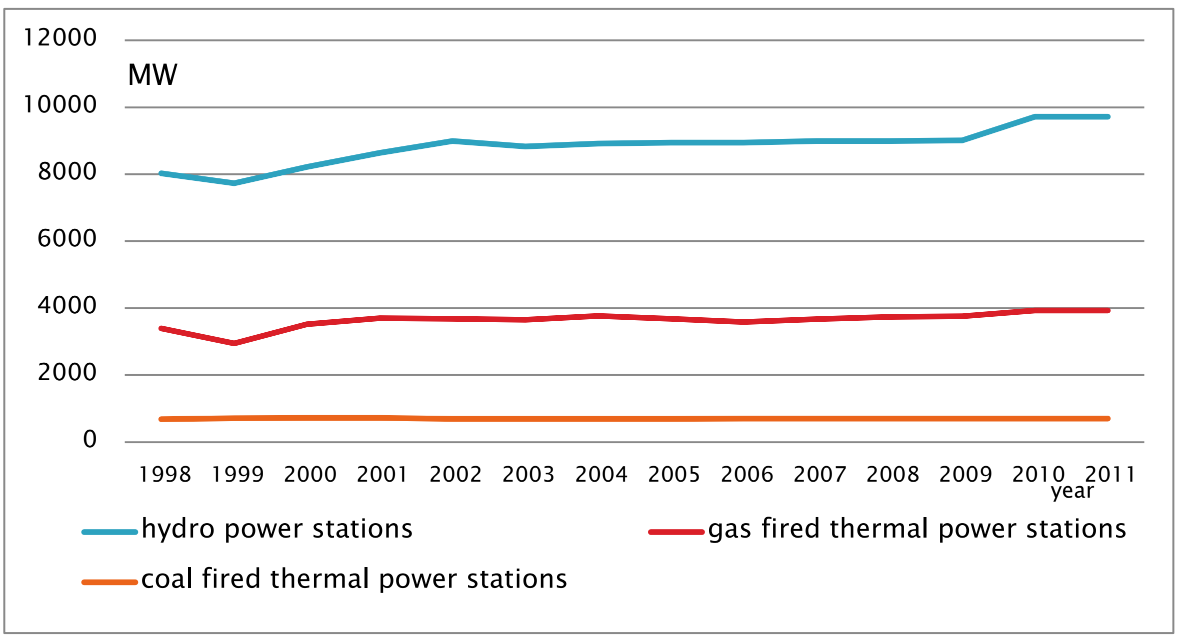

Fig. 2.a: Installed Generation Capacity (Reference Mode)

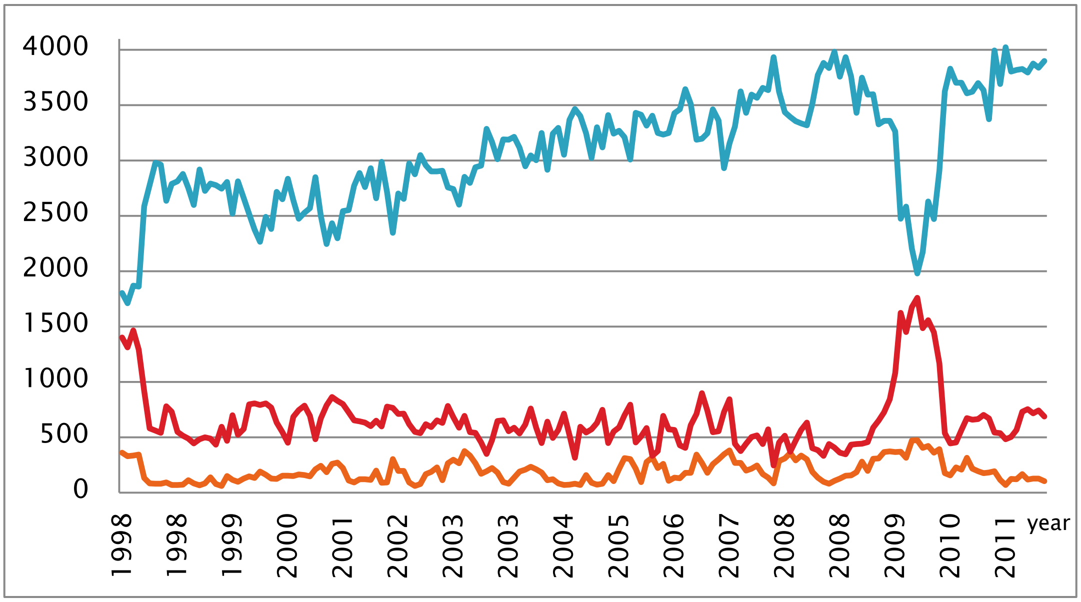

Fig. 2.b: Electricity Generation (Reference Mode)

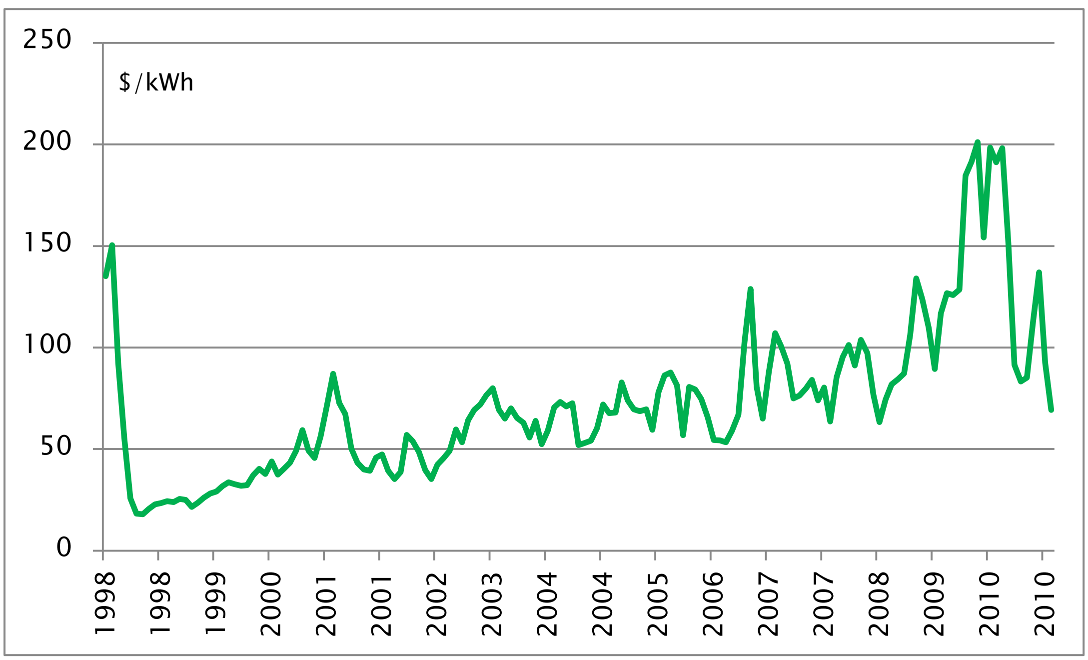

Fig. 2.c: Electricity Price (Reference Mode)

2. The Problem

After deregulation, Colombian Electricity Market (CEM) has developed satisfactorily in some sectors, especially regarding generation, sales to large costumers and household sector. (Larsen et al, 2004). However, CEM's characteristics are unique: Around 70 % of its production capacity is based on hydroelectric power stations. In many cases, hydroelectric power stations are built using one or more dams. Those dams are from time to time affected by severe weather conditions which might reduce the water inflow by up to 50 %. The macroclimate phenomenon called ENSO (El Niño South Oscillation) is a strong dry season or drought that occurs randomly. Therefore, to secure electricity supply, new power stations might be required when the next severe weather condition occurs.

Over the last years, and according to expected demand, the Colombian planning unit, UPME, has developed a capacity expansion plan which includes the power stations that should start operation in the near future. These new projects were awarded generation companies that were financially able to construct the power stations and to do so for the lowest price. However, the construction of two main power stations with dams was canceled due to social and environmental concerns. They were expected to produce a total of 535.2 MW by 2015.

The main objective of this thesis is to evaluate whether these projects can be replaced through the construction of small hydro power stations that each one has a lower generation capacity, but in total have less social and environmental impact.

In order to secure electricity supply, the Colombian energy planning unit, UPME, must determine when the construction and operation of the required small hydro power stations must start. On the other hand, investors are predominantly concerned with the expected profitability of the required small hydro power stations.

In the electricity market, as in any other deregulated market, the electricity generation price is set according to the electricity generation cost and the market competition. The electricity generation cost changes from generator to generator due to the fixed cost and the variable cost. The fixed cost includes the construction cost, the debt cost, the operating and maintenance cost. On the other hand, the variable cost depends on the production or generation level. The electricity generation cost is usually expressed in terms of $/MWh.

For any investment project like small hydro power stations, all the possible investors have calculated their electricity generation cost. As an example, a density distribution of investors in hydro power stations in the US is shown in Fig. 3 (U.S. et al., 2007). This density distribution of investors symbolizes how many investors will generate at a set electricity generation cost. As electricity production will always incur expenses, there is no investors who will produce at 0 $/MWh or close. Fig. 3 also shows that few investors will generate at a low cost, below 30 $/MWh. There are mostly investors who will generate electricity at a cost above 30 $/MWh but lower than 50 $/MWh.

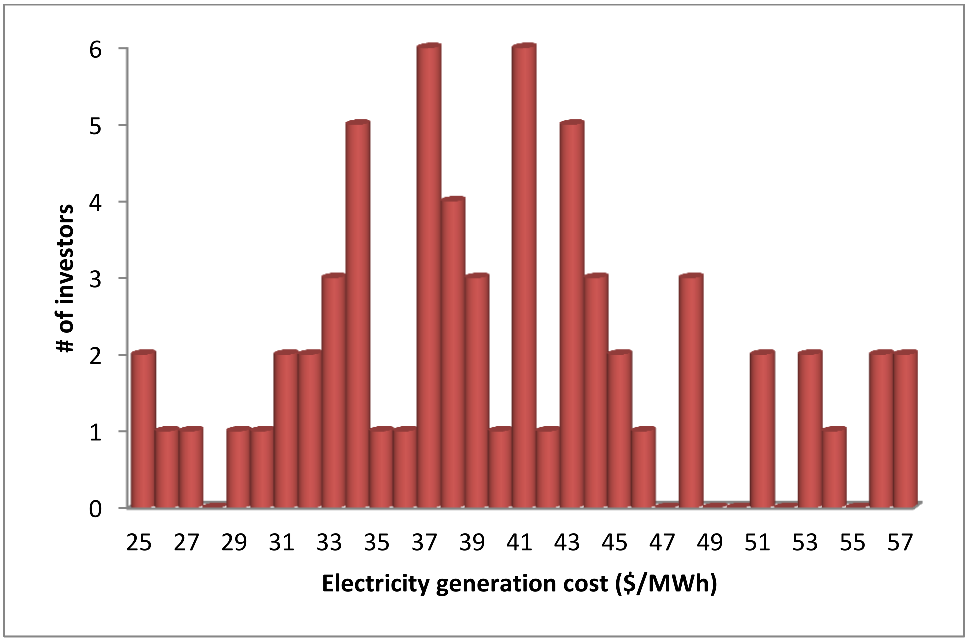

Figure 3: Density distribution of investors(U.S. et al., 2007)

The normalized cumulative distribution of investors is shown in Fig. 4 and represents the fraction of investors generating at current electricity generation cost or lower. This graph shows a fast accumulation of investors in percentage terms when the electricity generation cost runs from 30 $/MWh to 45 $/MWh.

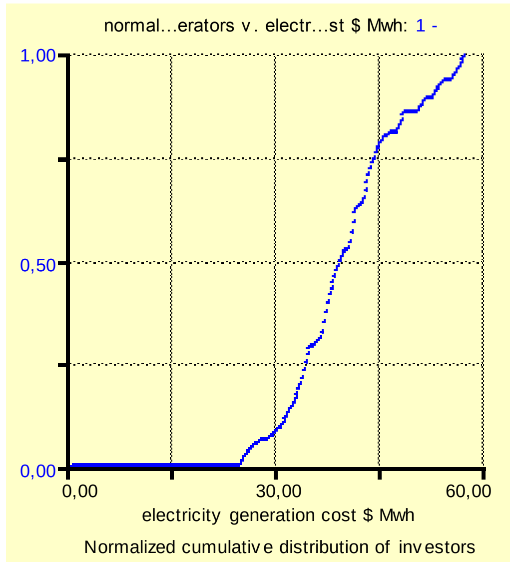

Figure 4: Normalized cumulative distribution of investors

Even though the electricity generation cost is an important factor when deciding on investments, other factors must be considered and will be included in the model that is being designed; factors like the current electricity generation price, its expected behavior in the future and how the market mechanism works.

In order to illustrate how the market mechanism works, we will refer to the previous example. If the expected electricity generation price is above 50 $/MWh in 2009, the investors with electricity generation cost below 50 $/MWh (in Fig. 3), will consider their investments as profitable. By way of illustration, we can assume an investor, named as X, who according to the previous market conditions decides to construct a small hydro power station with an associated cost of 40 $/MWh in 2009. The small power station is completed 2 years later, in 2011. However, other power stations were also completed during these 2 years and will also generate electricity at that time. The recently completed power stations have changed the market balance and as the supply is larger, the electricity price was reduced and is currently 38 $/MWh in 2011.

When X is ready to start to generate electricity in 2011, the electricity price of 38 $/MWh is below the electricity generation cost of 40 $/MWh and there is no profitability on generating or the expected profits are diminished.

Nevertheless, other generators can make the choice of pulling out their power stations or not generate. Additionally, the electricity demand is increasing over time. In 2012, the excess of generation capacity is reduced by means of an increasing demand and the electricity generation prices increases until 43 $/MWh. Under these new market conditions, X will generate and gain a net profit from its activity. We used X as an investor to illustrate a process that is dynamic in which each investor does not know the choices of the rest of investors, but has to make his own choices. Hence, a system dynamics model is required in order to analyze the interactions among investors and the electricity market, but guaranteeing a secure supply.

2.1. Literature review for model construction

Previous to Ford (1996), quite a few applications of system dynamics had been developed in the energy sector. The most important applications related to electric power industry are listed in Systems Dynamics and the Electric Power Industry (Ford, 1997, 59). Additionally, through his document, Ford portrays the debate on small power generators versus large power stations in the US and describes key feedback loops in the utility system. The three main loops that should be considered are represented in Fig. 5.

The first loop in Fig. 5 is the construction loop. This is a goal seeking or balancing feedback loop that represents the utility's intention to match the capacity needs with the installed capacity.

The "death spiral" in Fig. 5 is a reinforcing loop. It involves the electricity prices and consumers' reaction to the prices. According to Ford "the indicated price stands for the price of electricity that regulators would normally allow the utility generate the allowed revenues". If indicated price increases, the actual price will also increase after a delay for regulatory review. Considering a delay among price's change and consumers' reaction, a decline in electricity consumption would be expected to result. Subsequently, a reduction in electricity consumption will result in an increase in the indicated price. This reinforcing feedback loop can be considered as disadvantageous feedback, due to its negative effect on the market: higher prices and lower consumption. The "death spiral" represents the price mechanism in the short term.

The larger loop in Fig. 5 was named the delayed demand control loop by Ford. This loop is a counteracting feedback loop. After an increase in the actual price, a reduction in electricity consumption would be expected, and likewise a reduction in the forecast of capacity needs. This results in a reduced capacity initiation rate, reduced installed capacity, reduced allowed revenues, and reduced actual price. This loop can also be interpreted as the price mechanism in the long term. Price influences the forecast of capacity needs and later, this forecast determines the installed capacity's behavior. So as to counteract the current price development.

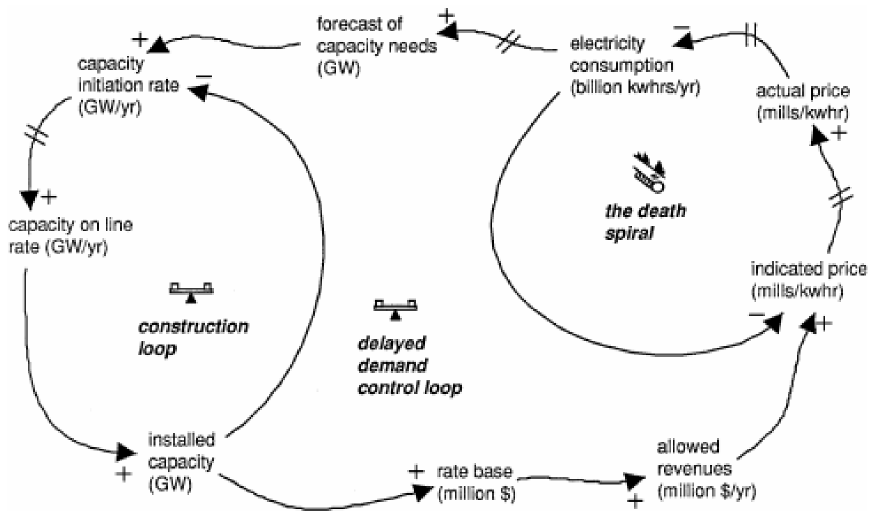

Figure 5: Key feedback loops in the utility system (Ford, 1996)

The electricity sector in Colombia has been analyzed through system dynamics' applications as well. Some authors, in particular Dyner and Arango have used Ford's work as a starting point. However, some modifications have been needed to adapt Ford's model to the Colombian case. Through their paper "Can a reliability charge secure electricity supply? An SD-based assesement of the Colombian power market", they present a general causal loop diagram for the policy analysis in the Colombian electricity market. This diagram is shown in Fig. 6. (Dyner et al, 2007)

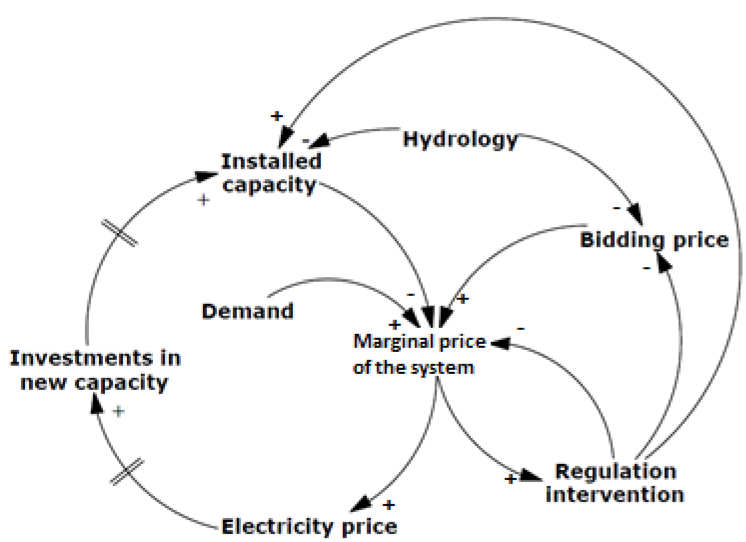

Figure 6: General causal loop diagram for the policy analysis in CEM (Modified from Dyner et al, 2007)

Initially, according to Dyner at el (2007), the electricity demand in Colombia is expected to develop as described by the scenarios considered by UPME (2010.a.). In system dynamics terms, demand can be considered an exogenous variable.

Ford's construction loop is replaced with an investment loop that is shown to the left in Fig. 6. An increasing electricity price will after a delay lead investors to finance capacity under construction (investments in new capacity). After a construction time, this capacity under construction will be completed and considered installed capacity. A larger installed capacity will reduce the marginal price of the system and so, the final electricity price. The marginal price of the system represents the generation price. However, other components like: transmission price, distribution price and trading price are included in the final electricity price.

According to their installed capacity and existing constrains, every day generators offer to the market an amount of electricity to a set price. The market manager organizes the supplies according to price (from lowest to highest price) until the total demand has been covered. The total supply is payed at the price that was offered by the last power station involved in satisfying the demand. This price is the system's marginal price and the process is called economic dispatch. Hence, electricity price is a consequence of the economic dispatch in the investment loop.

Hydrology has a large effect on the Colombian electricity market. Dyner et al represents the effect of hydrology on installed capacity and bidding price in Fig. 6. On the one hand, hydroelectric power stations modify their production according to the availability of water. On the other hand, hydrology influences generator short term variable costs, and so the electricity price that is offered by the generators.

Government as regulator intervenes in the system. The regulator adjust the long term market rules and investment incentives. After the deregulation of the electricity market in Colombia, two different mechanisms have been implemented with the aim of increasing incentives for investment in new generation capacity. Currently, the reliability charge is the mechanism that is operating in the electricity sector. This mechanism was explained in a previous section of this thesis.

For the model that is being developed in this thesis, demand will be assumed according to the escenarios developed by UPME thar are explained in the scenarios chapter. It means that demand mechanisim can be omitted at least for now. This mechanism was represented through "the death spiral" in Fig. 5. The delayed demand control loop understood as price mechanism will be included in this model, but in a further section of this thesis. The previous assumptions allow us to focus on the construccion loop in Ford's model.

Ford (1996) and Dyner et al (2007) both argue that an increasing demand will rise capacity initiation rate which will increase generation capacity under construction after a delay. This capacity under construction will subsequently be completed and considered installed generation capacity.

A stock and flow diagram that represents the construction process is show in Fig. 7

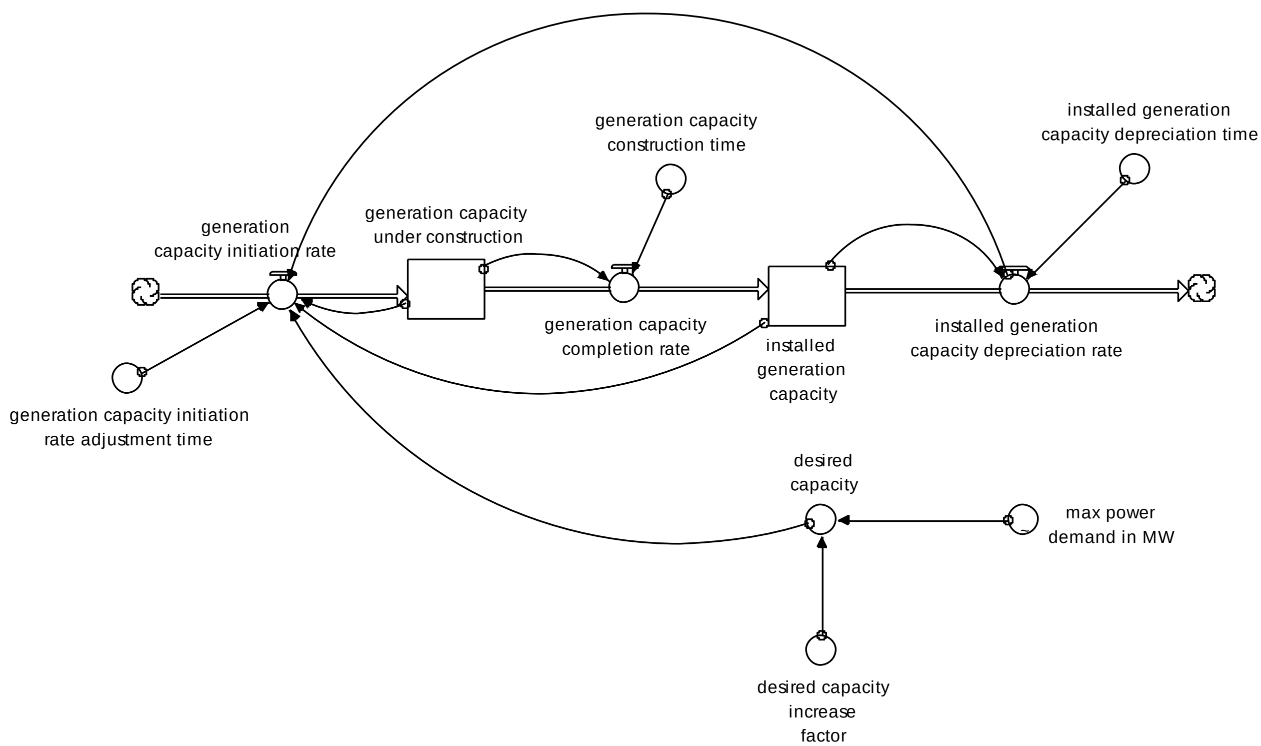

Figure 7: Construction loop in the electricity market (stock and flow)

3. A Model of the Colombian Electricity Market

In this chapter we describe a model of the Colombian electricity market. This model is a system dynamics representation of the Colombian electricity market with emphasis on the supply of various competing technologies ***(Installed generation capacity sector).*** The power generation consists of two main technologies, hydro and thermal. The hydro generation is separated according to the infrastructure and their operation into power stations with and without dam ***(generation sector).*** The thermal power consists of coal and gas fired power stations; these technologies have different characteristics in terms of investment and operating costs, fuel, operational conditions, etc. In the model, the Colombian Electricity Market sets the Electricity Price for each month in accordance with the installed capacity and the weather conditions ***(Price sector).*** The Electricity Price is the most important information for investors on the supply side ***(Investment sector).*** Constraints on transmission capacity between the regions within the country are not considered in this model. Other generation technologies like co-generators and Eolic were disregarded due to their extremely low participation on the power generation.

The time horizon (2002 - 2011) is long enough for validating the model and its accuracy in comparison to the reference mode while the time resolution is sufficiently small to capture the short term mechanisms like rainfall seasonality, its first effect on the dam level, and later its impact on the electricity price. In a further section of this thesis, the time horizon will be extended until 2031 with aim of evaluating the long-term impact of the demand/supply balance over the years. The interplay between the different generation technologies in the short term (generation scheduling and price set) and the long term (price set and capacity acquisition) is the focus on this thesis.

This model focus is on the supply side of the Colombian Electricity Market and the demand side is less detailed. However, different sensitivity analyses will be conducted to assess the impact of variations in the expected demand.

Fig. 8 shows the main feedback loops that influence the development of each electricity generation technology.

Hydro generation capacity acquisition loop (B1) is the process of new hydro capacity investments based on the critical price methodology as decision rule. This methodology includes a comparison between the expected electricity price and the critical price. The critical price is the price level at which it is profitable to implement a project under consideration. Long delays (approval and construction times) are involved in the capacity acquisition process. This process could take several years, so the price expectations are based on forecasts several years ahead. The construction process varies from power station to power station depending on the capacity (large, medium or small hydro power station). This feedback loop may also be interpreted as a long term price mechanism because the reserve margin increases when the hydro power stations installed capacity rises. A larger reserve margin reduces the electricity price and discourages the investments in new hydro power stations.

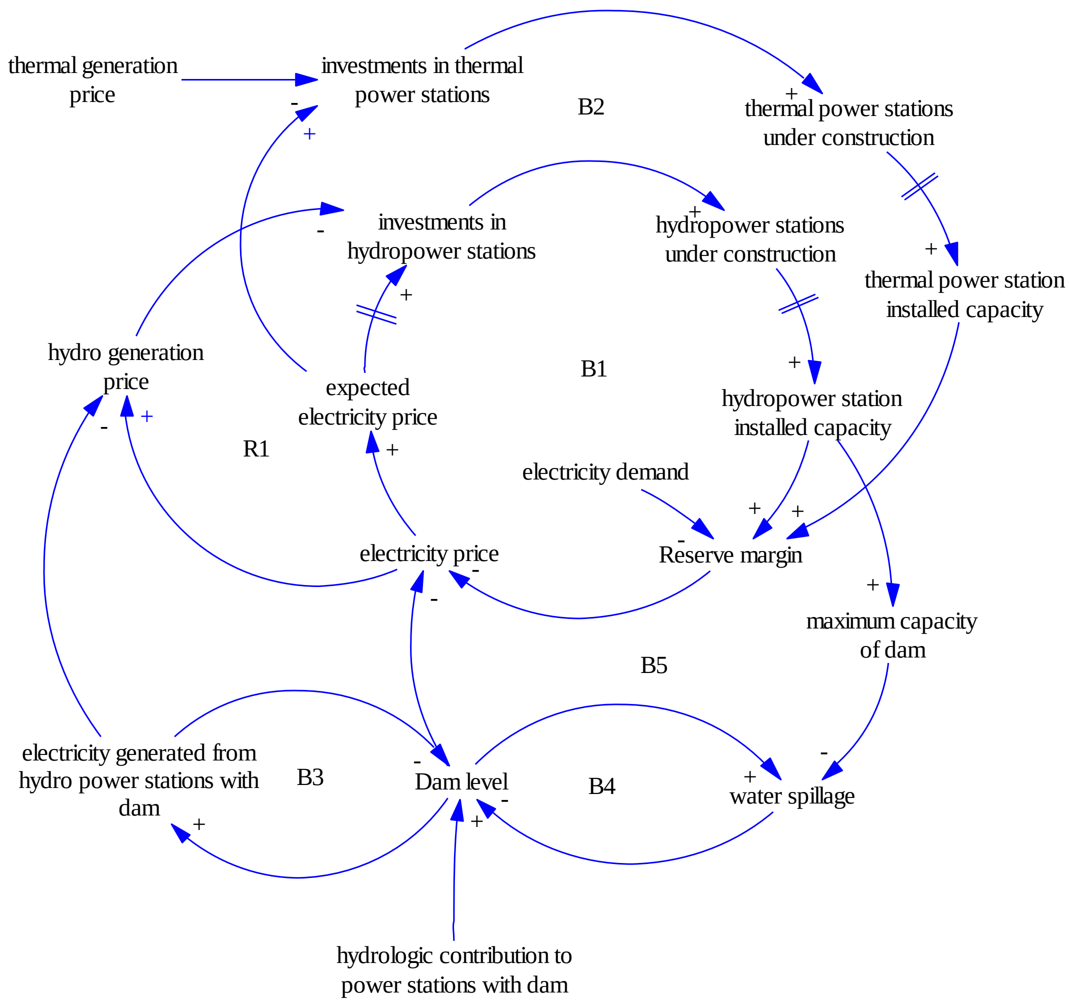

Figure 8: Simplified causal loop diagram of the Colombian Electricity Market

Thermal generation capacity acquisition loop (B2) works as described for B1, but this time for thermal power stations.

Dam management loops (B3, B4), the dam level is regulated through two outflows and one inflow. The inflow is the hydrologic contribution that is governed by the rainfall seasonality. The water spillage process is governed by a goal seeking loop (B4). When the dam level exceeds its maximum capacity, the spilling mechanism is activated and the exceeding potential electricity flows out, keeping the dam level at or below its maximum. B3 represents the electricity generation process, as electricity is generated, the dam level decreases.

Electricity price short term mechanism (B5) represents the short term market response to the dam filling fraction of its maximum capacity, considering the dam filling fraction as the available potential electricity generation in the current month and in the near future. A high dam filling fraction causes a low electricity price that discourages the investment in additional power stations.

Water value adjustment loop (R1), this loop adjusts the hydro generation price in accordance to the electricity price. If a change has occurred in the market (for example, some thermal capacity is phased out), that will lead to expectations of higher long term electricity prices. So the hydro generation price must be adjusted upwards. Otherwise the dam level will be depleted. Later on, this additional storage will lead a new increase on the electricity price. The estimation of hydro generation price is not a simple process. Therefore, the explanation of this loop will be elaborated in in the description of the investment sector.

Fig. 9 shows a simplified stock and flow diagram (SFD) of the model. The four sectors that were mentioned at the beginning of this chapter can be easily identified in Fig. 9, each sector will be explained in detailed in its respective section that is indicated into brackets:

- ***Installed capacity sector (Section 3.1.)*** describes the process of planning and applying for permits before investing and building the new capacity. The planning, approval and construction process involve significant delays.
- ***Generation sector (Section 3.2.)*** coordinates the participation of each generation technology in the total electricity generation. Typically the hydrogenation is prioritized due its lower cost compared to thermal generation.
- ***Price Sector (Section 3.3.)*** contains a dynamic formulation of the price estimation in the Colombian Electricity Market. This estimation takes input from the generation (the dam filling fraction) and installed capacity sectors. The electricity price is forecasted some years ahead using the trend function, an adaptive exponential smoothed forecast.
- ***Investment sector (Section 3.4.)*** includes the cost model for thermal power stations and describes the methodology that is used in order to calculate the hydro generation price. This sector also embraces a profitability assessment based on the critical price methodology.

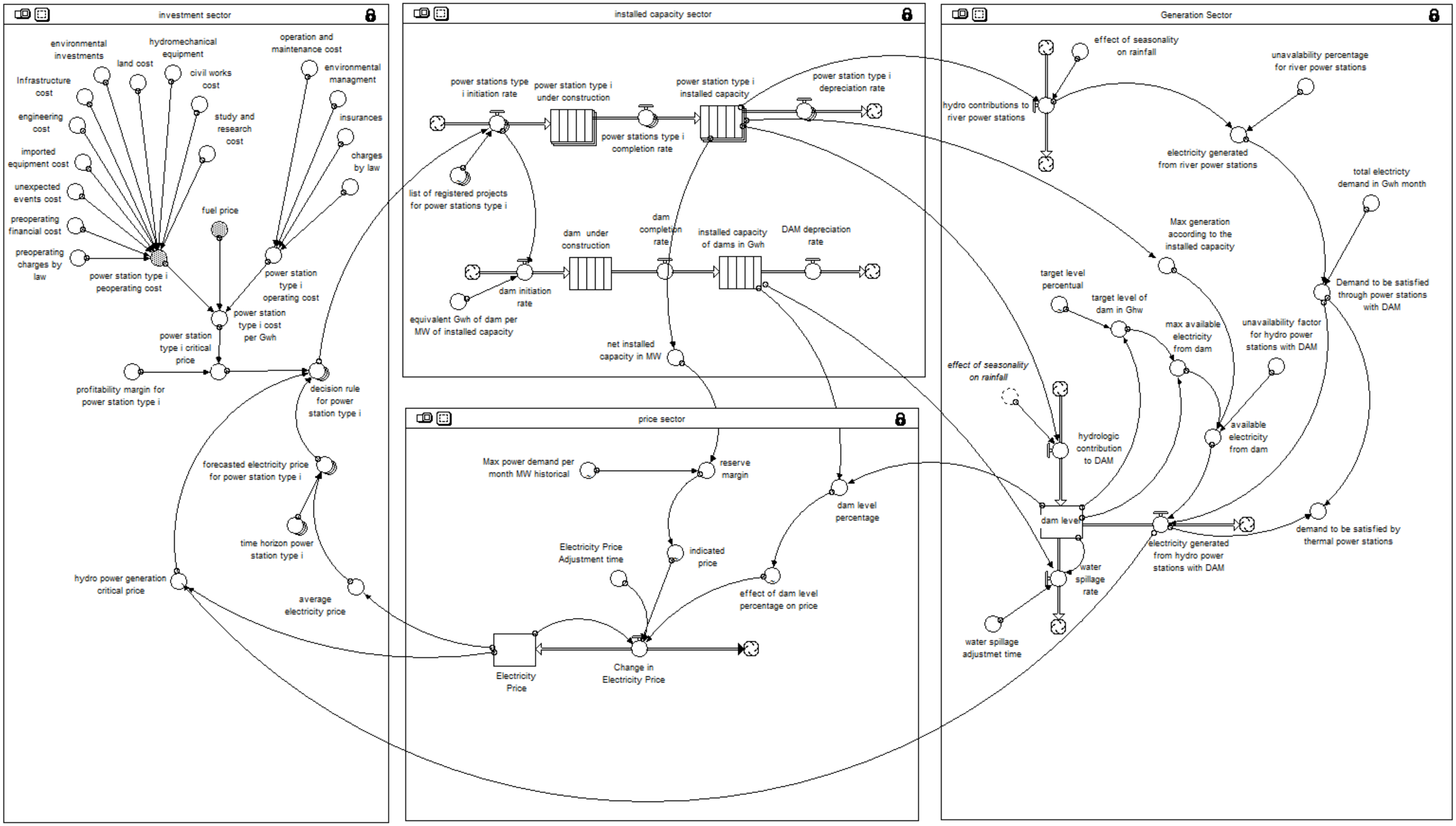

Figure 9: Simplified stock and flow diagram (SFD) of the Colombian Electricity Sector

3.1. Technologies involved in electricity generation

The electricity production capacity was described in Fig. 7 as a unique and unspecified technology. In fact, the Colombian electricity market involves different technologies, mainly hydroelectric and thermal. The former depends on water availability and the latter uses gas and coal as raw materials to generate electricity.

In the model therefore, we disaggregate the installed generation capacity into the following technologies; river hydro power stations, hydro power stations with dam, gas fired thermal power stations and coal fired thermal power stations. For the hydro power stations, a sub classification is included. A utility with a generation capacity below 20 MW is considered a small hydro power station. A medium size hydro power station has an installed generation capacity above 20 MW but below 400 MW. A utility with a generation capacity larger than 400 MW is assumed as large.

Each type of power stations is given its own construction loop to capture their different lead times. The lead times are set as shown in Table 1.

Power station type	Power station size	Lead time (year)	Planning and approval time (year)	Construction time (year)
River hydro	Small	4	2	2
	Medium	6	2	4
Hydro with dam	Medium	7	2	5
	Large	9	2	7
Gas fired thermal		4	2	2
Coal fired thermal		4	2	2

Table 1: Model parameters for the construction loop for each type of power station

3.2. Generation Scheduling

The generation scheduling is a complex process that depends on the daily offers made by every generator in the electricity pool. Each generator offers its power stations with a unique price for the next 24 hours. The market manager organizes the offers according to their merit (from lowest price to highest) until covering the projected demand for each hour. Total supply is determined at the price offered by the last power station required to satisfy demand.

A strict replication of the generation scheduling requires a large amount of data about the supply curves' estimation. These supply curves use as input variables such as, technology, time, fuel prices and macroclimatic conditions. In our model, a detailed replication of the pool mechanism has been omitted due to the lack of information and the confidentiality agreements that have been previously signed by the data providers.

Nevertheless, a different and simplified way to calculate the generation has been introduced. The main assumption for this calculation is based on the fact that hydrogenation is the cheapest one, and is prioritized (Garcia & Palacio, 2006). So the thermal fired power plants are used sparsely because of the water opportunity cost; water is cheaper than gas and coal (Mekechuck, 2000).

3.2.1. Hydro scheduling

In order to calculate the electricity generation from hydro power stations, two structures have been designed to capture the presence or absence of a dam. Thus, we have one structure for river power stations and another structure for power stations with dam.

3.2.1.1. River power stations' hydro scheduling

Since river power stations cannot store water, they use the water that flows through the river with the aim of generating electricity. Thus, in terms of the model, the hydrologic contribution is the water, in terms of potential electricity (Gwh/month) that flows through the river per month. This hydrologic contribution depends on the seasonality that has been studied previously by other authors and institutions in Colombia and, e.g. UN – COLCIENCIAS – ISA (2001). The hydrology seasonality is named the effect of seasonality on rainfall in this model and is shown in Fig. 10.

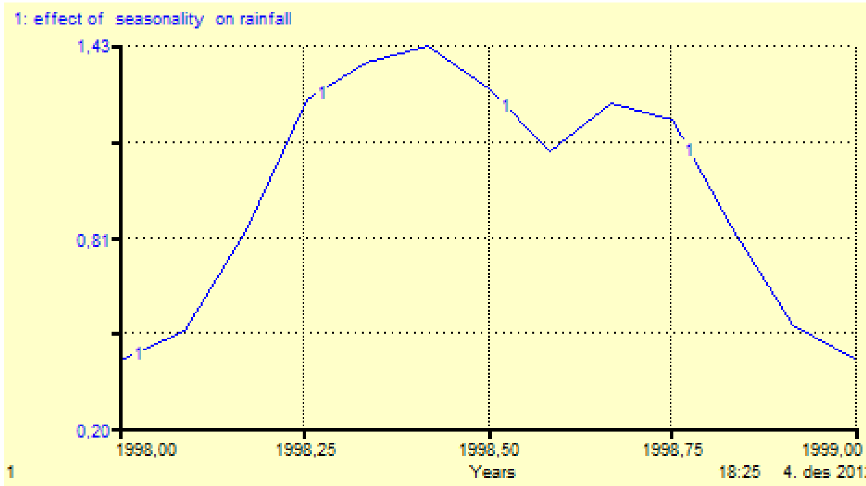

Figure 10: Effect of seasonality on rainfall in Colombia during a year period

As this thesis does not focus on hydrology, the information about the effect of seasonality on rainfall is considered an exogenous variable. The hydrologic contribution is calculated according to equation 1 (Ochoa, 2010):

Hydro contribution to river power stations = total installed_capacity_of_river_power_stations * Gwh_in_a_MW * effect of seasonality on rainfall

Equation 1

Nonetheless, the total hydro contribution to river power stations is not used to generate electricity because of interruptions caused by maintenances, breaks, damages or extremely low level of the rivers. These interruptions are represented through the 'unavailability fraction for river power stations'. Hence, the electricity generated from river power stations is represented by equation 2:

Electricity generated from river power stations = hydro contribution to river power station * (1 - unavailability factor for river power stations)

Equation 2

.

3.2.1.2. Power stations with dam

The water storage process is relevant due to the lack of efficiency in storing electricity as a final product (Ford, 1999). Hence, understanding what determines the availability of water within the dam is our next concern.

In system dynamics terms, the water that is stored within the dam is a stock (Fig. 11). This stock constantly changes as a result of its inflow and outflows. The hydrologic contribution, as inflow, is calculated in the way we indicated when describing river power stations (Ochoa, 2010), (Vogstad, 2004).

The dam level is reduced through two outflows. On the one hand, the water spillage rate works according to a goal seeking loop that is shown on B4 in Fig. 12. When the dam level exceeds its maximum capacity, the spilling mechanism is activated and the exceeded potential electricity flows out, keeping the dam level at or below its maximum. (Ochoa, 2010), (Vogstad, 2004).

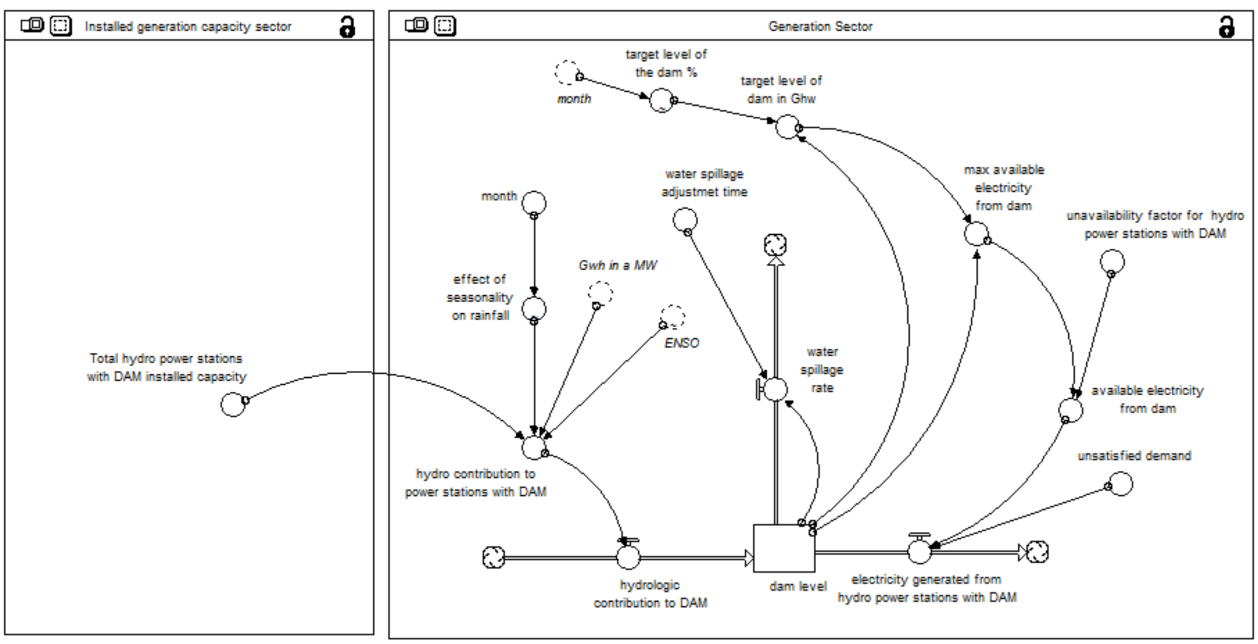

Figure 11: Stock and flow diagram of electricity generation from hydro power stations with dam

On the other hand, electricity generated from hydropower stations with dam represents the potential electricity per month that flows out while generating electricity (see B3 in Fig. 12). In order to calculate the electricity generation from hydro power stations with dam, the generators have established a 'target level of the dam' as a fraction of its maximum capacity. The target level of the dam varies from month to month throughout the seasons. The 'target level of the dam in Gwh' is defined with the aim of generating electricity also during the dry season. The difference between the current 'dam level' and the 'target level of dam in Gwh' is the 'max available electricity from dam'. However, the 'max available electricity from dam' may not be generated because of interruptions such as, maintenances, breaks, damages, etc. These interruptions are represented through the 'unavailability factor for hydro power stations with dam', defined as a fraction of a year time. The 'unavailability factor for hydro power stations with dam' affects the 'available electricity from dam'. Finally, the 'electricity generated from hydropower stations with dam' is the minimum of the 'unsatisfied demand in Gwh' and the 'available electricity from dam'.

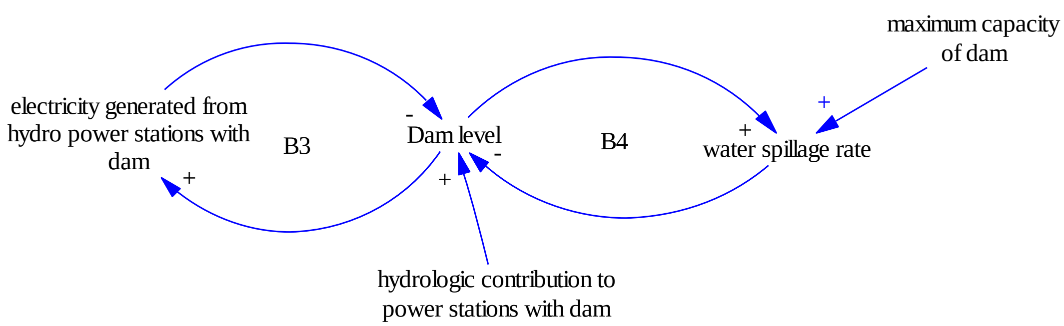

Figure 12: Dam management loops

3.2.2. Thermal scheduling

As we stated previously, the thermal fired power plants are used sparsely. They will generate electricity in order to satisfy the demand that is unmet after the hydro scheduling. In the model, gas and coal fired thermal power stations are treated similarly, assuming fuel availability (Dyner at el , 2007). So the variable that affects the electricity generation by thermal plants is the unavailability factor. The unavailability factor for the various technologies is shown in Table 2.

Power station type	Unavailability factor (1/year)
Hydro with dam	0.05
Gas fired thermal	0.1
Coal fired thermal	0.1

Table 2: Model parameters for the unavailability factor for each type of power station

3.3. The estimation of the electricity price

Various authors have highlighted that the reliability of the generation system and its effect on the electricity price can be assessed by parameters such as the reserve margin. The reserve margin is a measurement of the available installed capacity to generate above the normal demand levels. The reserve margin, RM, is calculated as follow:

RM = (net installed capacity – maximum power demand) / maximum power demand

Equation 3

Bunn and Larsen (1992) focused their study on the reserve margin as an indicator of periods of under and over construction. Bunn and Larsen's case study addresses the electricity market of England and Wales and was conducted using a system dynamics' model. In their model, the reserve margin is calculated in order to evaluate the loss of load probability (LOLP). LOLP indicates the need for new capacity or the required level of long term investment in generation (Bunn et al, 1992)

A few years later, Kottick et al. developed a method to correlate the generation reserve margin with the reliability of supply to costumers in the case of Israel. Kottick et al. state that "*the number and extent of power cuts are directly influenced by the installed generation reserve margin"* (Kottick et al, 1995). Andrew Ford affirmed that the LOLP is extremely sensitive to the system reserve margin. This statement can be found in his paper: Cycles in competitive electricity markets, a simulation study of the western United States (Ford, 1999). Bunn and Larsen, Kottick et al. and Ford agree on the fact that the reserve margin governs the electricity price in the long run in deregulated electricity markets. Quite a few of Colombian publications that are based on system dynamics also state that the reserve margin is a good input or factor when determining the electricity price. (Zambrano and Olaya, 2011), (Becerra and Franco, 2008), (Hoyos et al. 2010) and (Lozano et al. 2011).

In this model, the electricity price is adjusted towards a goal defined as the indicated price times the effect of dam filling fraction (see SFD Fig. 13 and Eq. 4). The change in electricity price is determined by two inputs, the indicated price and the effect of dam filling fraction on the indicated price.

Change_in__Electricity_Price = (indicated__price*(effect_of_dam_filling_fraction_on_price)-Electricity__Price)/Electricity_Price_Adjustment_time

Equation 4

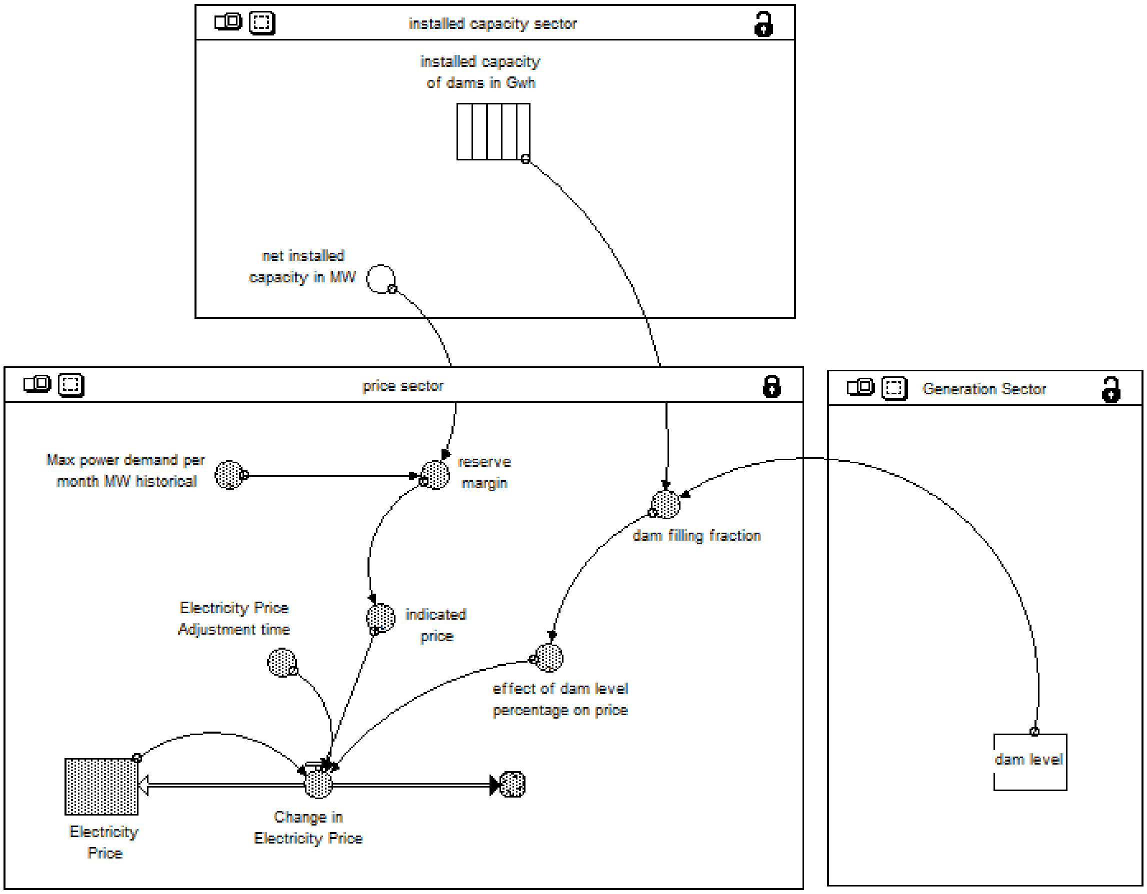

Figure 13: Stock and flow diagram of the price estimation

First, the indicated price is based on the reserve margin. Keeping a large reserve margin is important in the Colombian case due to severe droughts reduce the opportunity to generate electricity; so a low reserve margin gives rise to a high indicated price. The nonlinear relationship between the reserve margin and the indicated price (Fig. 14) has been calculated based on the past behavior of the reserve margin and the electricity price as shown in Fig. 15. From the Fig. 15, we may conclude that a radical and drastic effect of the reserve margin on the electricity price has occurred at least twice in 1998 and 2010, when the reserve margin was about 0.5. On the other hand, reserve margins above 0.7 causes a drop in the electricity price; see the period 2001 - 2002.

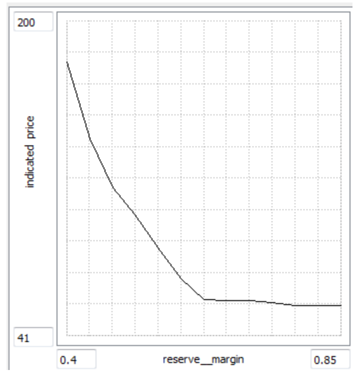

Figure 14: Reserve margin vs. Indicated Price

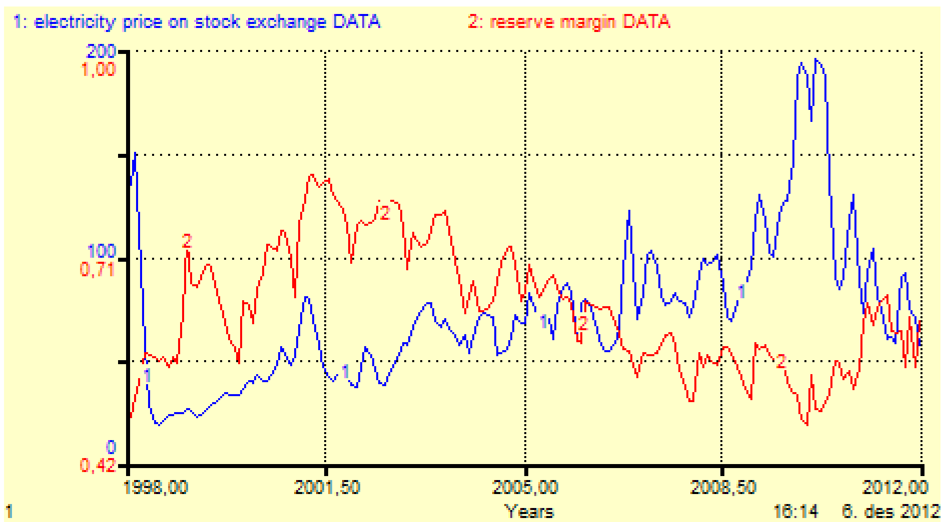

Figure 15: Historical reserve margin and the electricity price in Colombia

According to another group of Colombian researchers, including Dyner et al. (2008), Olivar et al. (2011), Castano and Franco (2011) and Ochoa (2010), however, the dam filling fraction is considered as a second factor that determines the electricity price in Colombia. These authors state that the dry seasons (i.e. a low dam filling fraction) induce high prices because a large fraction of the demand must be satisfied through thermal power stations which are more expensive than the hydro power stations. In contrast, the electricity generation cost is reduced during the rainy seasons due the minimum participation of thermal generators. Hence, the effect of the dam filling fraction on the indicated price will be included as a second input combined with the indicated price when calculating the electricity price in this thesis.

The effect of the dam filling fraction on the indicated price represents the short term market response consideringing the dam level as the oportunity to generate electricity during the current month and in the near future. Thus, an increase of the dam filling fraction above 0.6 reduces the indicated price. However, a dam filling fraction below 0.6 may push the electricity price to a high level. The fig. 16 portrays the relationship between the dam filling fraction and its effect on the indicated price.

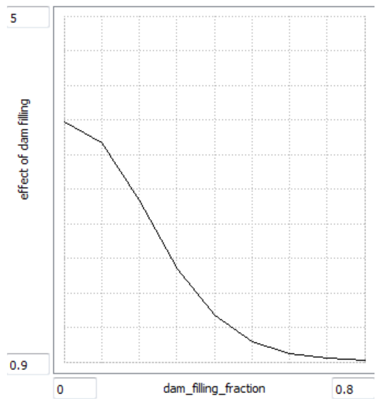

Figure 16: Effect of the dam filling fraction on the indicated price

3.4. The investment sector

The aim of this sector is to represent the decision rule actually governing the investment behavior rather than a perfect investment procedure.

The investment decision in any project takes the project's costs and the expected electricity price as inputs in order to calculate the expected profits. However, the costs vary according to the generation source. Hence we need a way to calculate the generation costs; we must take into account the particularities of this specific market. In the Colombian Electricity Market, it is difficult to calculate the price of the hydraulic generation; here we explain a way to do so.

3.4.1. The water value regarding electricity generation

The traditional investment methods are based on the estimation of the investment, management, operation and mainteanence costs, and also fuel cost. These methods are very accurate for thermal power stations. But the water value estimation is a much more complex issue. Quoting Vogstad, *"The water value of hydropower generation is associated with the expected profits of storing the water for later use. "* (Vogstad, 2004).

Some authors have presented different alternatives to estimate the water value. Some, like Zucker and Jenkins (1984), and Gibbons (1986), have stated that it is possible to value the water through a comparision between hydraulic generation cost and the next suitable alternative's cost. Gil et al (2003), Orrero and Irving (1998), Salam et al (1998) and Fuentes and Quintana (2003) value the hydro resources using some optimitazion models. There seems to be no standarized international methodology that allows us to estimate the water value.

It is a fact, however, that the hydraulic generators in Colombia translate the rainfall variations into their daily offers and the respective prices, creating a high volatility on the electricity price during the dry seasons. This volatility is stressed, when an extreme dry season ocurrs.

Therefore, Lemos (2011) has developed a method that helps us estimate the price of hydraulic generation. Lemos's work is relevant owing to the fact that his method was developed for the Colombian case. Lemos states that the prices that are offered by the generators, do not reflect the true generation costs, but that they do represent each generator stategy related to the distorsions in the market. The Colombian case is not unique: Vogstad has designed a model for the Nord Pool, and he assertes that *"In a competitive enviroment where information about competitors is limited,* *exploratory srategies are probably pursued"* (Vogstad, 2004). These distorsions may be structural (for example, oligopolies), regulatory and strategic type.

In the case of Colombia, we observe strategies such as (Lemos, 2011):

- Offering a high price with the intention of not being included in the day after generation but earning the relialability charge. The reliability charge is a premium that is paid to those generators that have accepted the obligation to supply the firm energy.
- Given that the generator has agreed a high amount of long term contracts, it offers a relative low price with the aim of being included in the next day generation and not buying any electricity from other generators.
- Offering a price below the market price guarantees the power station to generate the day after, knowing that the final price (generator's income) will be higher than the offered due to the Marginal Price of the System mechanism.

Lemos' assumptions

Even though there are distorsions in the market, the electricity price reflects the market conditions and the volatility of resources assessment. Lemos starts from the electricity market price that reflects the interaction and particularities of each energy source price. Lemos confirms that his model is based on historical data and works under the following assumptions (Lemos, 2011):

- Most of the variations in the electricity price depend on the hydraulic generation variations. This assumption is supported in the fact that there is a large participation of hydraulic sources on the total electricity generation. Additionally, severe and long-lasting changes in the market have occurred during extreme dry seasons. The assessment of the available hydro resource is higly subjective. It mainly responds to generators' rainfall expectations (for example the need for storing water for the next dry season) rather than the real generation costs.
- Thermal generation costs might be estimated through a cost model that includes the fixed and the variable costs. The variable costs are affected by the fuel prices and other macroeconomical variables such as exchange and inflation rate and the expected business profitability. The cost model that we apply here was designed in 2004 by UPME that is an official institution in Colombia and is part of the Ministery of Energy.

- The small hydro power stations do not have a large market share, so they are assumed as price takers. Therefore, the generation cost for small hydro power stations is the electricity price set by the other competing technologies.
- Any effect caused by the reliability charge is disregarded.

The resource assessment

The price's series for the thermal resources is obtained by way of the following equation:

$$Pi = INV_i + OMF_i + OMV_i + Fuel_i$$

Equation 5

Where:

Pi: Generation price in the period i (COP$/Kwh)

INV_i: Investment value in the period i (COP$/Kwh)

OMF_i: Operation and maintenance fixed cost in the period i (COP$/Kwh)

OMV_i: Operation and maintenance variable cost in the period i (COP$/Kwh)

$Fuel_i$: fuel cost in the period i (COP$/Kwh)

The following assumptions apply:

- Operation and investment costs for thermal power stations are obtained from the UPME's report. This report used constant Colombian currency (COP$) in 2004. So, Colombian inflation rates are applied to calculate the nominal values.
- The investment cost was transformed to an annual value, using a discount rate equals to 12 % and a 20 years of discount period. This rate represents the project's profits.
- The natural gas (as fuel) cost was calculated using the maximum reference price that is defined by the Gas and Energy Regulatory Comision in Colombia (CREG, in Spanish) for the main gas center in Colombia (located in the Guajira region). The gas transportation cost was added to the fuel cost in order to obtain the total gas cost for gas fired thermal power stations.
- The coal (as fuel) cost was obtained from UPME historical data for coal fired thermal power stations.

- The monthly exchange rate (US$ - COP$) was used to transform all the values into nominal Colombian currency.

UPME does not report directly the total generation cost of any power stations. Therefore, we include in our model the complete cost structure for thermal power stations.

Gas fired thermal power stations

Based on the UPME cost report (2004), the following diagram (Fig. 17) shows a summarized version of the investment cost and the operation and maintenance costs that are used to represent the price of gas fired thermal power stations. All the values for each one of these variables were obtained from the UPME report.

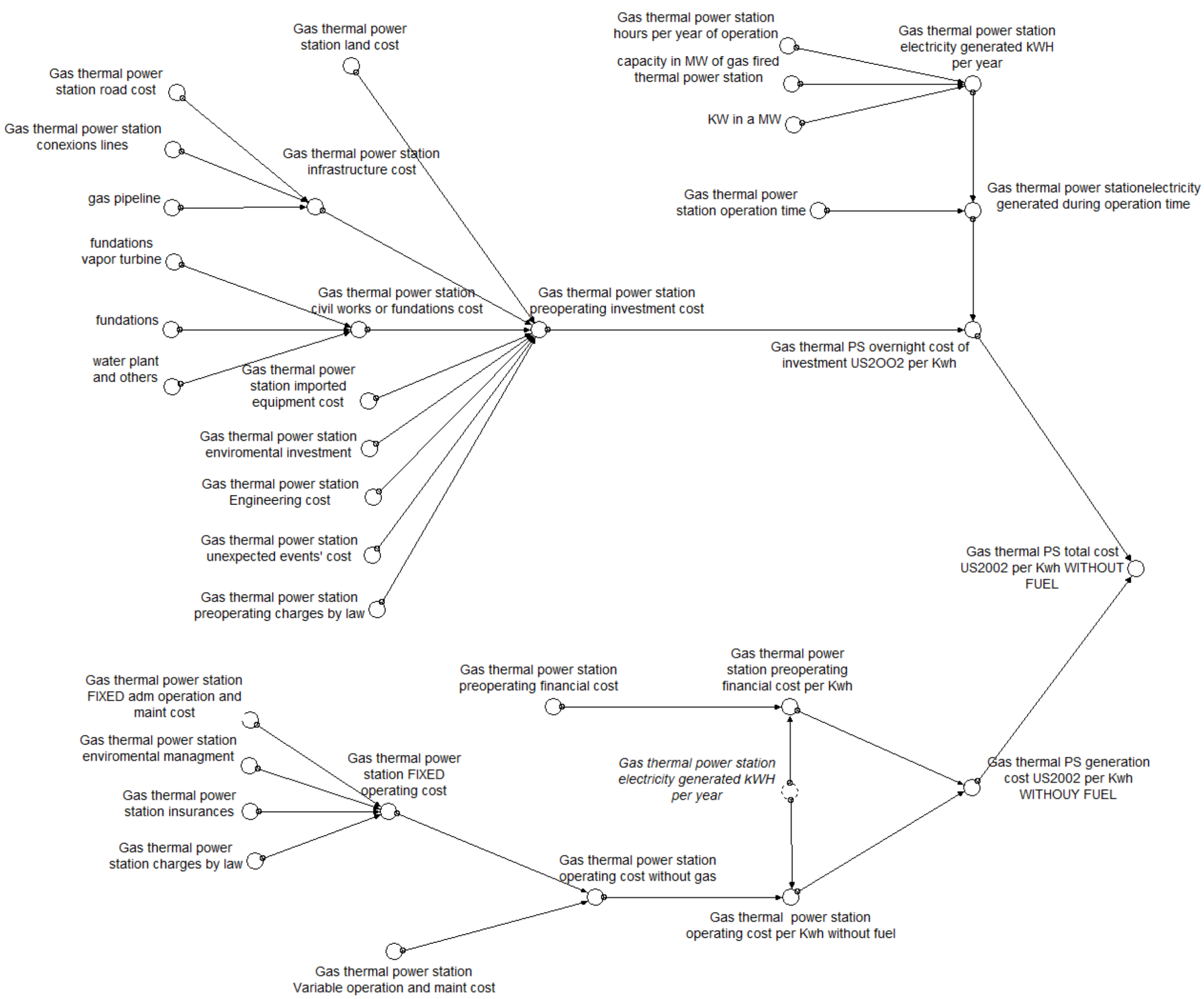

Figure 17: Model cost for gas fired thermal power station

Fig. 17 shows the cost structure without fuel for gas fired thermal power stations. The historical gas price (US$/barrel) is shown in Fig. 18. The gas price is not calculated in Colombian currency, so Fig. 19 shows the exchange rate (COP$/US$).

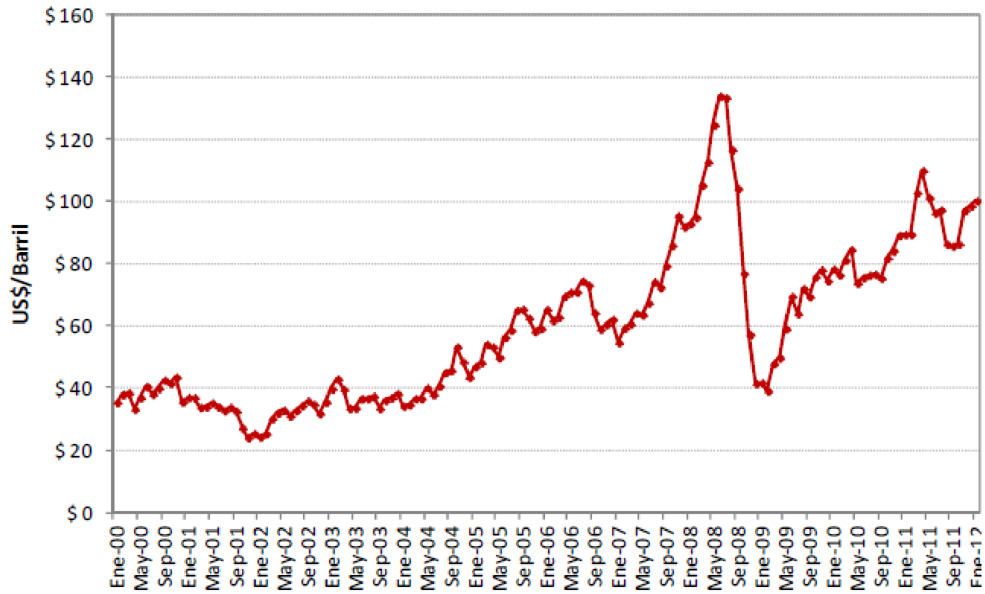

Figure 18: Gas price (US$/barrel) Source: US Department of Energy

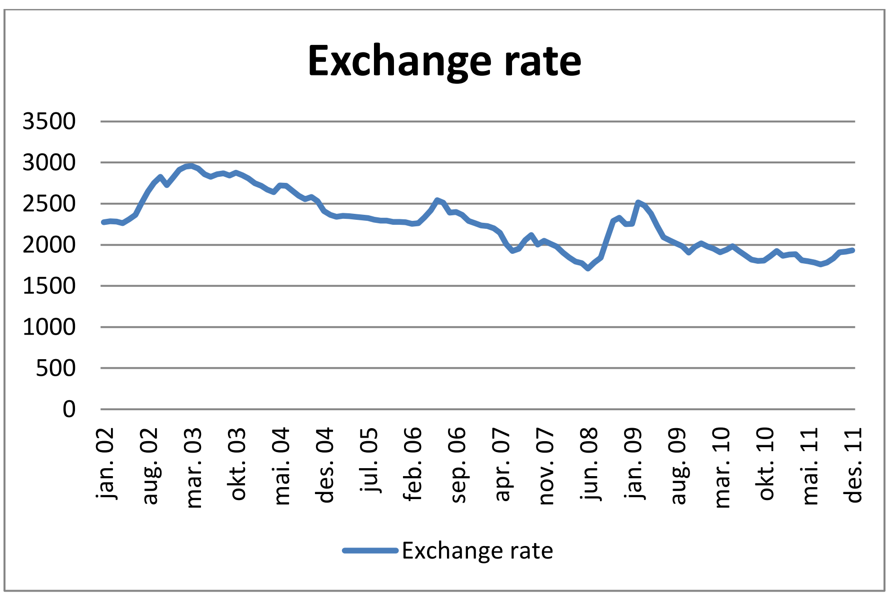

Figure 19: Colombian Exchange Rate (COP$/US$) Source: Banco de la república de Colombia

Coal fired thermal power stations

The main differences between gas and coal fired thermal power station's cost model are the civil works and the imported equipments composition. Based on the UPME cost report (2005), the following diagram (Fig. 20) shows a summarized version of the investment cost and the operation and maintenance cost that are used to calculate the price offered by coal fired thermal power stations. All the values for each one of these variables were obtained from the UPME report (2005).

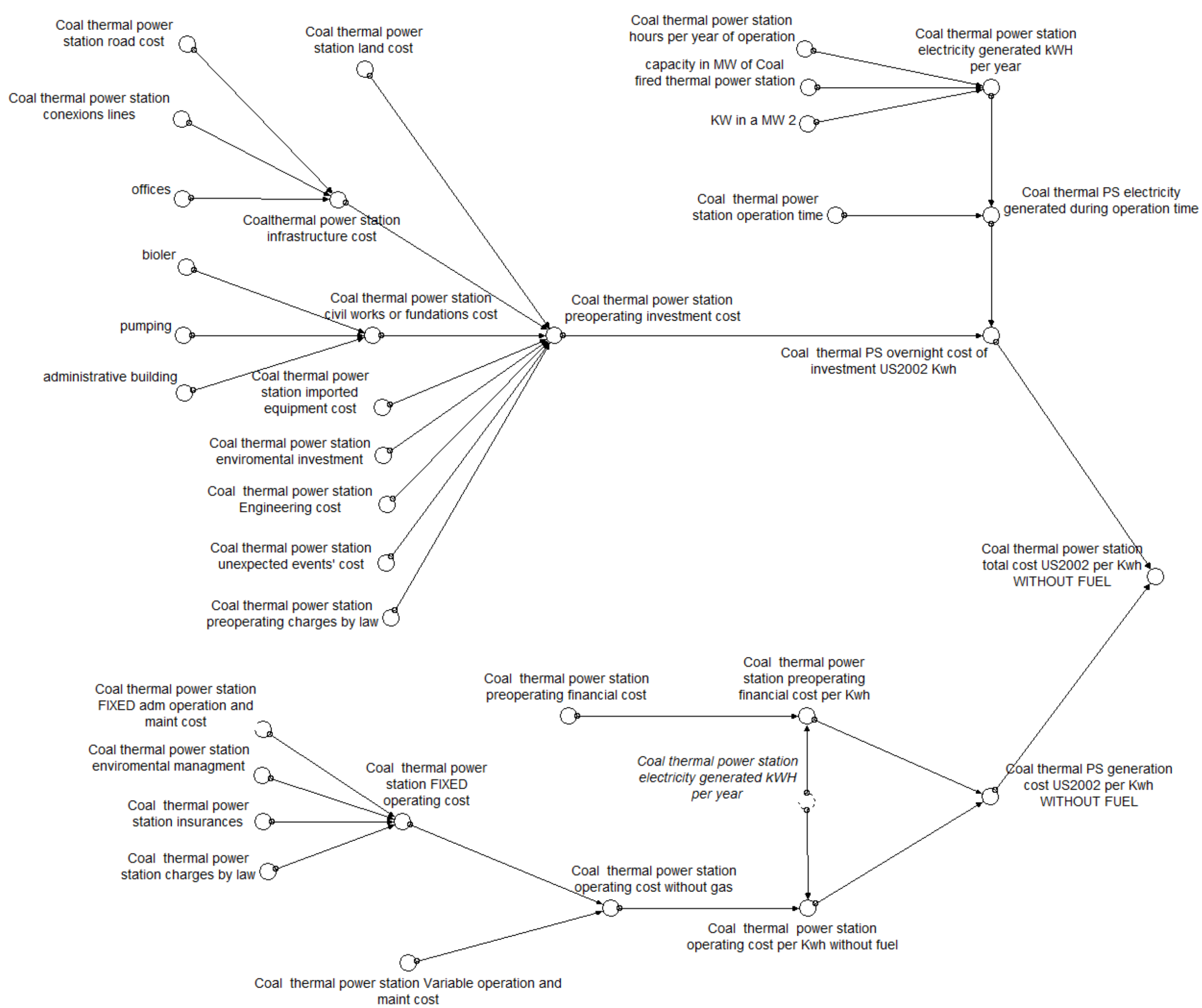

Figure 20: Model cost for coal fired thermal power station

Fig. 20 shows the cost structure without fuel for coal fired thermal power stations. The historical coal price (US$/ton) is shown in Fig. 21.

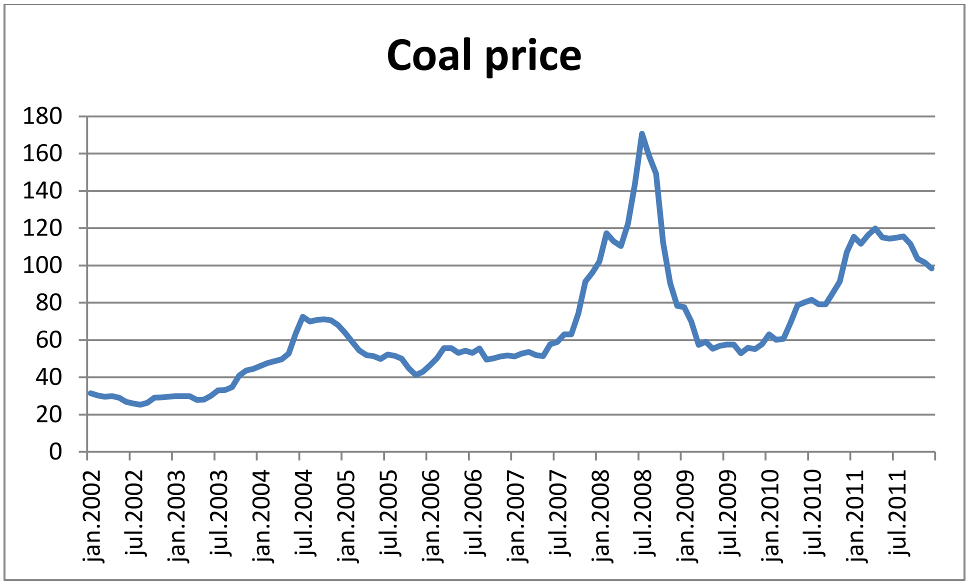

Figure 21: Coal price (US$/ton) Source: indexmundi.com

3.4.2. The formation of the hydro power stations' price

Even though there are distorsions in the market, the electricity price reflects the market conditions and the volatility of resources assessment. Lemos starts from the electricity market price that reflects the interaction and particularities of each energy source price. This method is based on the fact that the electricity market price might be dissagregated as a function of each generation source's market participation and prices, using this equation:

$$EP = P_{LH} * Part_{LH} + P_{CT} * Part_{CT} + P_{GT} * Part_{GT} + EP * Part_{SH} \qquad \textbf{Equation 6}$$

Hence, the hydraulic generation price might be found from the following equation:

$$P_{LH} = \frac{(EP - P_{CT} * Part_{CT} - P_{GT} * Part_{GT} - EP * Part_{SH})}{Part_{LH}} \qquad \textbf{Equation 7}$$

Where:

EP: Electricity price originating from the price sector.

P_i: Price for the generation source type i.

$Part_i$: Monthly participation of each source on the generation.

The following table shows the convention that was used for the types of generation sources.

Symbol	Type of source
LH	Large Hydro
CT	Coal fired thermal
CG	Gas fired thermal
SH	Small Hydro

Table 3: Convention used for the types of generation sources

So far we have discussed the method that has been implemented when calculating the cost and the price for each generation source. However, the purpose of the investment sector is to decide whether new investments are profitable or not. In case the investment is profitable, the model should include a decision rule that allows the new power stations to enter into the electricity market. Then the next section will explain the decision rule governing the construction of generating capacity.

3.4.3. The critical price methodology

The investment decision rule in the model is regulated by the critical price methodology. The critical price, CP, is the price level at which a project under consideration is profitable (Dixit and Pindyck, 1994). The CP values are the ones that were estimated in the previous section from the UPME's report and by means of Lemos' methodology.

The investment decision rule is a comparison between the CP with the Expected Electricity Price, EEP. If CP < EEP, there is an investment in a new project (Dyner et al, 2007). The decision rule is explained by the way of the diagram in Fig. 22. In terms of the model, the new investment is represented through a larger initiation rate.

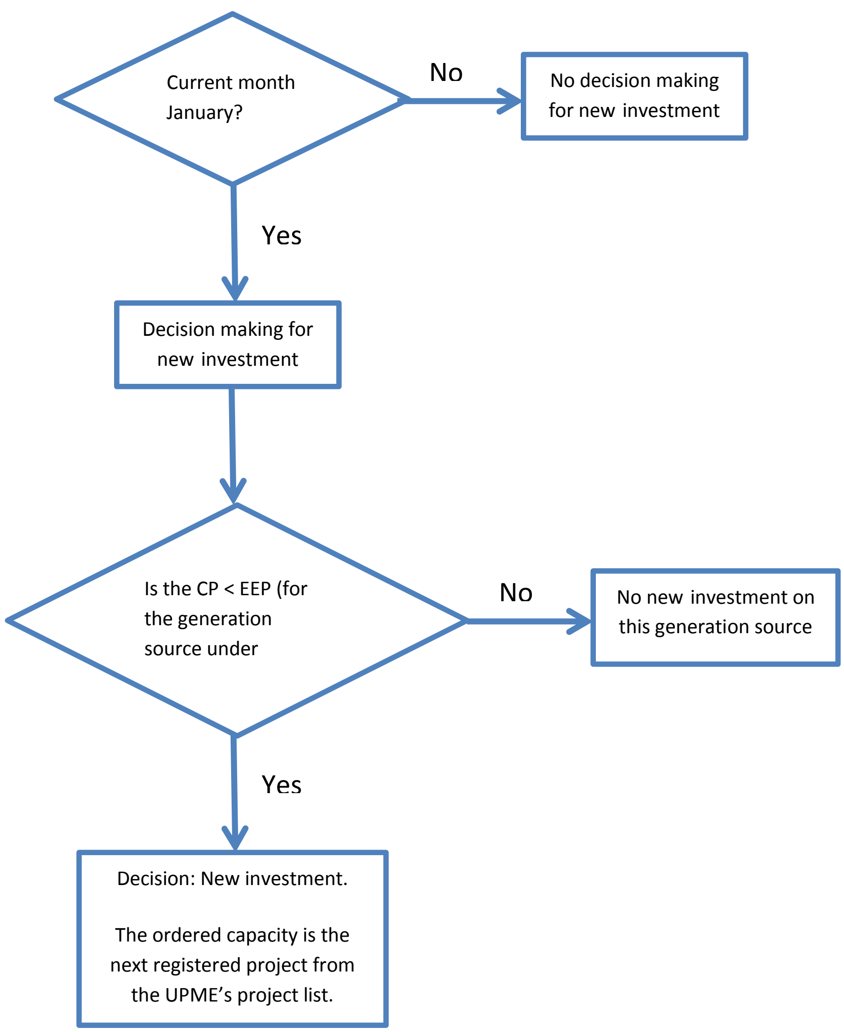

Figure 22: Investment in new power stations' decision rule

Profits expectations govern investments in new capacity. The profits expectations are based on future price expectations that depend on the market development. The Expected Electricity Price is an investor's expectations of market development. In the Colombian electricity Sector, investors consider a large number of variables such as supply and demand balance, technology characteristics and incentives (reliability charge) when estimating the electricity price (Dyner et al, 2007). In the model, the EEP is calculated by way of a trend extrapolation of the historical electricity price. Quoting Sterman, "The TREND function generates the expected rate of change in the input variable, expressed as a fraction of the input variable per time unit [...] The TREND function allows the decision maker's belief about the trend input variable to adjust gradually to the value indicated by the most recent data". The model's forecast will use the historical electricity price as input, but the time horizon will depend on the generation source and the specific characteristics of the power stations. The variation on time horizon is due to the different construction times; as the construction time is larger, the electricity price needs to be forecasted even further. In order to replicate the historical installed capacity, the model will select from the project list that is registered by UPME. This list also includes the time when each project was registered. These projects have been classified according to the generation source; among hydro power station, there is also an extra classification related to the presence or absence of dam, and the power station size (small, medium or large) in order to match with the already established installed capacity sector.

At the moment that the investment in a specific project is considered as unprofitable, the project will be remained in a stock named as projects under consideration. In the case the model presents favorable investment conditions (i.e. a CP lower than the EEP) the stored project will flow out to be a project under construction, see Fig. 23.

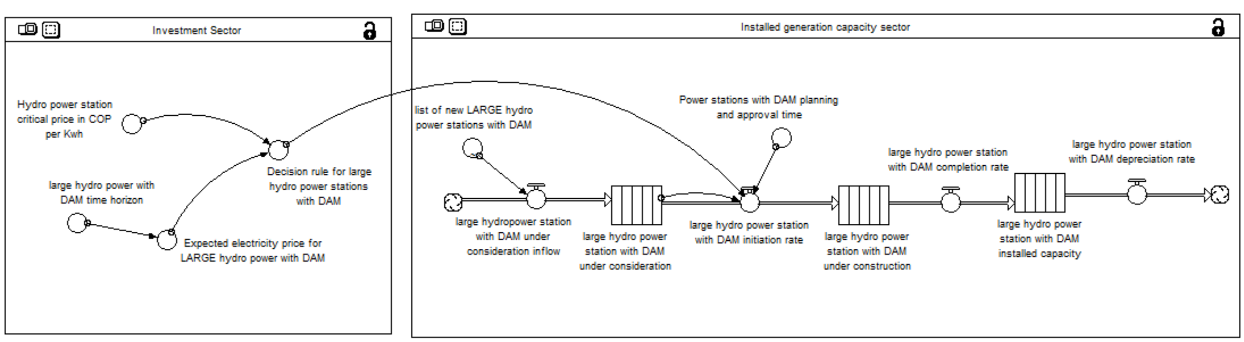

Figure 23: Stock and flow diagram of investment in new power stations

4. Model Analysis and Validation

In order to calibrate the model and gain confidence in it, the following tests were conducted: confirming unit consistency (4.1.), defining and conducting extreme condition tests (4.2.), comparing the model behavior with the reference mode (4.3.), conducting and evaluating structure-behavior tests (4.4.) and conducting parameter sensitivity tests (4.5.) (Sterman, 2001) & (Wheat et al, 2011).

The simulation time is 120 months that represents the period from January of 2002 until December 2011.

4.1. Confirming unit consistency

We performed equation-by-equation checking and unit consistency checks. When a new equation or structure was added to the model, we tested both the face validity of the model and the consistency of the model's units. Through the unit consistency test, we obtained a deeper understanding of the model that helped us to improve it. Also, the test clarified the nature of some variables and made the selection of the appropriate name for them easier.

4.2. Defining and conducting extreme condition tests

We conducted the extreme condition tests in order to analyze the plausibility of the model in response to extreme parameter values. The model should be robust so as to exhibit a plausible behavior under such circumstances (Peterson and Eberlein, 1994). We tested a variety of components of the model, but we will focus on the consequences of:

- Reducing the rainfall significantly.
- Reducing the electricity demand considerably.
- Increasing the gas and coal prices as fuel.
- Increasing the approval and construction times significantly.

The results for the first extreme condition test illustrate that, when the rainfall is set to zero, the dam level is reduced until zero (see Fig. 24.a), and, therefore, the electricity generated from hydropower station with dam reaches zero as well (see Fig. 24.b). The most drastic consequence of reducing the rainfall to zero, is the increase in the electricity price. As we explained above, a high dam level secures the generation of electricity in the near future, but the electricity price trend is governed by the reserve margin that is not affected during this extreme condition test. Hence, an extremely low dam level will push the electricity price to a very high level, but not to infinity (See Fig. 24.c).

This extreme condition has been pretty useful, because we realize an inconsistency in the model. The hydro generators cannot operate when the dam level is below its technical minimum. Therefore, we introduced, in the model, a restriction in the hydro scheduling; there will not be hydro generation when the dam level is at or below its technical minimum that is around 0.06 of the dam capacity based on historical data. For the variables in the model, the historical data was obtained from the website of the electricity market's manager in Colombia, XM (XM, 2012).

Figure 24: Extreme condition test (the rainfall seasonality is set to zero)

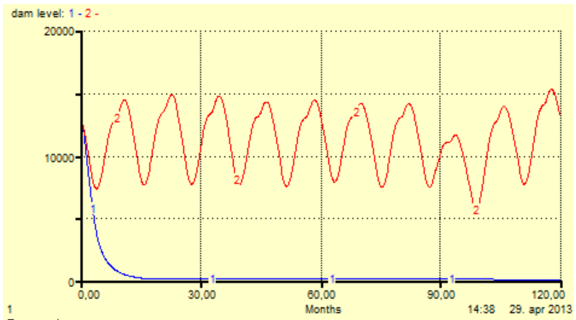

Fig. 24a: Dam level, under normal (red line) vs. zero (blue line) rainfall seasonality

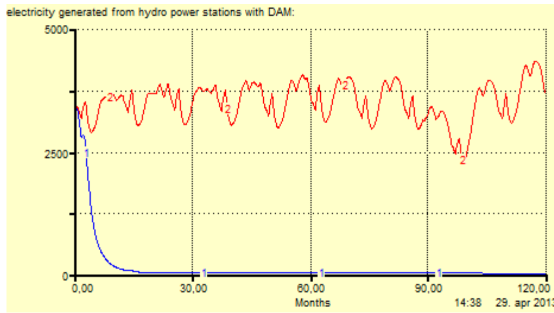

Fig. 24.b: Hydroelectricity generated, under normal (red line) vs. zero (blue line) rainfall seasonality

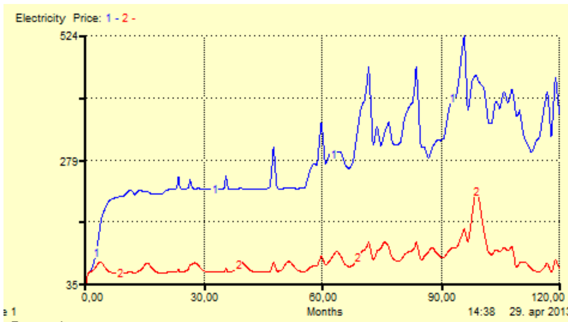

Fig. 24.c: Electricity price, under normal (red line) vs. zero (blue line) rainfall seasonality

The second extreme condition test is the reduction of the electricity demand to an extremely low value. The electricity demand is an essential variable in the model. It restricts the total electricity that is generated by all the sources. Fig. 25.a shows how the dam level reaches and keeps its maximum when there is an extremely low electricity generation by the dam (see Fig. 25.b). The electricity demand is also an input for the reserve margin. As we explained above, the reserve margin governs a long term price mechanism. Therefore a very high reserve margin discourages the construction of new power stations by means of a very low electricity price as shown in Fig. 25.c. It is important that the model does not drop the electricity price to zero, because there is no realistic generation without a generation cost.

Figure 25: Extreme condition test (extremely low electricity demand)

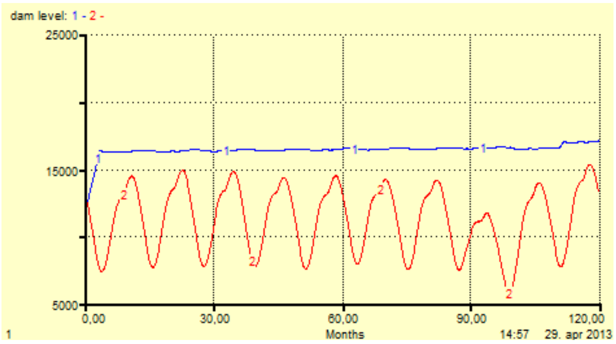

Fig. 25.a: Dam level, under normal (red line) vs. minimum (blue line) Electricity Demand

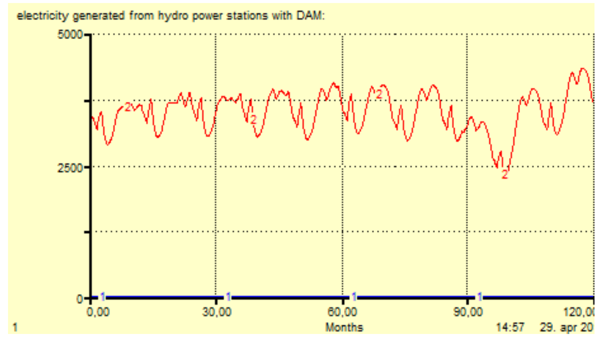

Fig. 25.b: Hydroelectricity generated, under normal (red line) vs. minimum (blue line) Electricity Demand

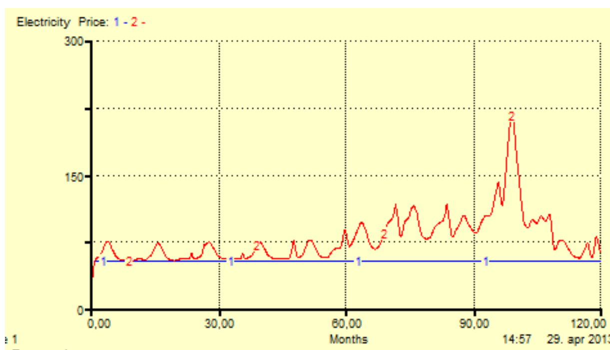

Fig. 25.c: Electricity price, under normal (red line) vs. minimum (blue line) Electricity Demand

The third test is an extraordinary increase in the critical price for thermal power stations. We run this test for gas and coal power station at the same time due the decision rules for investment in new power stations are completely independent of technology. This test is conducted in order to validate that the installed capacity is reduced when the investment in new power stations is unprofitable. As we expected, the installed capacity for coal (Fig. 26.a) and gas (Fig. 26.b) fired thermal power station is decreasing. The initial increases are caused by the gas and coal power stations under construction that come on line when the simulation starts. A lower installed capacity will cause a rise in the electricity price as shown in Fig. 26.c. But, the rise is not very significant because of the large participation of hydro power stations in the system that keeps the reserve margin close to a desired level.

Figure 26: Extreme condition test (increase in the critical price for coal and thermal power station)

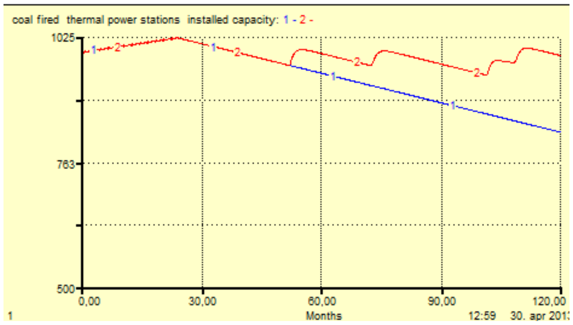

Fig. 26.a: Coal fired power station installed capacity, under normal (red line) vs. extremely (blue line) high critical price [1]

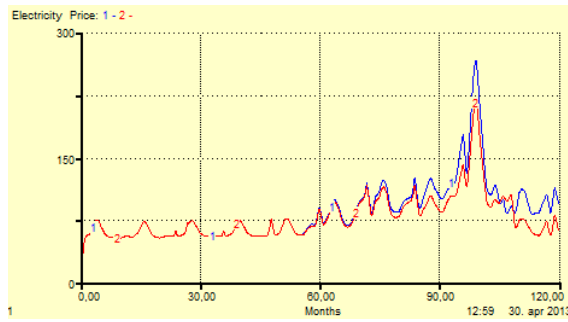

Fig. 26.c: Electricity price, under normal (red line) vs. extremely (blue line) high critical price

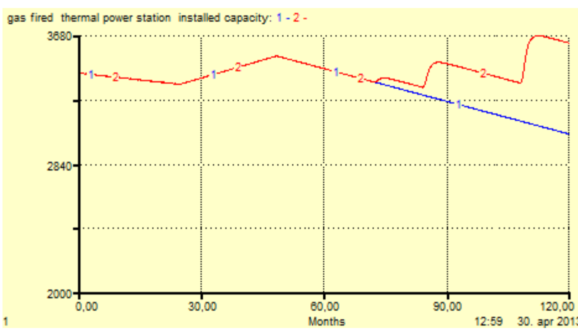

Fig. 26.b: Gas fired power station installed capacity, under normal (red line) vs. extremely (blue line) high critical price

1 The installed capacity was modeled with conveyors/pipeline delays. The power stations cannot be used as their construction progresses; their use always starts when the whole construction of the power stations is finished.

The last extreme condition test is stretching the approval and construction time for the hydro power stations. As a result the installed capacity of hydro power stations will be lower than that obtained under normal parameter values as shown Fig. 27.a. Correspondingly, the construction of dams will be delayed as we can see in Fig. 27 b. The final and more relevant effect of longer construction times is the one on the electricity price. A reduced reserve margin will raise the electricity price as shown in Fig. 27.c.

Figure 27: Extreme condition test (increase in approval and construction time for hydro power station)

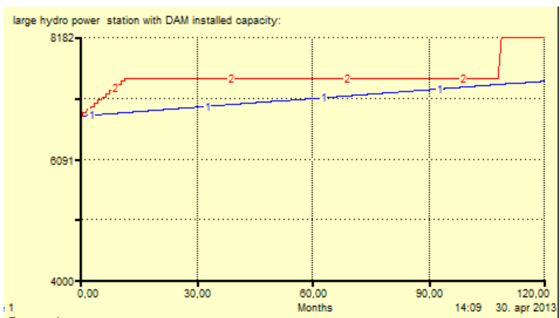

Fig. 27.a: Large hydro power station with dam installed capacity, under normal (red line) vs. extremely (blue line) long construction delay

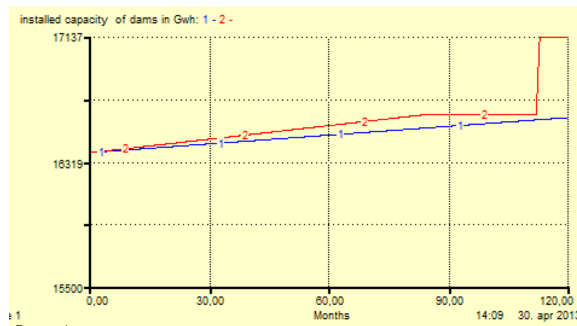

Fig. 27.b: Installed capacity of dam, under normal (red line) vs. extremely (blue line) long construction delay

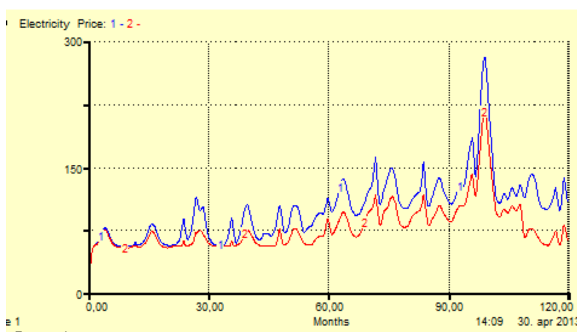

Fig. 27.c: Electricity price, under normal (red line) vs. extremely (blue line) long construction delay

4.3. Behavior pattern tests

The purpose of this section is to compare the model simulation results with the reference mode. This comparison is a step of the modeling process and is a response to the question: Does the model reproduce the problem behavior adequately? (Sterman, 2000). We compare the resulting simulations with the corresponding historical data. The visual comparison illustrates that the behavior patterns for each variable are similar, even though the point to point estimation is not completely accurate.

We calculate some metrics to assess goodness-of-fit which are summarized in table 4. First, and according to table 4, the coefficient of determination (R^2) is appropriate for most of the variables with the exception of hydro generation (Fig. 28). The coefficient of determination (R^2) measures the fraction of the variance in the data explained by the model. Even though R^2 is the most widely reported measure of fit, it is not very useful (Sterman, 2000). In the case of the electricity generated by hydropower stations with dam, we inferred that this variable is crucial for the hydro generators, therefore much more complex stochastic models might be used by the hydro generators when defining their offers. Hence, this is the lowest R^2 that we obtained.

		Theil's Inequality Statistics			
Variable	**RMSPE**	**U^m**	**U^S**	**U^C**	**R^2**
Hydro generation	0.106522	0.064632	0.024601	0.910767	0.329119
Dam level	0.140918	0.10751	0.127365	0.759879	0.592998
Electricity Price	0.249057	0.122928	0.106903	0.765926	0.677084
Installed Capacity	0.011576	0.06901	0.072206	0.807091	0.811851

Table 4: Metrics to assess goodness of fit

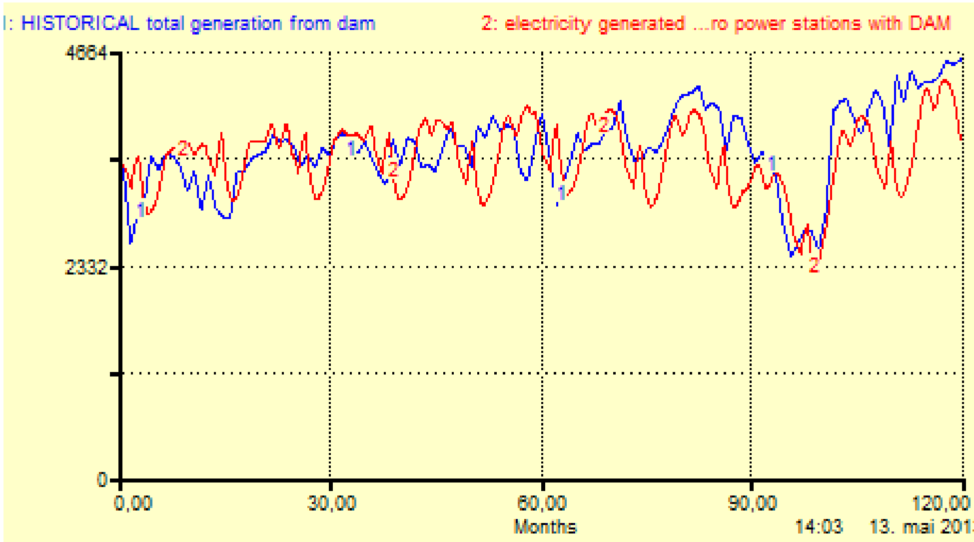

Figure 28: Hydro generation from dam, reference mode (blue line) vs. simulation (red line)

The second metric in table 4 is the root mean square prediction error or RMSPE. It provides a measure of the average error between simulated and historical data. It is always better to have a low value in the RMSPE. For the purpose of this model, a value of 0.15 represents a low error between the simulated and the historical time series. Table 4 shows that three of the four variables have a RMSPE that is lower than 0.15. The exception is the electricity price with RMSPE equals to 0.249. The explanation for this RMSPE is the difference between simulated and historical electricity price between months 85 and 95 as shown in Fig. 29. In the Colombian Electricity Market, traders also vary the price offered according to the weather forecast. This means that they probably forecasted the drought that occurred between months 90 and 100 and increased the electricity price prior to the drought. However, the System Dynamics model that is explained in this thesis does not include the weather forecast, but the rainfall itself.

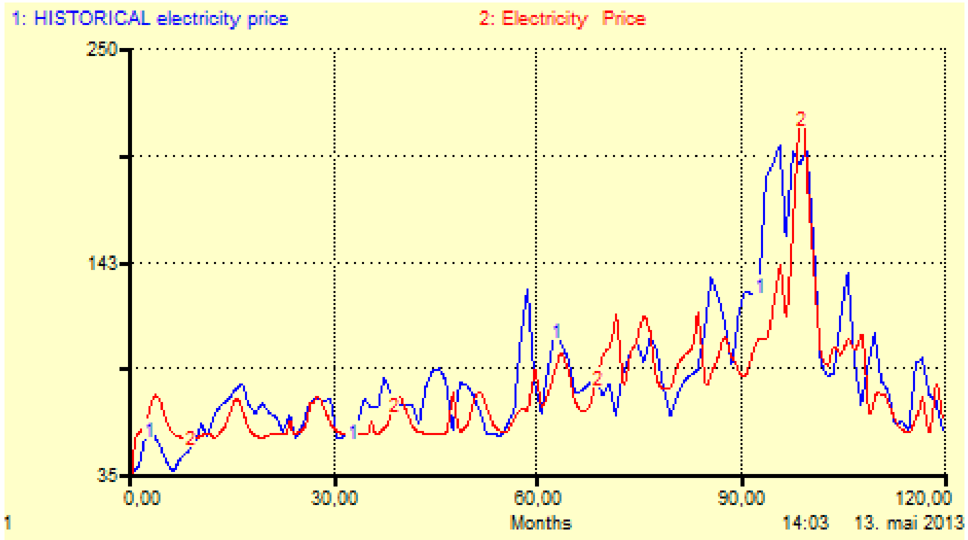

Figure 29: Electricity Price, reference mode (blue line) vs. simulation (red line)

Finally, table 4 presents the Theil's Inequality Statistics. This metric measure how much of the error between simulated and historical data that can be explained by bias (U^M), unequal variation (U^S) and unequal co-variation (U^C), respectively (Sterman, 2000). The error for the four variables predominantly arises from the differences in the point by point; U^C is larger than 0.75 in all the variables. In the cases of the dam level (See Fig. 30) and the electricity price, the error is also explained by a different variation around the mean, U^S.

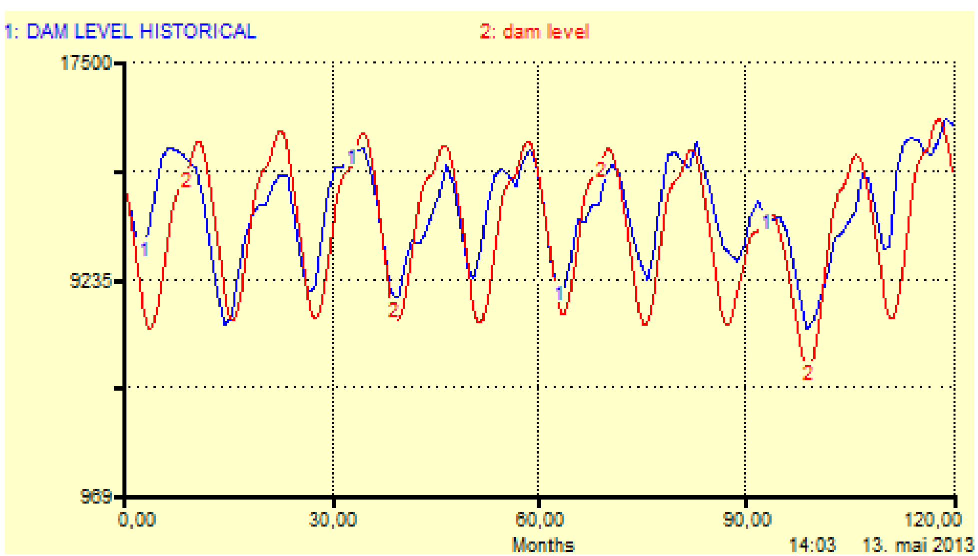

Figure 30: Dam level, reference mode (blue line) vs. simulation (red line)

Fig. 31 shows the installed capacity which is mainly explained by un-equal co-variation (U^C). However, this variable has the best R^2 and RMSPE.

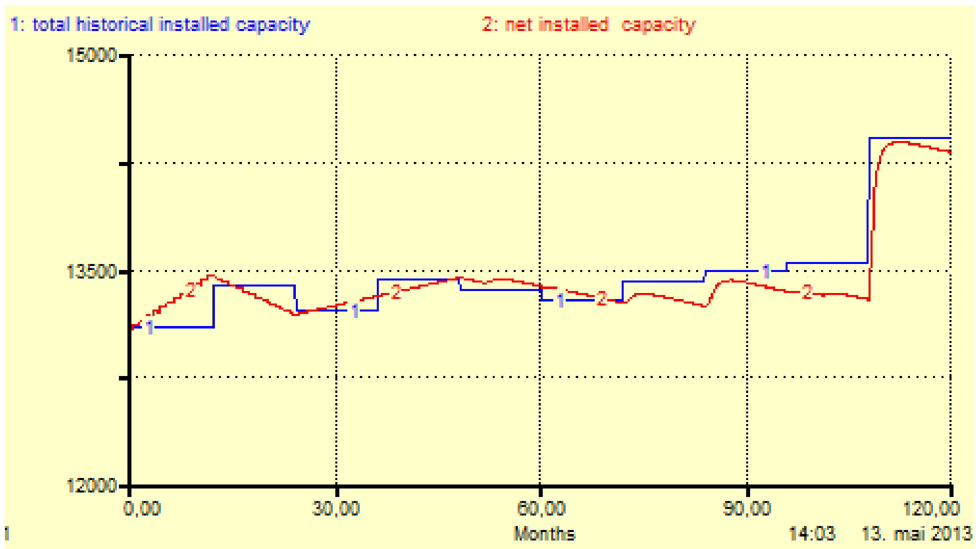

Figure 31: Installed capacity, reference mode (blue line) vs. simulation (red line)

4.4. Conducting and evaluating structure-behavior tests

We run the structure – behavior test in order to analyze the parts of the feedback structure that are predominantly responsible for behavior. We cut loops B1/R1, B2, B3, and B5 explained in Fig. 8. The loops B1 and R1 are used as input for the decision rule of investments in hydropower stations. Therefore cutting B1 also implies cutting R1 at the same time.

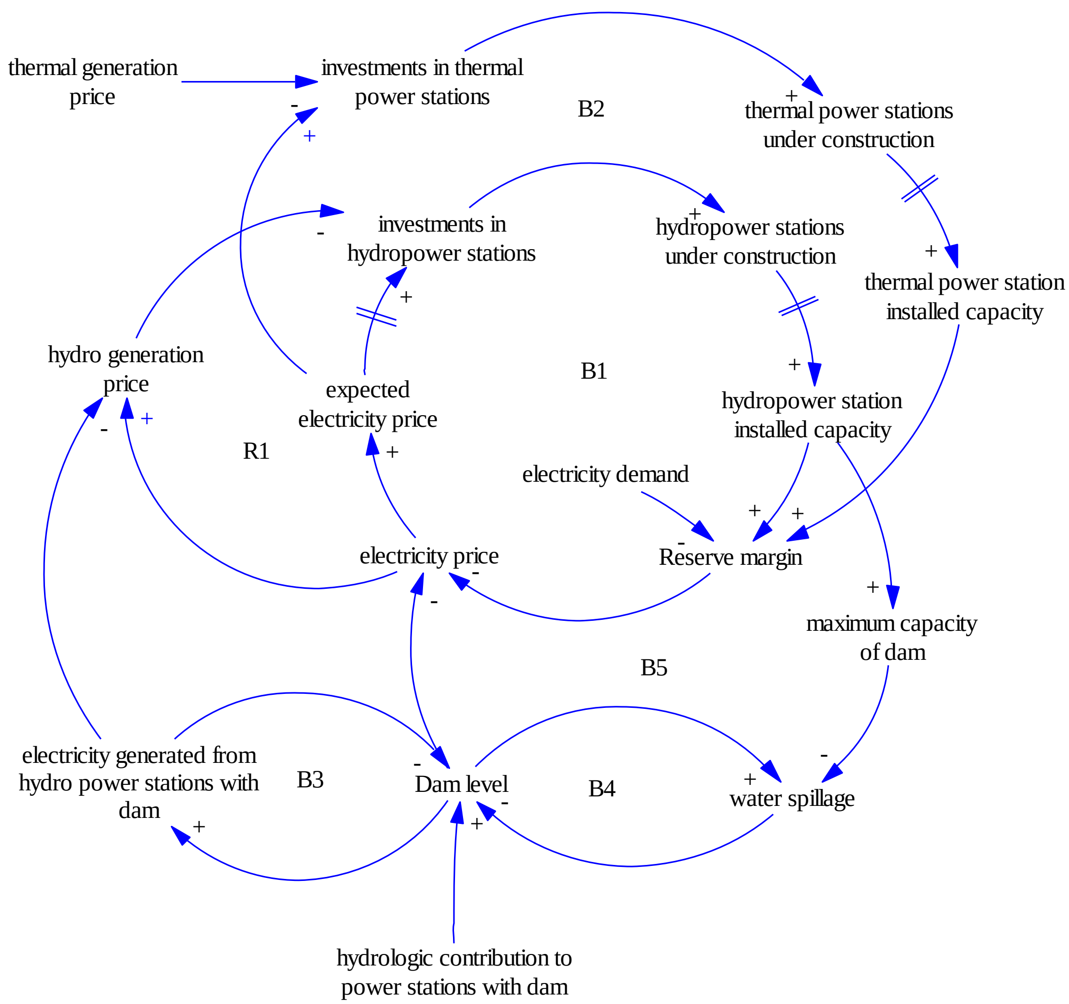

Figure 8: Simplified causal loop diagram of the Colombian Electricity Market

Loop B1 and B2 cause the dynamics of investment in new hydro and thermal power stations, respectively. Without loop B1, Fig. 32.a and Fig. 32.b show a lower installed capacity of hydro power stations that is due to the fact that no additional power station comes online. On the other hand, Fig. 33.a and Fig. 33b display a similar behavior for thermal power stations installed capacity when omitting loop B2. The most remarkable behavior is observed in Fig. 32.c and Fig.33.c that show the Electricity Price. In both cases, the electricity price raises when there is no investment in new power stations. However, the increase is more significant when cutting B2. The behavior that is portrayed in Fig. 33.c. is due to the fact that the aggregate capacity of new thermal power stations that did not come online is larger than the hydro plants that did not come on line when cutting B1. As we stated above, the model selects from the project list that is registered by UPME. These projects have been classified according to the generation source. As the thermal plants that did not come on line is larger than the hydro projects lack, the reserve margin is much more drained when cutting B2 causing a higher electricity price.

Figure 32: Structure – Behavior test (loop B1)

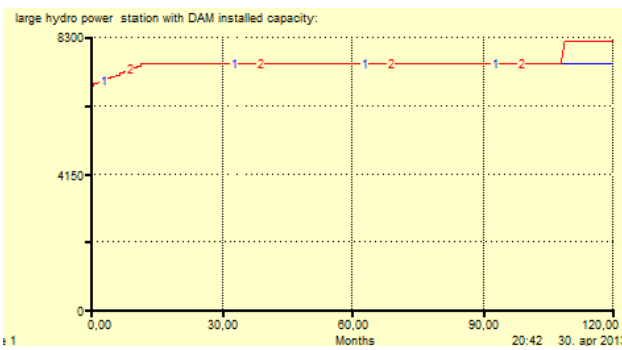

Fig. 32.a: Large hydro power station with dam installed capacity, normal (red line) vs. without B1 (blue line)

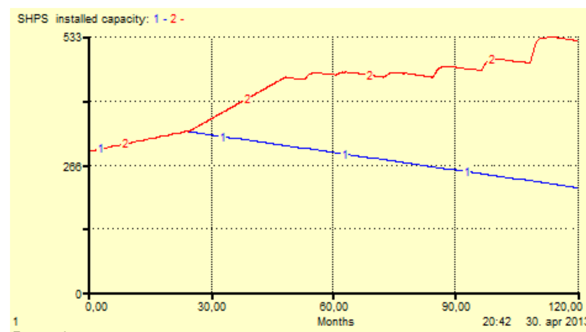

Fig. 32.b: Small hydro power station installed capacity, normal (red line) vs. without B1 (blue line)

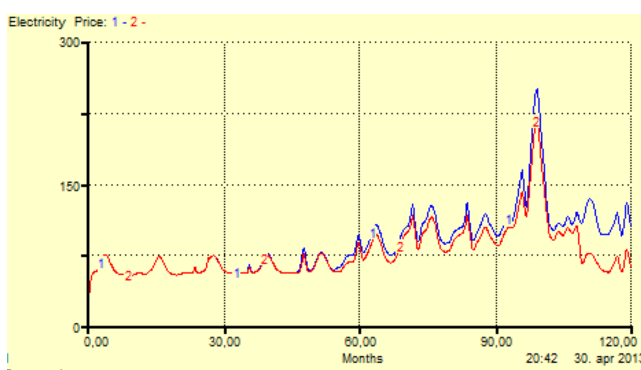

Fig. 32.c: Electricity Price, normal (red line) vs. without B1 (blue line)

Figure 33: Structure – Behavior test (loop B2)

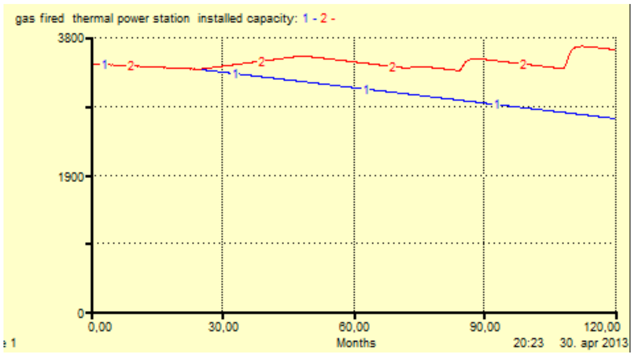

Fig. 33.a: Gas fired thermal power station installed capacity, normal (red line) vs. without B2 (blue line)

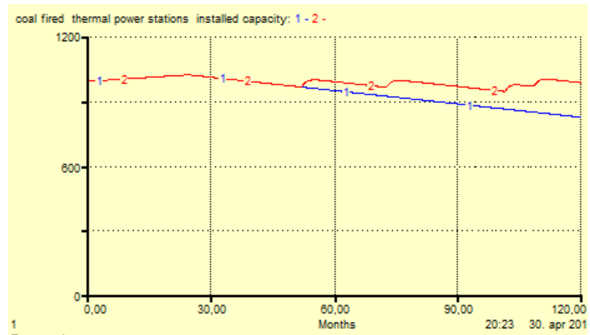

Fig. 33.b: Coal fired thermal power station installed capacity, normal (red line) vs. without B2 (blue line)

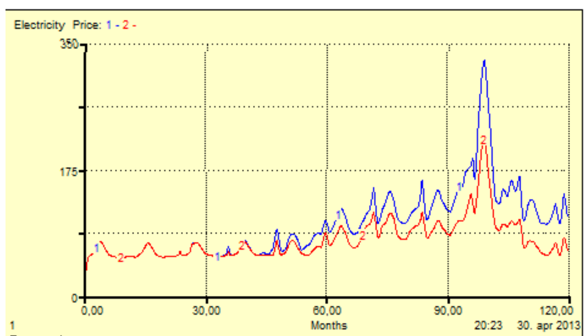

Fig. 33.c: Electricity Price, normal (red line) vs. without B2 (blue line)

Loop B3 governs the electricity generation from the dam (see Fig. 8). So the first effect of cutting the loop B3 is that the dam level reaches its maximum (See Fig. 34.a). Moreover, the electricity demand must be satisfied through thermal power stations. Fig. 34.b shows the increase of thermal generation due to the lack of hydro generation. As thermal power stations gain a larger portion of the generation, we would expect a larger electricity price. However, the dam level is maximum and it means a lot of potential electricity is currently stored. Due to this extremely high dam level, the market does not respond by raising the electricity price but by reducing it, as indicated in Fig. 34.c .

Figure 34: Structure – Behavior test (loop B3)

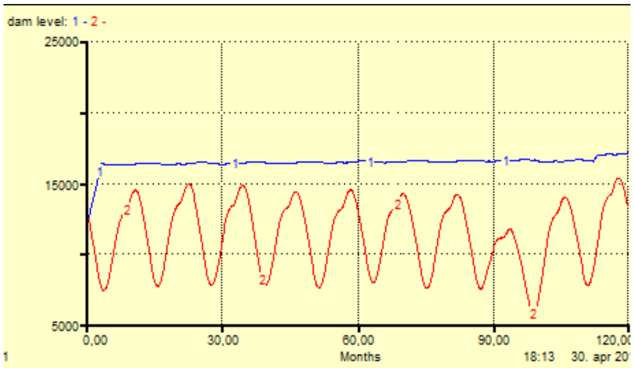

Fig. 34.a: Dam level, normal (red line) vs. without B3 (blue line)

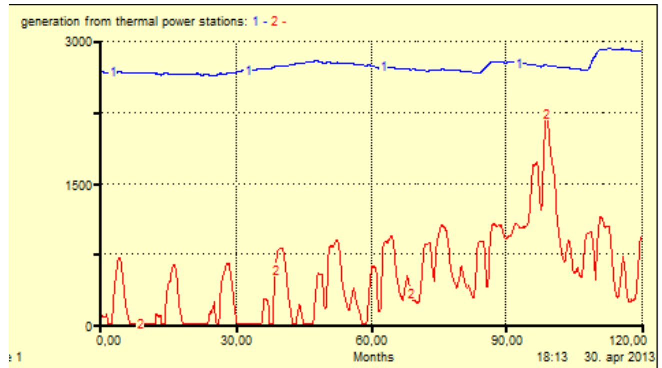

Fig. 34.b: Generation from thermal power stations, normal (red line) vs. without B3 (blue line)

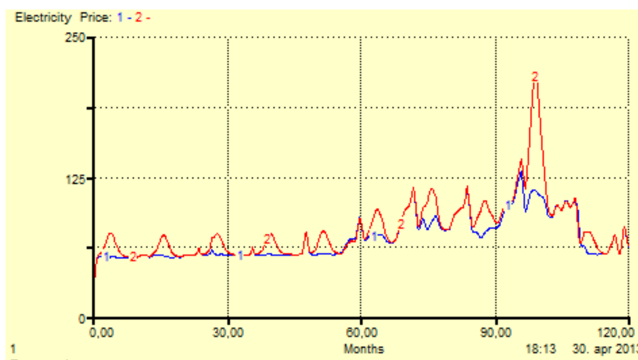

Fig. 34.c: Electricity price, normal (red line) vs. without B3 (blue line)

B5 controls the short term price mechanism (see Fig. 8), i.e. means how the electricity price responds to the dam level. In Fig. 35.a., we see how the electricity price does not vary during the first 60 months in the absence of the B5 loop. The most significant variation is observed around month 95. This corresponds to an extreme drought in 2009. Without B5 loop, the market does not perceive that the dam level is exceptionally low and this might cause a difficulty when generating electricity in the near future. Hence, the peak in the electricity price, which is observed under normal conditions, is not present. Even though there are variations in the electricity price when cutting the B5 loop, the electricity price's trend is the same. We can infer that the electricity price trend (long term price development) is governed by the reserve margin. As we keep the electricity price trend, there is no important effect on the investments in new power stations, see Fig. 35.b and Fig. 35.c.

Figure 35: Structure – Behavior test (loop B5)

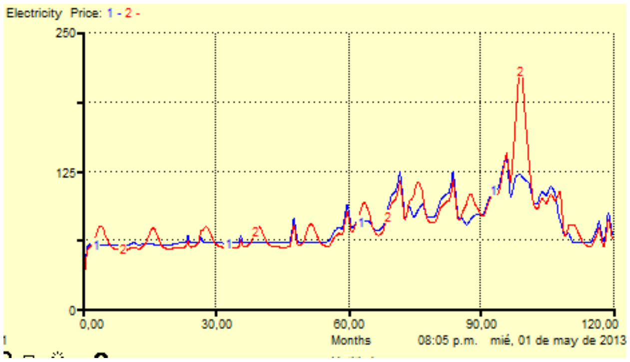

Fig. 35.a: Electricity price, normal (red line) vs. without B5 (blue line)

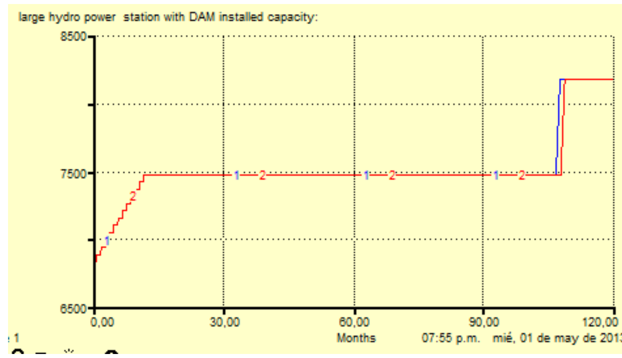

Fig. 35.b: Large hydro power station with dam installed capacity, normal (red line) vs. without B1 (blue line)

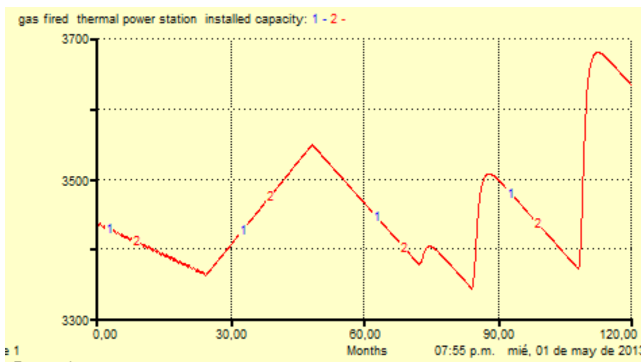

Fig. 35.c: Gas fired thermal power station installed capacity, normal (red line) vs. without B5 (blue line)

4.5. Conducting parameter sensitivity tests

According to Barlas (1994), "Behavior sensitivity test consists of determining those parameters to which the model is sensitive, and asking whether the real system would exhibit a similar high sensitivity to the corresponding parameter". In this model, there are several parameters that were estimated based on expert knowledge, statistical reports, and databases. Still, they may also be subjected to sensitivity analysis. In this section, we will analyze the impact that a variation in the values of the most important parameters and nonlinear relationships have on the model variables such as dam level, electricity generated from the dam, electricity price and installed capacity.

Fig. 36 presents the sensitivity analysis for the rainfall. As we explained in our description of the model, this is the water, in terms of potential electricity (Gwh/month), that flows through the river per month. We use a uniform distribution to run the sensitivity analysis and test the reaction of the main variables of the model to rainfall values. As rainfall is represented exogenously as a graph in the model, one that varies month by month, we added a factor that multiplies into this graph. The distribution is defined with the actual factor for the rainfall represented by 1, a minimum value by 0.9 and a maximum by 1.1 of the actual one. The graphs in Fig. 36 show that the dam level (Fig. 36.a) and the electricity generated by hydropower stations with dam (Fig. 36.b) are sensitivity to the parameter. It means that they react significantly to the values that the factor takes. However, the model is robust since the general behavior of each of the variables does not change when different parameter values are taken. In particular, the electricity price (Fig. 36.c) behaves very robustly.

Figure 36: Sensitivity analysis (Rainfall Seasonality)

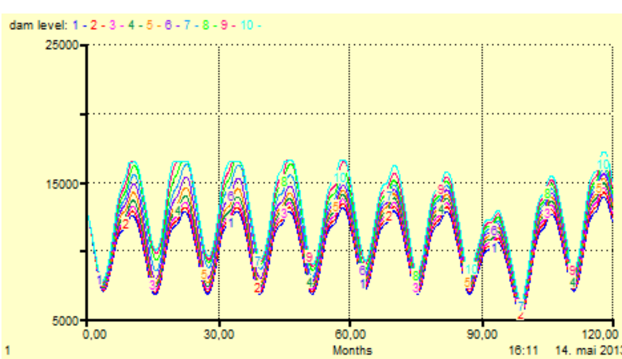

Fig. 36.a: Dam level, Sensitivity analysis (Rainfall Seasonality)

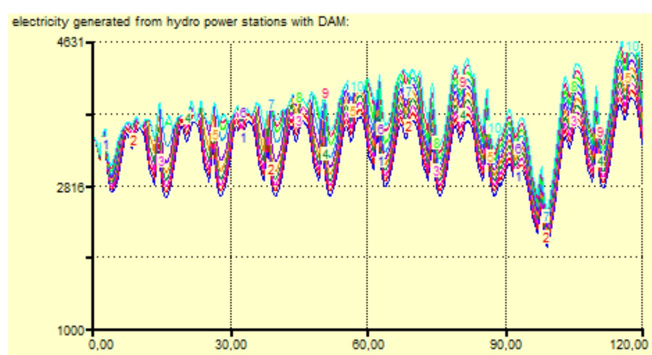

Fig. 36.b: Electricity generated from dam, Sensitivity analysis (Rainfall Seasonality)

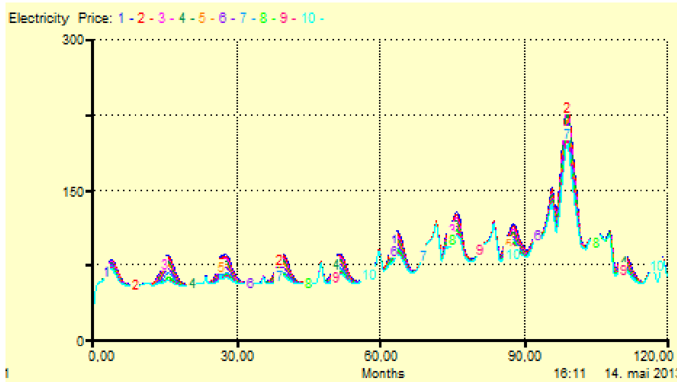

Fig. 36.c: Electricity price, Sensitivity analysis (Rainfall Seasonality)

The second sensitivity test evaluates the sensitivity of the model to the target level of the dam. This target level is also a graphical function and represents the desired level of the dam that is defined monthly by the generators before generating electricity. In order to test the effect of various values of the target level, we include also in this case a factor that multiplies into this graphical function. We use a uniform distribution to run the sensitivity analysis and test the reaction of the main variables of the model to different values of the target level. The distribution is defined with the actual factor for the target level of the dam represented by the value of 1, a minimum value of 0.95 and a maximum of 1.05. Fig. 37 shows that the dam level (Fig. 37.a) and the electricity price (Fig. 37.c) are more sensitive to this parameter than to the rainfall. The electricity generated from the dam is also sensitive to this parameter, but to a lesser extent that what we see in Fig. 36.

Figure 37: Sensitivity analysis (Target level of the dam)

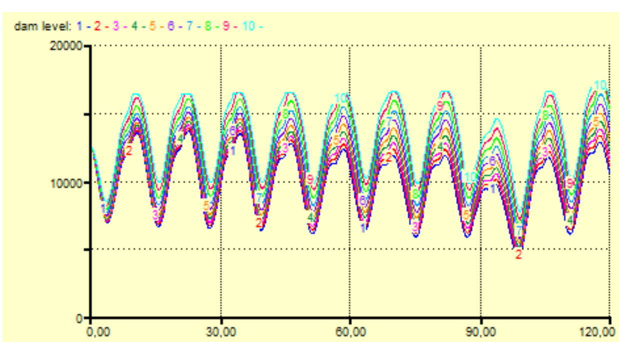

Fig. 37.a: Dam level, Sensitivity analysis (Target level of the dam)

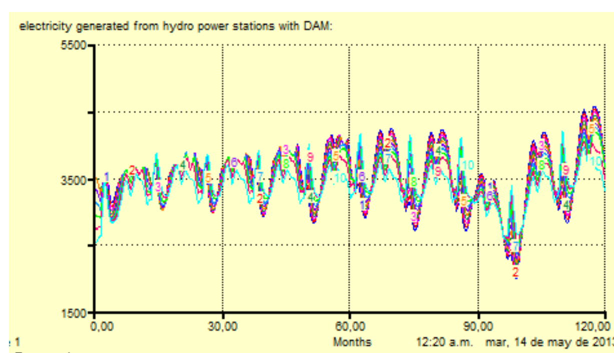

Fig. 37.b: Electricity generated from dam, Sensitivity analysis (Target level of the dam)

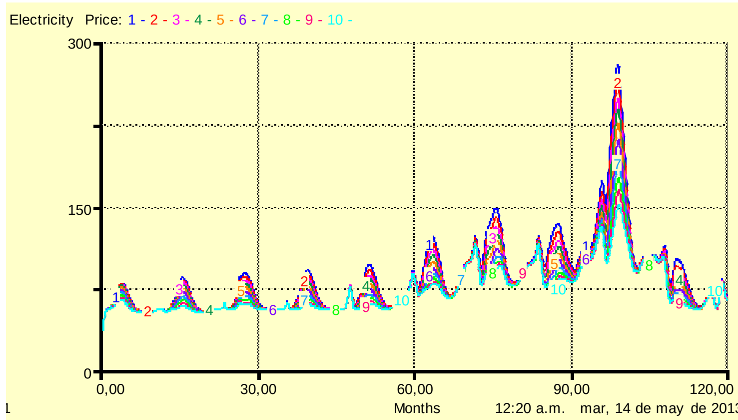

Fig. 37.c: Electricity price, Sensitivity analysis (Target level of the dam)

The third test evaluates the sensitivity of the model to the indicated price. The indicated price is governed by a nonlinear relationship that uses the reserve margin as input and represents the long term price mechanism. With the aim of varying the indicated price, a multiplicative factor, was included again. We use a uniform distribution to run the sensitivity analysis and test the reaction of the main variables of the model to different values of the indicated price. The distribution is defined with the actual factor for the indicated price represented by 1, a minimum value of 0.75 and a maximum of 1.25. The results show that the electricity price (Fig. 38.a) is highly sensitive to the indicated price. However, there are not significant variations on the installed capacity for large hydro power stations with dam (Fig. 38.b). Even lower prices are good market signals that lead to the construction of additional hydro power stations. The result is different for gas fired thermal power stations. When the indicated price is lower than the normal setting of the model (red, blue and pink lines in Fig. 38.c), the investment in thermal power stations is discouraged.

Figure 38: Sensitivity analysis (Indicated price)

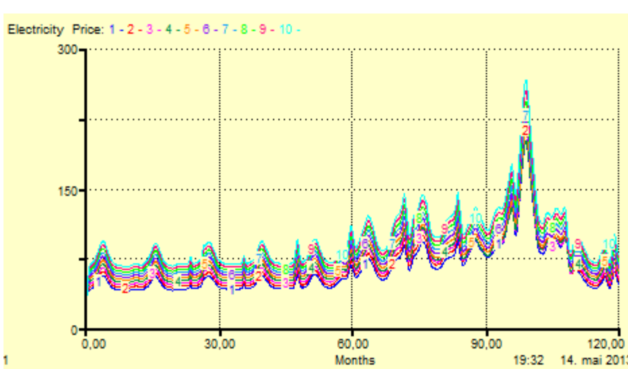

Fig. 38.a: Electricity price, Sensitivity analysis (Indicated price)

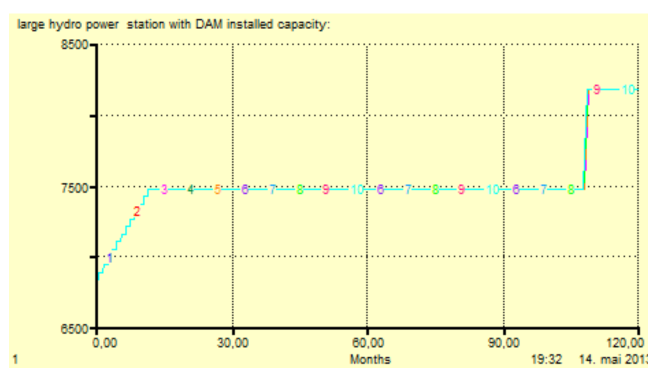

Fig. 38.b: Large hydro power stations with dam installed cap, Sensitivity analysis (Indicated price)

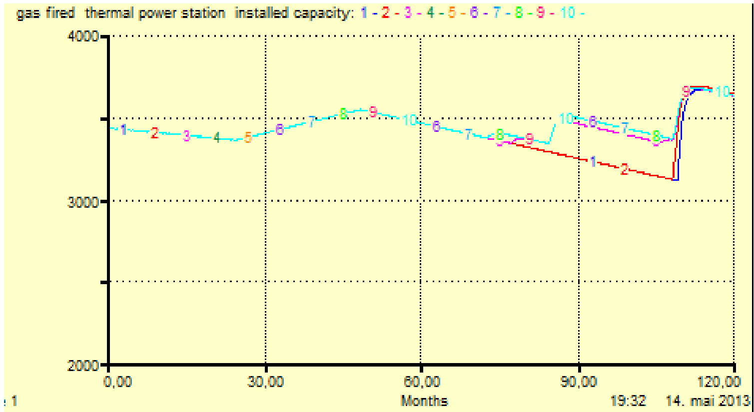

Fig. 38.c: Gas fired thermal power stations installed capacity, Sensitivity analysis (Indicated price)

Finally, we test the sensitivity of the model to the construction times for medium and large hydro power stations with dam. We use uniform distributions to test both construction times at the same time. In the model, the construction times are set to 60 and 80 months, respectively, for medium and large hydro power stations with dam. The distributions have the actual values of the construction times, and variations of 24 months above and below the actual ones. The results in Fig. 39.a and Fig. 39.b show that the general behaviors of the installed capacities are unchanged when the construction times take different values. The longer/shorter construction times have an effect on the electricity price. For example, as the construction of additional power stations takes shorter times, the reserve margin will decrease faster, leading to a lower price as shown in Fig. 39.c. All the results are as expected; the general behavior of each of target variables does not change.

Figure 39: Sensitivity analysis (Construction times)

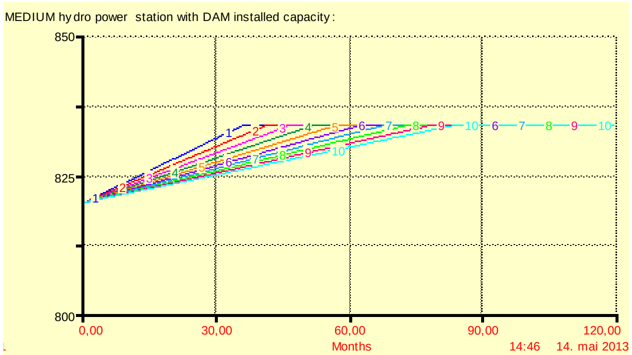

Fig. 39.a: Medium hydro power stations with dam, Sensitivity analysis (Construction times)

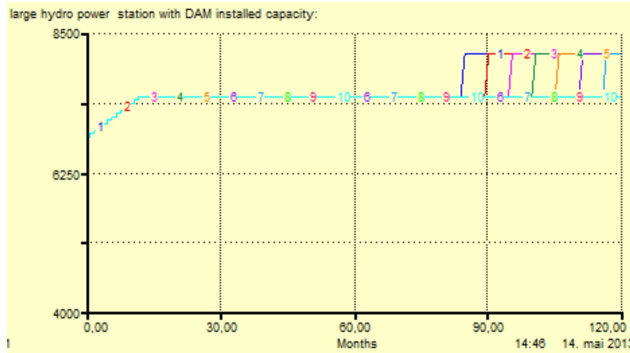

Fig. 39.b: Large hydro power stations with dam, Sensitivity analysis (Construction times)

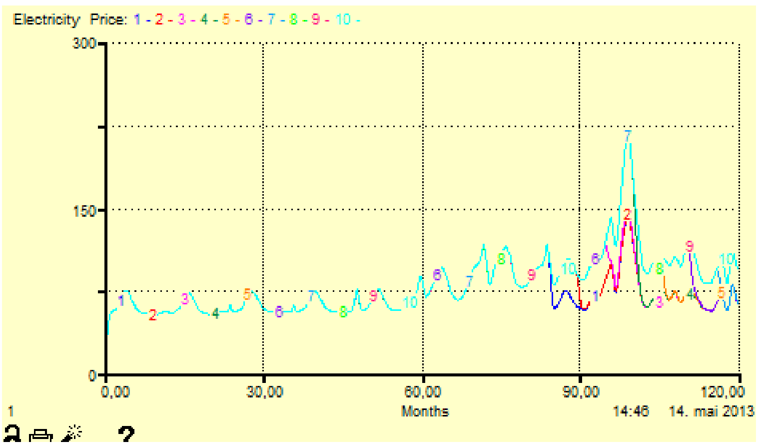

Fig. 39.c: Electricity price, Sensitivity analysis (Construction times)

5. Scenarios

The purpose of this chapter is to present the resulting simulations when the model is applied to forecast the future development of the most important variables in the Colombian Electricity System. As a foundation for any forecast, we must use the forecasts of some variables that are not defined by the model, such as:

- The inflation and the exchange rate.
- The hydrologic scenarios.
- The gas price.
- The coal price.
- The electricity demand.
- The investment paths.

5.1. Forecast of some variables

5.1.1. The inflation and the exchange rate forecast

The Central Bank of Colombia (Banco de la República de Colombia, in Spanish) is the institution that “issues and administrates the legal currency and exercises the function of banker of banks. Furthermore, it controls the country’s monetary system, credit system, and foreign exchange system/rates”. Some of its principal functions include (Banco de la República de Colombia, 2012):

- To manage and direct the country’s monetary (inflation controls) and financial policy.
- To carry out currency transfers with other countries of the world, amongst other functions.

Therefore, the forecasted inflation rate, and the forecasted exchange rate are calculated by the Central Bank of Colombia. The Central Bank of Colombia has estimated an inflation rate equals to 3 % per year in the long run, and the exchange rate by 1900 COP/US$ (Banco de la República de Colombia, 2012). In the model, the inflation rate, and the exchange rate are used when estimating the generation cost for thermal power stations.

5.1.2. The Hydrologic Scenarios forecast

In the model we utilize scenarios of the occurrence of the ENSO phenomenon. %. The macroclimate phenomenon called ENSO (El Niño South Oscillation) is a strong dry season or drought that occurs randomly. Both the occurrence or not of the ENSO will affect the hydro contribution, and, later, the dam level and the electricity generated by hydropower stations in the future years. Arango (2000) presents five hydrologic scenarios that were developed in the INTEGRAL et al.'s report (2000). The scenarios differ on the date of occurrence of the ENSO phenomena, its frequency and duration. In the next graphs the value 0.7 represents the occurrence of the ENSO, and the value 1 represents a situation with average rainfall.

Figure 40: Hydrologic Scenarios

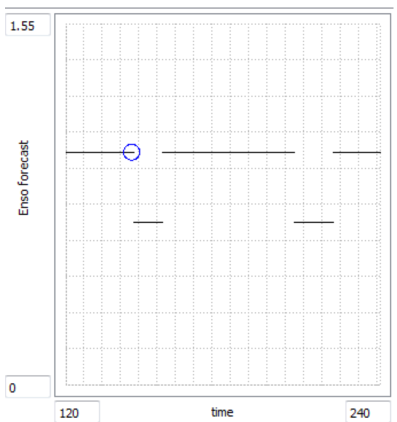

Fig.40 .a: Hydrologic Scenario 1

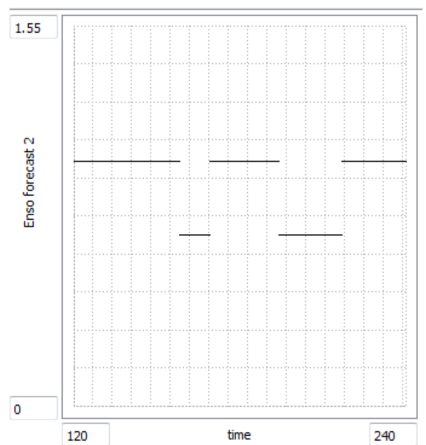

Fig.40 .b: Hydrologic Scenario 2

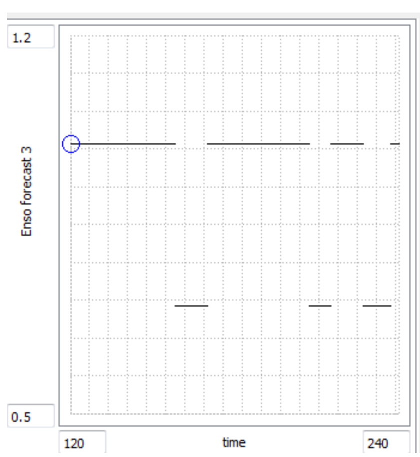

Fig.40 .c: Hydrologic Scenario 3

5.1.3. The Gas Price Forecast

The natural gas price in Colombia is forecasted by UPME, based on the following method. We consider three characteristics of the gas supply chain (UPME, 2012):

- The estimation of the gas price at the wellhead for the main supply sources: Guajira and Cusiana, the two places in Colombia where the wells are located (we will use the forecast of the Guajira well because of its significance).
- The estimation of the gas transport cost.
- The estimation of the total cost of the natural gas, i.e. the sum of the two previous characteristics.

The estimation of the wellhead gas price in Guajira

The gas price is set according to the procedure that was established through the resolutions 119, 187 and 199 issued in 2005, 2010, and 2011 by CREG[2]. The procedure uses as evaluation parameter, the development of the prices of the sulfur residual fuel N.6 1.0 % that is obtained from the "Platts US Gulf Coast Residual index". The Guajira's gas price must be updated each semester, in February 1st, and in August 1st. The annual growth rate of the Residual fuel N.6 is obtained from the Annual Energy Outlook[3]. Fig. 45 shows the forecast of the wellhead gas price at Guajira. The average growth rate is equal to 2.44 % per year for the reference scenario, whereas for the high and low scenarios the annual growth rates are 5.02 % and -3.1% respectively (UPME, 2012). In our case, we will use the reference scenario.

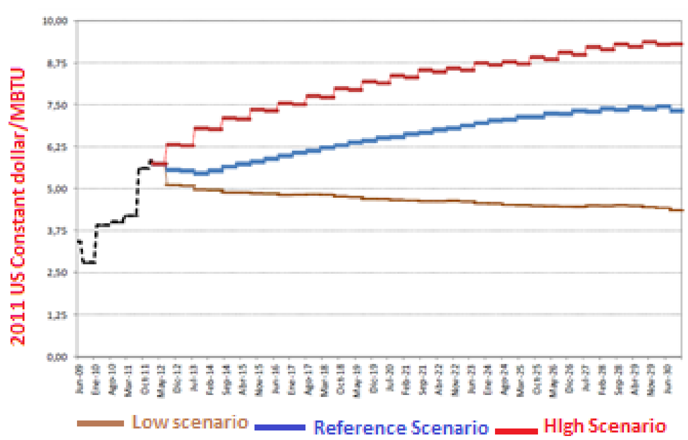

Figure 41: Forecast of the wellhead gas price in Guajira (UPME, 2012)

2 CREG: Regulatory Commission for Electricity and Gas
3 www.eia.doe.gov

The estimation of the gas transport cost

This estimation takes into account some CREG resolutions such as: 070, 076, 125, 0111, and 0195 issued in 2003, 2002, 2003, 2011, and 2011, respectively. The gas transport cost for each thermal plant is forecasted considering the gas entrance and exit point in the gas network (UPME, 2012). For this thesis, we will calculate a weighted average gas transport cost that includes the installed capacity of the gas fired thermal power stations, and their specific gas transport cost forecast (UPME, 2012). The total cost of gas is the sum of the two.

The supply of natural gas in Colombia

As we stated in the previous paragraphs, the two main wells that produce natural gas in Colombia are Guajira and Cusiana. However, the gas transport infrastructure is a main factor that constraints the free gas supply in Colombia. In order to include this constraint, we consider the fact that UPME has regionalized the gas supply/demand balance, instead of national supply/demand balance, and the results are presented in Fig. 42 and Fig. 43 (UPME, 2012).

Fig. 42 portrays the available natural gas in the Atlantic region (where the Guajira's well is located) compared to the demand. It shows that the supply is sufficient to satisfy the demand until 2018, considering the reference or medium growth scenario. Nevertheless, after 2019, an extra source of natural gas will be needed (UPME, 2012).

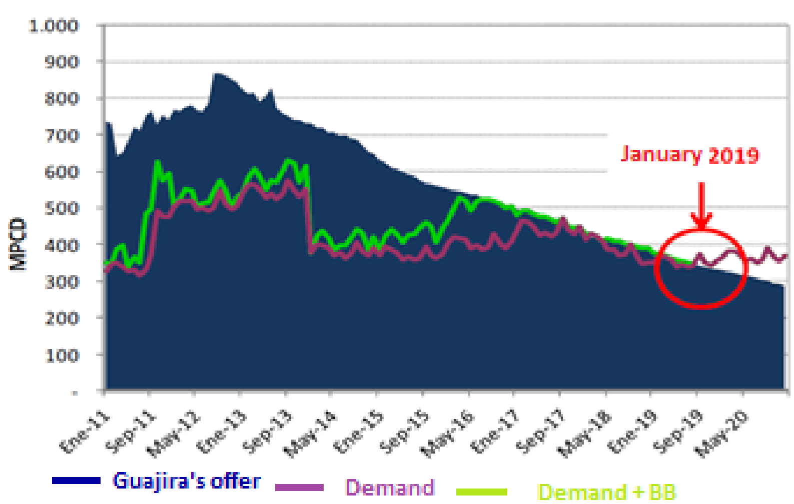

Figure 42: The gas natural supply/demand balance in the Atlantic region (UPME, 2012*[4]*)

4 In Figure 46, Demand + BB means the Atlantic region demand plus the demand from another region that is located next to it.

The gas natural supply/demand balance in the inner region is portrayed in Fig. 43, and this estimation indicates that there will be a natural gas deficit as of 2016. Therefore, UPME has considered the import of gas natural from Trinidad and Tobago after 2018, and 2016 for the Atlantic and inner region, respectively (UPME, 2012).

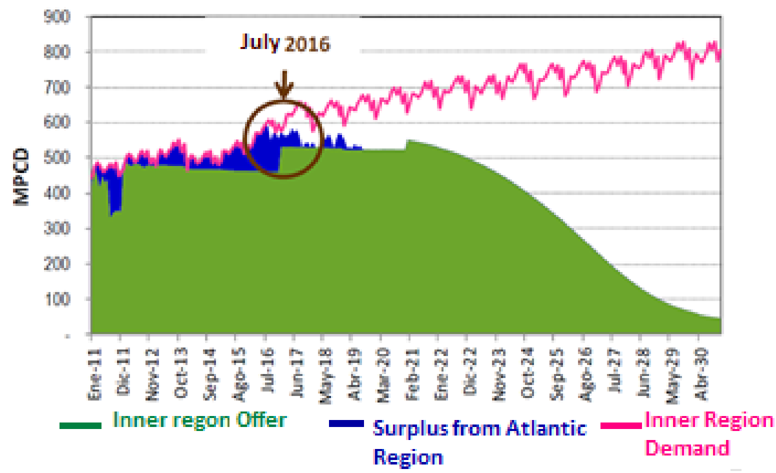

Figure 43: The gas natural supply/demand balance in the inner region (UPME, 2012)

Due to the expected natural gas deficits that were presented in the two previous paragraphs, the gas price for the Guajira's well will rise sharply after 2019, taking into account the new market conditions as shown in Fig. 44.

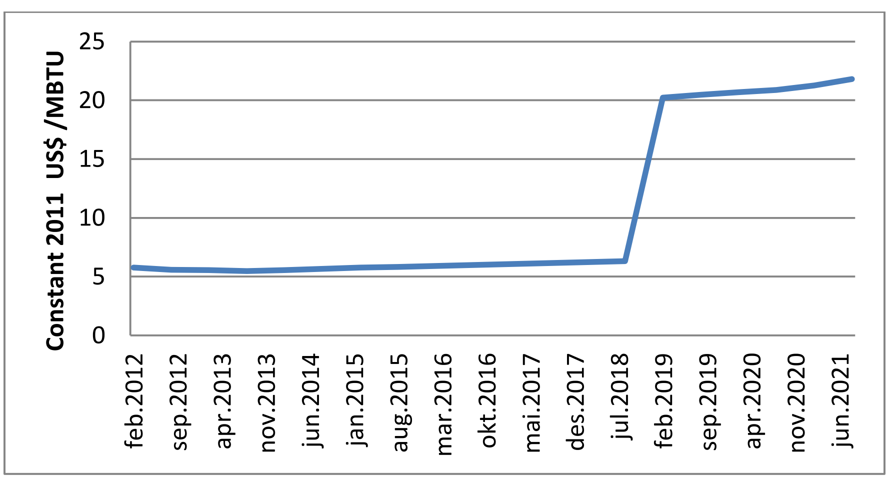

Figure 44: The forecast of the natural gas price in Guajira's well

5.1.4. The Coal Price Forecast

UPME has forecasted the coal price in Colombia using an econometric model that was developed based on a monthly series of the Colombian coal prices (registered for international transactions), and the coal price in the international market, during the period from January 2005 until February 2010. UPME assumed the API # 6[5] New Castle (Australia) coal as the international market reference. The result of the coal price estimation for the Colombian Market is portrayed in Fig. 45 (UPME, 2010.b.). We will use the reference simulation in our model.

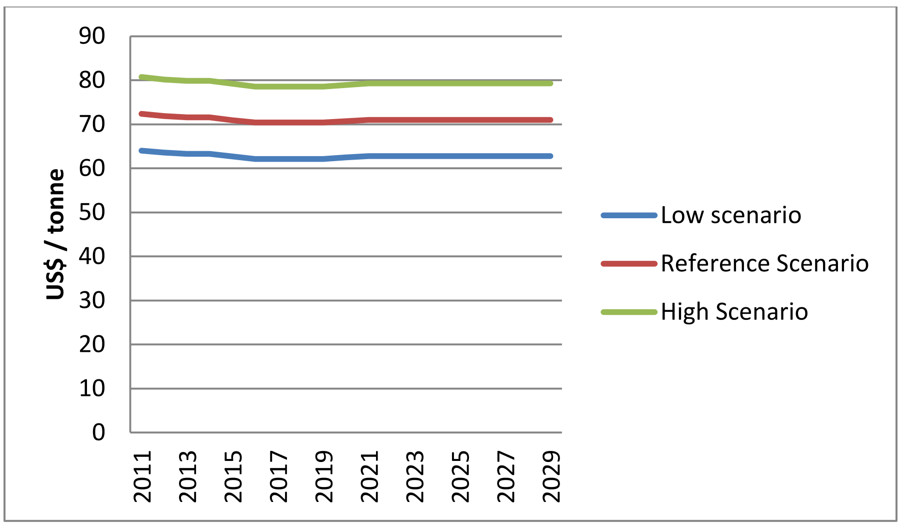

Figure 45: The forecast of the coal price in Colombia (UPME, 2010.b.)

5 The coal API # 6 is a weekly index for the New Castle's coal (Australia) that has a caloric power of 6700 kcal/kg.

5.1.5. The Electricity Demand Forecast

Through this section, we will explain how the electricity demand forecast is calculated by UPME (2010.a.).

National projections of electricity demand

The domestic demand of electricity is constituted by the sum of: the sales to the regulated market, and the sales to the unregulated market demand, and the transmission and distribution losses.

Demand = Sales to the regulated market + unregulated market demand + losses

Demand = (1) + (2) + (3)

- **Sales to the regulated market**

UPME (2010.a.) applies a variety of econometric models to forecast the time series that represent the annual electricity demand. Those models are also used to estimate the future electricity demand based on variables such as: Gross Domestic Product –GDP-, the final consumption in the economy, the price's index, the population size, etc. The expected behavior of the GDP is shown in Fig. 46.

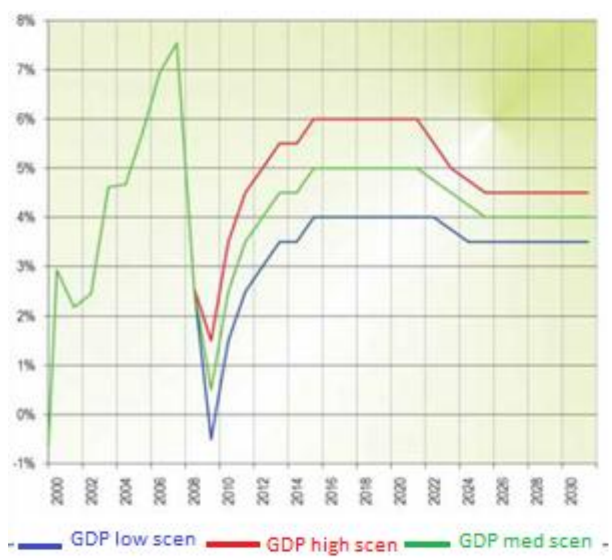

Figure 46: Scenarios of GDP % growth (Translated from UPME, 2010.a.)

- **Unregulated market demand**

Electricity demanded by unregulated consumers is called special charges. This demand is calculated based on estimates offered by the three large kinds of agents (generators, transmitters and distributors) in the market and the possibility to satisfy this demand by means of the available infrastructure. This demand is shown in Table 5 (UPME, 2010.a.).

GWh	High	Medium	Low
2008	2,470	2,398	2,154
2009	2,516	2,404	2,164
2010	2,523	2,443	2,168
2011	2,533	2,449	2,170
2012	2,463	2,446	2,177
2013	2,398	2,382	2,205
2014	2,322	2,303	2,205
2015	2,241	2,210	2,152
2016	2,135	2,107	2,046
2017	2,025	1,936	1,932
2018	1,853	1,812	1,764
2019	1,812	1,733	1,644
2020	1,815	1,736	1,647
	...	...	...
2025	1,811	1,732	1,643
	...	...	...
2030	1,811	1,732	1,643

Table 5: Scenarios of special charges (UPME, 2010.a.)

- **Losses**
  - **Losses of electricity on the central national transmission system (> 200 KV)**

According to UPME (2010.a.), electricity losses related to national transmission system will remain at its historical level. The historical losses are been quantified to about 2, 4 % of electricity sales. This value is assumed constant through the projection.

  - **Losses of electricity on the local and regional distribution systems (<= 220 KV)**

Distribution losses in Colombia have been calculated according to traders and distributors' criteria. The historical data series are shown in Fig. 21. Distribution losses were estimated to be between 13 % (according to traders) and 15, 4 % (according to distributors) (UPME, 2010.a.).

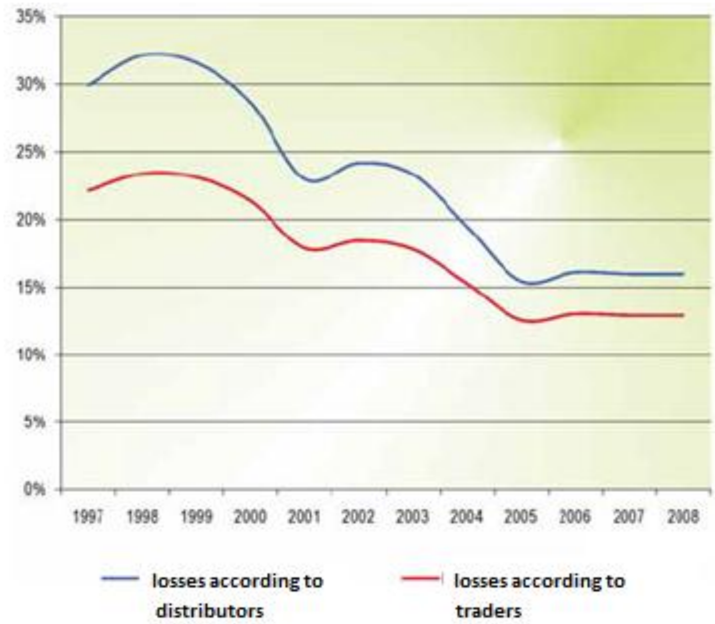

Figure 47: Electricity losses on distribution system (UPME, 2010.a.)

Finally, Fig. 48 portrays the demand projections for electricity production per year and Fig. 49 represents demand for output capacity of the generators in Colombia. These estimates are shown until 2031 (UPME, 2010.a.).

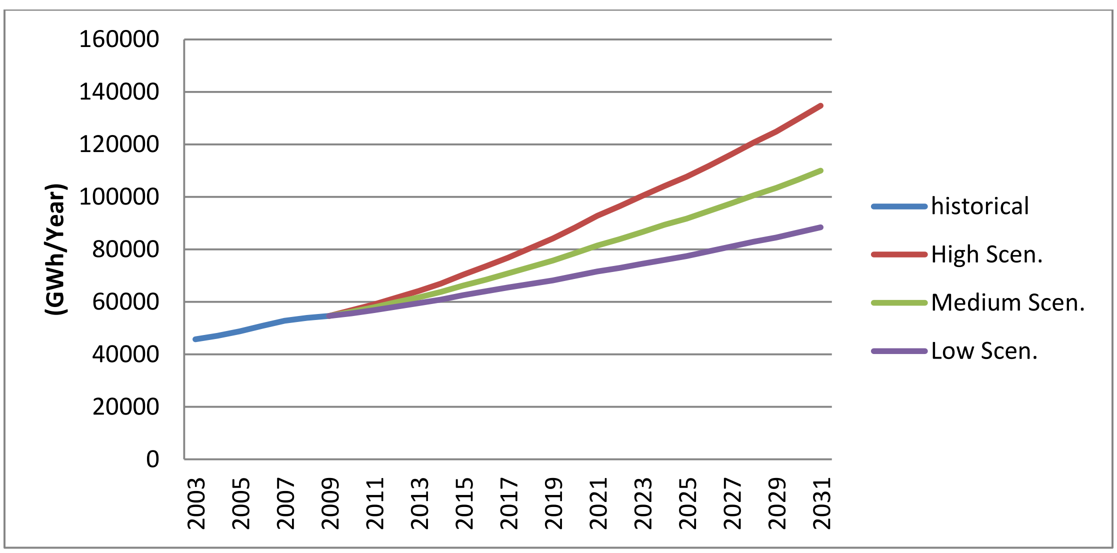

Figure 48: Historical Electricity Demand and projections in Gwh/year (UPME, 2010.a.)

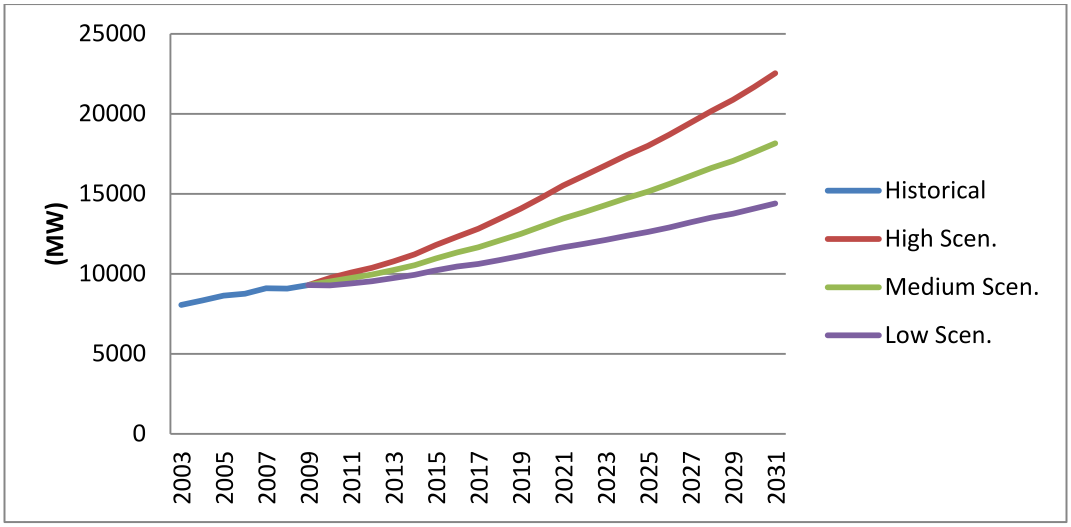

Figure 49: Historical Power Demand and projections in MW (UPME)

Even though three scenarios have been forecasted by UPME, the medium or realistic scenario will be taken as business as usual for the simulations in this thesis.

5.2. The investment paths

As we stated during the problem presentation, the main objective of this thesis is to evaluate whether the two main power stations with dams, whose construction was canceled, can be replaced by a series of small hydro power stations. The two larger power stations were expected to constitute a total installed capacity of 535.2 MW by 2015. Therefore, we will use a normal distribution of generation capacity that in total represents 535 MW. The density distribution of capacity shown in Fig. 50 symbolizes how many MW of power will be installed at a set critical electricity price.

In order to design the density distribution of capacity, we need to define a minimum, and a maximum critical price. We will assume 96 COP/Kwh as minimum critical price. This value is the average electricity price of the last 60 months, and it was calculated using the system dynamics model described in this thesis. This 96 COP/Kwh corresponds to the average electricity price during the period 120 (December 2011). The estimation of the maximum critical price is more arbitrary, we will use a maximum critical price of 150 COP/Kwh that represents about 1.5 times the minimum one. However, in the model, the user can define the minimum and the maximum critical price, prior to any simulation.

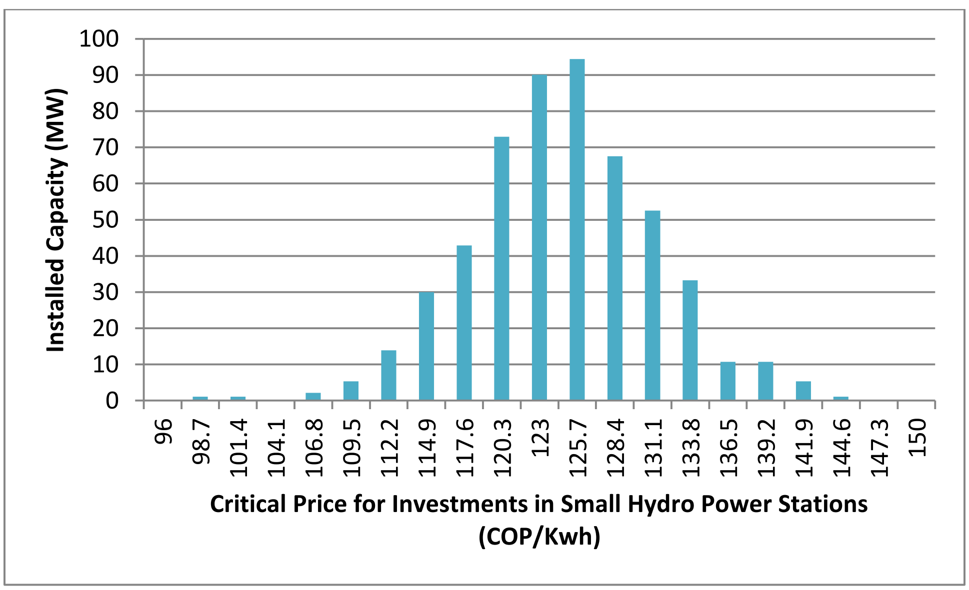

Figure 50: Density Distribution of Capacity

The focus of this section is the investment behavior. In order to assess the profitability of a new small hydro power station, the investors forecast the electricity price. The forecast of the electricity price varies from investor to investor. Some of them will analyze the future market development to assess the profitability to form an expectation, while as others are more sensitive to the historical electricity price. In general, each investor will assign a weight to the historical electricity price, and another weight to the expected market development when forecasting the electricity price.

Ford (2001) describes investors as:

- Believers
- Pre counters

The believers do not include the power stations under construction in their forecasts; they do believe that the new power stations are for real when they see them in operation (Ford, 2001). The believers are quite sensitive to the historical electricity price though.

The pre counters confide that any power station under construction will be completed and come on line. They count the new installed capacity into their forecast as soon as the construction is initiated (Ford, 2001). The pre counters are quite sensitive to the expected market development.

In each of our scenarios, we will assume different investor sensitiveness. We start from the full believers that when forecasting the electricity price, are not sensitive to the expected market development, but to the historical electricity price; and we will continue on the way to the investors that are 100% sensitive to the market expectations when forecasting the electricity price. It is important to keep in mind that the sum of the weights, that the investors give to the forecast based on the historical electricity price, and to the forecast based on the market development, cannot be larger than 1. So we will have the combinations that are shown in Table 6:

Categories	Weight to the forecast based on the historical electricity price	Weight to the forecast based on the expected market development
1 - Believers	1	0
2 - Highly Believers	0.75	0.25
3 - Neutral	0.5	0.5
4 - Highly Pre Counters	0.25	0.75
5 - Pre counters	0	1

Table 6: Weight set to the electricity price forecasts by investors

The investors that have any level of sensitivity to the expected market development need to know about the power stations that have already committed to construction, in order to estimate the expected installed capacity in the coming years. Therefore, we will use the list of projects that have been already registered by UPME, as a good estimate of the installed capacity that will come online in the near future.

Table 7 presents a summarized list of projects that have been recently registered before UPME (2013). These projects are classified according to the technology applied, and also according to the stages, i.e. the number of remaining years before starting the construction. The projects are classified by UPME as follows (2007):

- Stage 1: the projects in this stage have realized a pre-feasibility study; they still must submit the feasibility study before UPME, with the aim of being promoted to the second stage. The construction of these projects will not until two years have passed.
- Stage 2: these projects already have a feasibility study; their construction is likely to start in one year. They still need some environmental licenses, a final project schedule, and a final financial assessment.

	Stage 1	**Stage 2**
Small Hydro	688.85	124.1
Medium hydro	736.13	0
Gas fired	0	34.5
Coal fired	299	0
Subtotal	**1724**	**158.6**

Table 7: Generation Projects registered by UPME

5.3. Scenarios and results

This section presents the resulting simulations when the model is used to forecast the future development of the most important variables in the Colombian Electricity Market. The density distribution of generation capacity, portrayed in Fig. 50, applies from the month 120, with the weights assigned to the electricity price forecasts by investors in Table 6. In the model, the expected electricity price is calculated through the equation 8.

$$EEP = W_1 * FEP_{HISTORICAL} + W_2 * FEP_{MARKET} \qquad \textbf{\textit{Equation 8}}$$

Where:

EEP: Expected Electricity Price

W_1: set weight to the electricity price forecast that is based on the historical electricity price (according to table 6)

W_2: set weight to the electricity price forecast that is based on the expected market development (according to table 6)

$FEP_{HISTORICAL}$: Forecasted Electricity Price based on the historical electricity price time series

FEP_{MARKET}: Forecasted Electricity Price based on the expected market development

FEP_{MARKET} is the result of forecasting the installed capacity in the future in parallel to the main model, i.e. in a module, when the main simulation is running. FEP is an average that takes the forecasted electricity price for the periods 180 – 240 as inputs when the time is equal to 120 months. Therefore, this FEP will be a constant value in the main simulation.

We simulated nine scenarios, defined by the combinations of three probable electricity demands (Section 5.1.5.), and three rainfall expectations (Section 5.1.2.). For each of these nine scenarios, we examine six investment behaviors. The first one, called business as usual, assumes that there is no additional investment by new investors; only the projects, initially registered with UPME, will come online. The other five categories include the projects already registered by UPME, and also, addition the ones based on the profitability (i.e. Critical Price Mechanism) of bringing them online and on the density distribution of capacity that is portrayed in Fig. 50. The five last investment behaviors vary in accordance with the five categories presented in Table 6. Finally, it is important to note that, for all the simulations, we assume that the gas price and the coal price are the ones specified under the reference or base scenario.

In all the scenarios, the simulation or run 1 (blue line) represents the business as usual investment path/behavior. Runs, from 2 to 6, include the evaluation of the normal distribution of generation capacity according to the five categories presented in Table 6, and the lines symbolize 2 - red, 3 – pink, 4 – green, 5 – orange, and 6 – purple, respectively . Therefore, the run N. 2 (red) is a believer; the investors are only sensitive to the historical electricity price. This sensitivity to the historical electricity price decreases from run to run in 0.25. The run N. 6 (purple) corresponds to the pre counters, who are not sensitive to the historical price, but to the future market development.

5.3.1. Low Electricity Demand

We run the model under a low electricity demand scenario, and combined it with the three hydrologic scenarios that were presented in the section 5.1.2. Fig. 51 portrays the results of combining a low electricity demand, and the hydrologic scenario 2. The results for the other two scenarios (low electricity demand, with the hydrologic scenario 1, and the hydrologic scenario 3) are shown in Appendix 1. However, under the low electricity demand scenario, the simulation results are quite similar, regardless of the chosen hydrologic scenario.

Under a low electricity demand scenario, Fig. 51.a. shows that the expected electricity price decreases as the investor is more sensitive to the expected market development (runs 3 to 6), this reduction of the expected electricity price means there is no need for new SHPS[6]; the current installed capacity, the projects under construction, and the projects already registered by UPME are sufficient to satisfy the electricity demand when this is low. The low expected electricity price is not a good market signal for the investors. Few investors decide to invest in SHPS in the simulations 4 – 6 as portrayed in Fig. 51.b. Therefore, less SHPS (see Fig. 51.c.) come on line as W_1 increases, having the same effect on the net installed capacity as shown in Fig. 51.d. Under this scenario the reserve margin oscillates in between 0.45 and 0.6 (see Fig. 51.e.) in the period 120 – 240. Due to this reserve margin, the average electricity price is around 100 – 110 COP/Kwh according to Fig. 51.f. This average electricity price is too low for the most of the possible investors considered in the density distribution of generation capacity. Consequently, under this scenario, only investors with a critical price below 110 COP/Kwh will invest in new SHPS.

6 SHPS stands for Small Hydro Power Stations

Figure 51: Results of the model under a low demand scenario, and under the hydrologic scenario 2

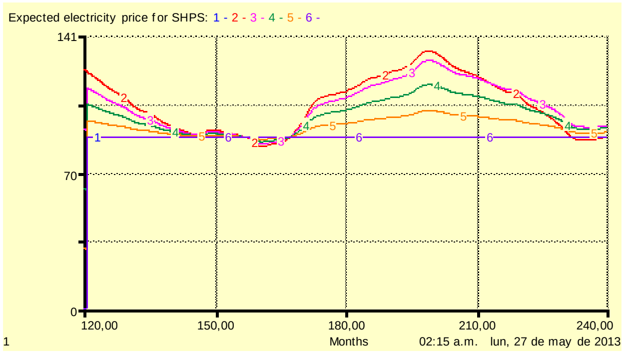

Fig. 51.a: Expected Electricity Price under a low demand scenario, and the hydrologic scenario 2

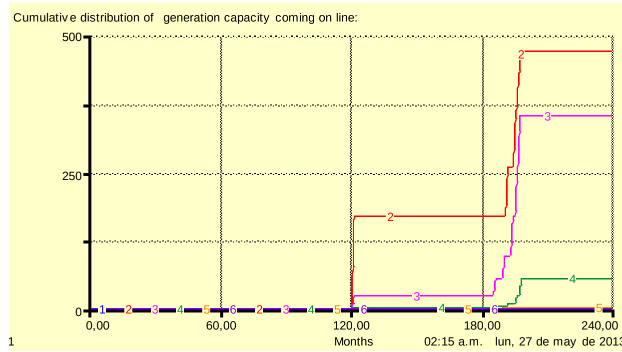

Fig. 51.b: Cumulative Distribution of Generation capacity under a low demand scenario, and the hydrologic scenario 2

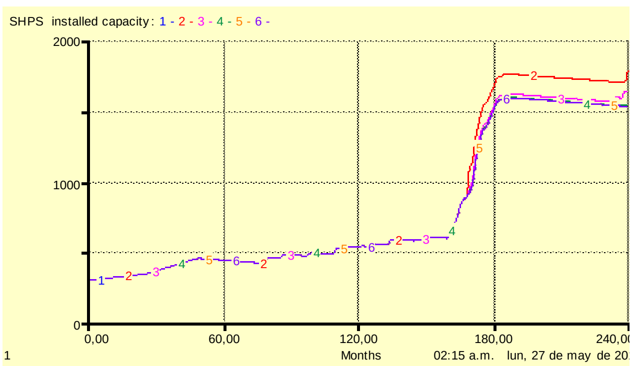

Fig. 51.c: SHPS Installed Capacity, under a low demand scenario, and the hydrologic scenario 2

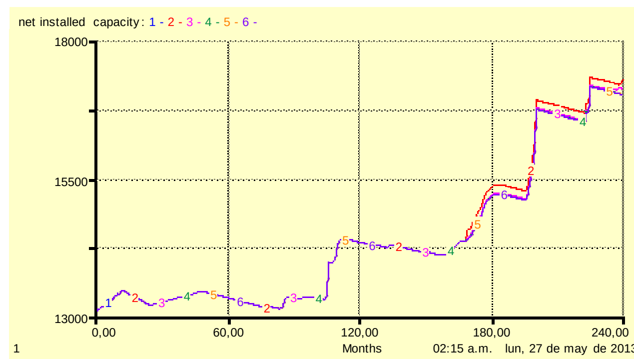

Fig. 51.d: Net Installed Capacity, under a low demand scenario, and the hydrologic scenario 2

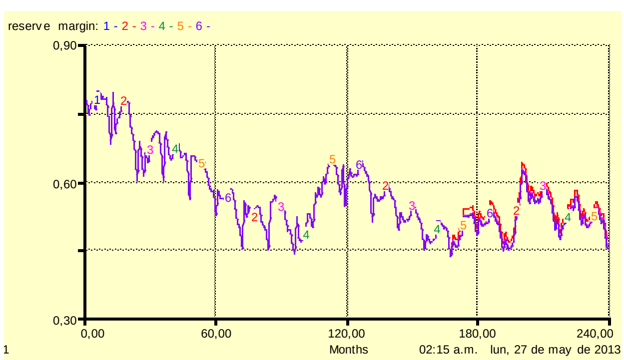

Fig. 51.e: Reserve Margin, under a low demand scenario, and the hydrologic scenario 2

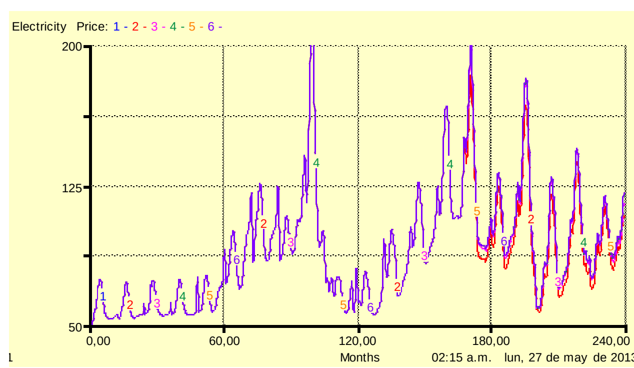

Fig. 51.f: Electricity Price, under a low demand scenario, and the hydrologic scenario 2

5.3.2. Moderate Electricity Demand

Fig. 52 portrays the results of combining a moderate electricity demand, and the hydrologic scenario 3. The results for the other two scenarios (moderate electricity demand, with the hydrologic scenario 1, and the hydrologic scenario 2) are shown in Appendix 1. However, under the moderate electricity demand scenario, the simulation results are quite similar, regardless of the hydrologic scenario.

Under a moderate electricity demand scenario, Fig. 52.a. shows that the expected average electricity price is 170 COP/Kwh for all the investment behaviors. This price is larger than the maximum critical price characterizing the density distribution of capacity considered. Therefore, sooner or later, all the new SHPS, i.e. 535 MW in Fig. 50, will come online as portrayed in Fig. 52.b. The installed capacity of SHPS will reach 2100 MW in the runs 2 – 6 in Fig. 52.c. Only in the case of business as usual scenario, the projects, that are already registered with UPME, come online. Therefore, the net installed capacity is lower in the business as usual simulation (blue line) as shown in Fig 52.d. In all the runs, the reserve margin, portrayed in Fig. 52.e, has the same value until month 170, when the SHPS start to come on line. The SHPS come on line faster as the investors are more sensitive to the market expectations (larger W_2). The variations in the reserve margin, under the different investment behavior, are reflected in the electricity price (Fig. 52.f). In the business as usual simulation (blue line), a lower reserve margin causes the electricity price to rise due to the fact that no additional power station comes online, especially after month 180.

Figure 52: Results of the model under a moderate demand scenario, and under the hydrologic scenario 3

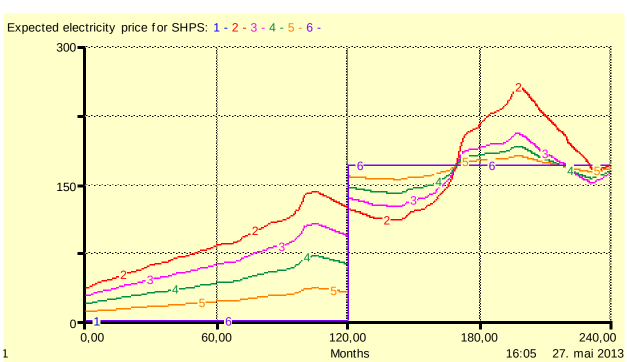

Fig. 52.a: Expected Electricity Price under a moderate demand scenario, and the hydrologic scenario 3

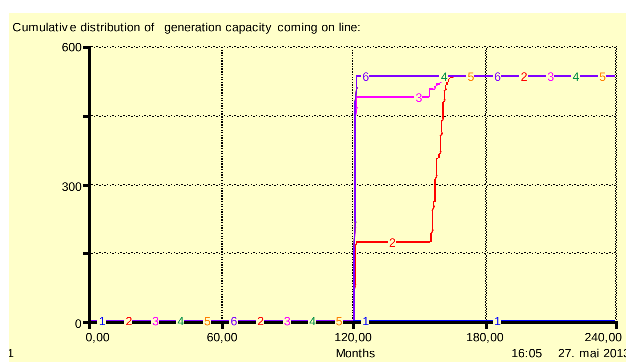

Fig. 52.b: Cumulative Distribution of Generation capacity under a moderate demand scenario, and the hydrologic scenario 3

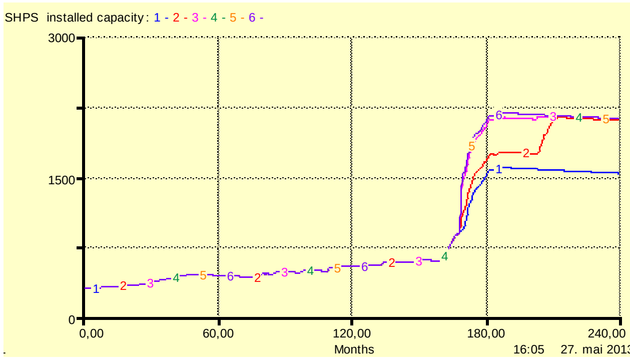

Fig. 52.c: SHPS Installed Capacity, under a moderate demand scenario, and the hydrologic scenario 3

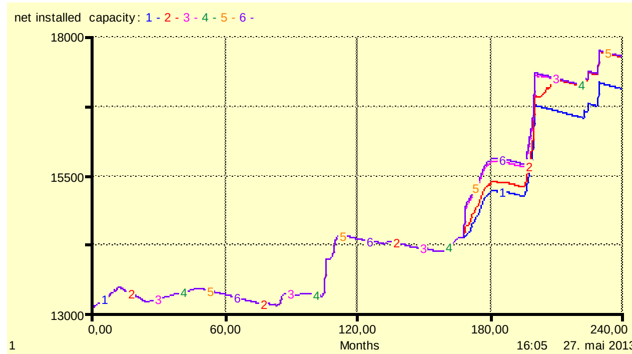

Fig. 52.d: Net Installed Capacity, under a moderate demand scenario, and the hydrologic scenario 3

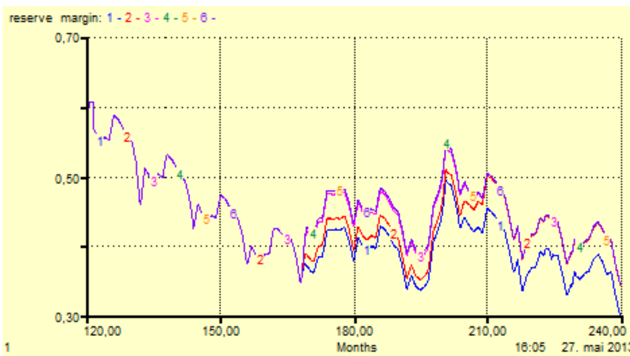

Fig. 52.e: Reserve Margin, under a moderate demand scenario, and the hydrologic scenario 3

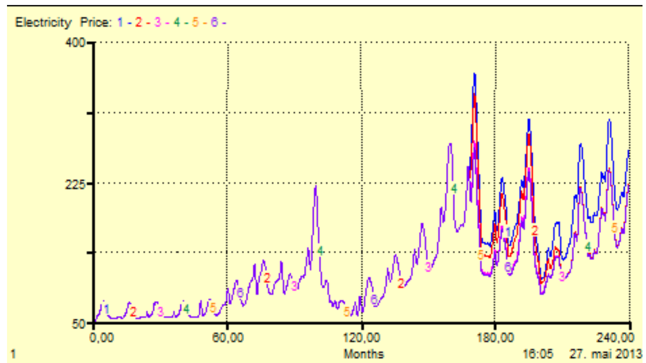

Fig. 52.f: Electricity Price, under a moderate demand scenario, and the hydrologic scenario 3

5.3.3. High Electricity Demand

The results of combining a high electricity demand and the hydrologic scenario 1 are presented in Fig. 53. The results for the other two possible scenarios (high electricity demand, with the hydrologic scenario 2, and the hydrologic scenario 3) are shown in Appendix 1. However, the simulation results are similar, under the high electricity demand scenario, regardless of the hydrologic scenario.

The expected electricity price decreases as the investors are more sensitive to the market development (runs 2 to 6). However, the expected electricity price, showed in Fig. 53.a, is on the average 300 COP/Kwh. This value is even twice the maximum critical price characterizing the density distribution of capacity. Therefore, all the investors decide to invest in SHPS, see runs 2 to 6 in Fig. 53.b. After month 180, 535 MW of power come on line, increasing the SHPS installed capacity as shown in Fig. 53.c. This increase in installed capacity is also shown in the net installed capacity as portrayed in Fig. 53.d. Under this scenario, the reserve margin decreases considerably (Fig. 53.e.), it means that the electricity demand grows faster than the supply. The business as usual simulation presents a lower reserve margin, due to the 535 MW of the density distribution of capacity that will not come on line. The reserve margin is a bit higher in the other investments behaviors (simulations 2 to 6), but not enough to avoid a drastic increase in the electricity price in the months 120 - 180 as shown in Fig. 53.f. The electricity price under the high demand scenario might reach values that have not been seen in the Colombian Electricity Market before.

The CEM might face some blackouts. The model has estimated that there will be an unsatisfied demand than may oscillate from 0 to 1400 Gwh/month, representing (maximum) 15% of the electricity demand. The shortage is forecasted to happen when the dam filling fraction is below 0.5 of its total capacity which coincides with the occurrence of the drought.

Figure 53: Results of the model under a high demand scenario, and under the hydrologic scenario 1

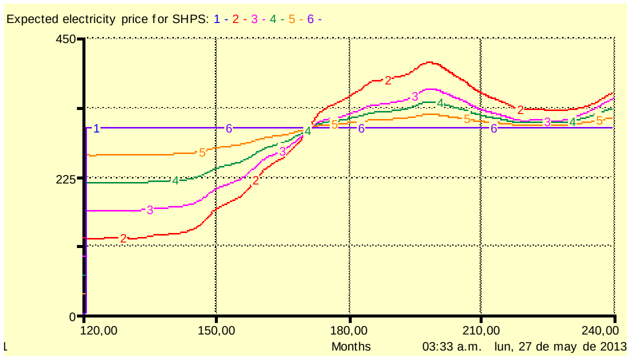

Fig. 53.a: Expected Electricity Price under a high demand scenario, and the hydrologic scenario 1

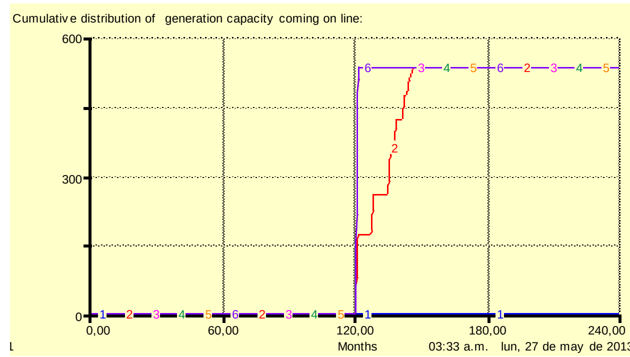

Fig. 53.b: Cumulative Distribution of Generation under a high demand scenario, and the hydrologic scenario 1

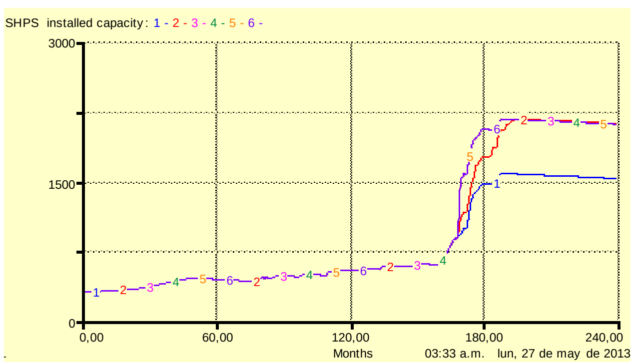

Fig. 53.c: SHPS Installed Capacity, under a high demand scenario, and the hydrologic scenario 1

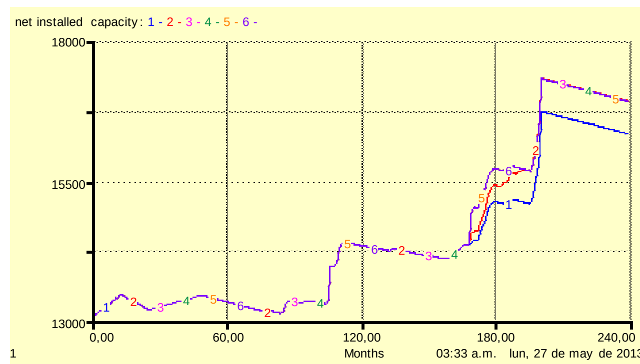

Fig. 53.d: Net Installed Capacity, under a high demand scenario, and the hydrologic scenario 1

Fig. 53.e: Reserve Margin, under a high demand scenario, and the hydrologic scenario 1

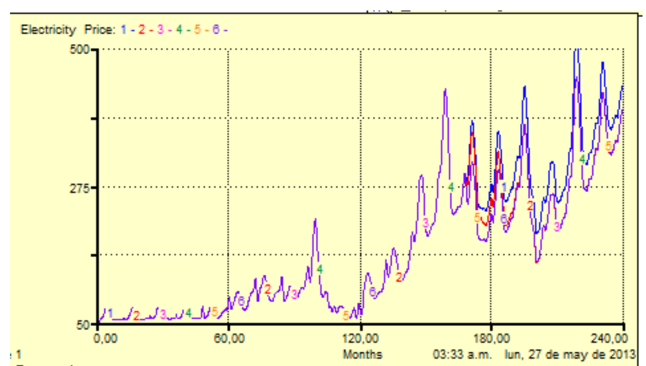

Fig. 53.f: Electricity Price, under a high demand scenario, and the hydrologic scenario 1

6. Conclusions

6.1. System Dynamics and the Colombian Electricity Market (CEM)

The CEM has complex characteristics such as time delays, feedback cycles, nonlinearities, stocks and flows that affect our understanding of the real system. Some examples of those complex characteristics that call for the use of System Dynamics are the construction delays, the effects of the reserve margin and the dam level on the electricity price, the trade-off between different generation technologies, etc.

Since its deregulation in 1994, the CEM has had a good performance in terms of: generation, sales to large costumers and to household sector. However, and due to the complexity of the CEM, and in the face of the upcoming severe weather conditions, a long term planning process is required to make sure an appropriate generation installed capacity is coming on line. System dynamics as a modeling tool captures all the complexity, i.e. feedback processes, stock and flows relationships, time delays, nonlinearities, that characterizes complex systems such as the CEM. Also, system dynamics facilitates the understanding and management (forecast of scenarios and strategy development) of a complex system as the CEM.

System dynamics has been regularly used to study the CEM in Colombia. Related to the investment in new power stations in Colombia, the literature reports the study carried out by Arango (2000). However, Arango's study is based on a simulator where the actors make their investment decision and subsequently investigates the performance of it, characterized by the behavior of some of the most important variables in the CEM. Arango's simulator presents the profitability assessment of three specific projects that vary due to technologies. Our model is focused on the CEM as a whole. Therefore, our approach is more general. It evaluates the impact of the cancelation of the two projects, and the viability of replacing them with small hydro power stations. So far, we do not know any other study that estimates the effect of substituting for the cancelation of those two large projects on the electricity price.

6.2. Results of the model under considered scenarios

Since the CEM was deregulated in 1994, the electricity price has been good enough to encourage the investment in new power stations, mainly hydro power stations, but also thermal power plants. However, social and environmental aspects have caused the construction of two main projects to be canceled. Nowadays, the generators, distributors, costumers, and, in general, the CEM are all wondering how these cancelations might affect the supply of electricity in the upcoming years. The electricity price is the indicator that reflects the supply/demand balance (reserve margin) in this model. The electricity price is also the main input that is used by investors when estimating the financial viability of their projects.

We study the consequences of keeping a business as usual scenario (i.e. not replacing the projects that were canceled), and the inclusion of some investments in small hydropower stations that would substitute the canceled projects. We apply a hypothetical density distribution of capacity under nine scenarios. The scenarios are the result of combining three probable electricity demands (high, moderate and low) with three hydrologic scenarios. For each scenario, we examine the business as usual scenario and five investment behaviors defined by the sensitivity of the investor to the electricity price data series, and to the expected market development.

Our model suggests that the electricity price will rise significantly under the high and moderate demand scenarios. This expected high price is an indicator that the supply might be not sufficient to satisfy the electricity demand. This result confirms our assumption that the electricity price trend is governed by the reserve margin. The expected reserve margin is quite low, raising the electricity price, and encouraging investors when they expect a high or moderate electricity demand. Therefore, the small hydro power plants, that were described in the density distribution of capacity, were taken into consideration and must come on line under the moderate and high demand scenarios. However, these additional small hydro power stations will not get the desired profits in the case of a low demand, due to the electricity price is below their critical price.

We also conclude that the electricity price will rise in the upcoming years, regardless to the expected weather conditions, under a high or moderate electricity demand. However, the projects that are already registered with UPME, and the small hydro power plants (assumed in the investment behavior) will reduce the electricity price when coming online. This reduction of the electricity price will create temporary oscillations as a result of the reserve margin variations. Therefore, oscillations will be a permanent characteristic of future electricity price. However, the electricity price trend will portray a linear or exponential growth depending on the electricity demand scenario that is considered.

In the case of a drought (mainly hydrologic scenario 2, the longest dry season scenario), and under a high electricity demand scenario, the CEM might face some blackouts. The model has estimated that there will be an unsatisfied demand that may oscillate from 0 to 1400 Gwh/month, representing (maximum) 15% of the electricity demand. The shortage is forecasted to happen when the dam filling fraction is below 0.5 of its total capacity which coincides with the occurrence of the drought.

The trend of a generation capacity mainly based on hydro power stations in Colombia seems not likely to change. As we explained during the gas price forecast, according to official estimations, the domestic supply of this fuel will not be enough to cover its demand in Colombia since 2019. Therefore, the gas price is projected to increase in a drastic way that will raise the generation cost for gas fired thermal power plants. Nowadays, the gas fired thermal plants are not competitive due to the low cost of generating hydroelectricity during the rainy seasons. As gas fired thermal plants must not be considered as feasible, the new investments are focused on hydro power stations as seen in the projects already registered by UPME.

6.3. Limitations of the model and further research

The model has several limitations. Two limitations address the issue of investments:

- Due to the lack of information and data regarding to the generation cost, we did not run an accurate profitability assessment for each project that is considered in the model. Rather, we use the critical price mechanism which was sufficient for the purpose of this thesis.
- This model is not capable of reproducing the magnitude of the investments, i.e. the model only decides whether the project comes on line or remains under consideration. The generation capacity of each new project is defined by assumption and represented in a capacity density distribution.

In terms of the electricity price estimation, we observe the following limitations:

- The model does not reproduce the daily pool mechanism, where the generators offer their power plants and their production capacity. We did estimate the electricity price based on the reserve margin and the dam filling fraction.
- There is not an explicit feedback from the electricity generated by the thermal plants to the electricity price. We assume that, as the dam filling fraction is decreasing, there is need for the utilization the thermal power plants, and the electricity price rises as a consequence. Nevertheless, we manifest our satisfaction with the obtained electricity price estimation, because we included the factors that govern the price formation.

The model also presents some opportunities for future research. First, a more accurate model might include feedback between the electricity price and the electricity demand. This feedback seems to be more important in the case of a high expected demand, when the electricity price rises a lot, likely reducing the electricity demand. Second, the reliability charge mechanism might be incorporated to this model because this mechanism disaggregates the electricity generation that is already committed by the generators. This commitment expresses the amount of electricity generation, and also the price that will be paid, in the case of scarcity. This scarcity price might be lower than the forecasted electricity price, reducing the expected average electricity price that was estimated by us. Therefore, a further development of the model might include the fact that the investors may split, in their profitability assessment, where some may base the expected incomes on the market electricity price and some may base the expected income on the price under the reliability charge mechanism. Finally, we use a density distribution of capacity that was built by us.

A more realistic model must obtain data by real investors, but we know that it is not easy to get such information, until the project is registered before UPME.

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Appendix 1

Figure 54: Results of the model under a low demand scenario, and under the hydrologic scenario 1

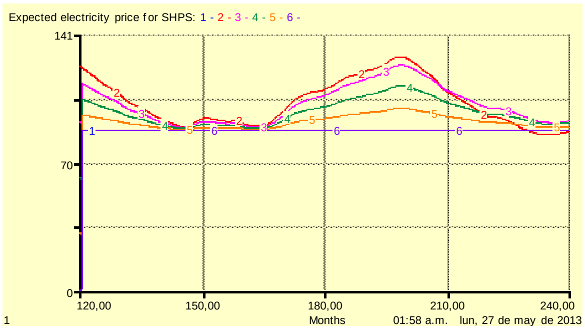

Fig. 54.a: Expected Electricity Price under a low demand scenario, and the hydrologic scenario 1

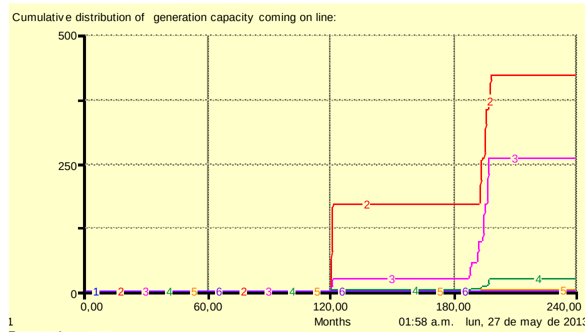

Fig. 54.b: Cumulative Distribution of Generation capacity under a low demand scenario, and the hydrologic scenario 1

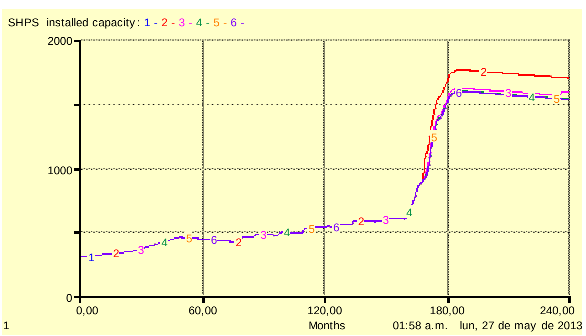

Fig. 54.c: SHPS Installed Capacity, under a low demand scenario, and the hydrologic scenario 1

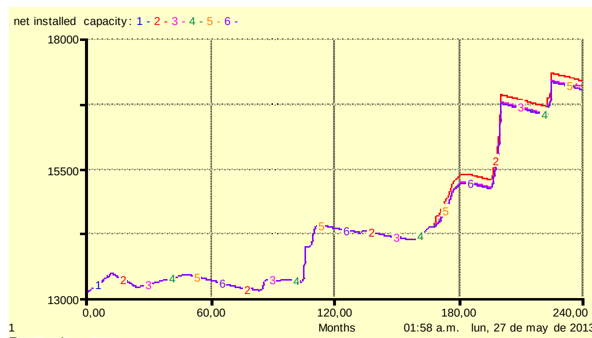

Fig. 54.d: Net Installed Capacity, under a low demand scenario, and the hydrologic scenario 1

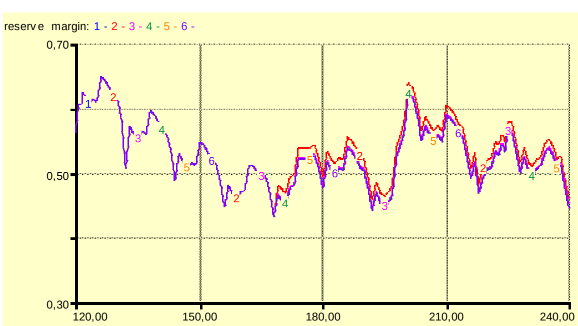

Fig. 54.e: Reserve Margin, under a low demand scenario, and the hydrologic scenario 1

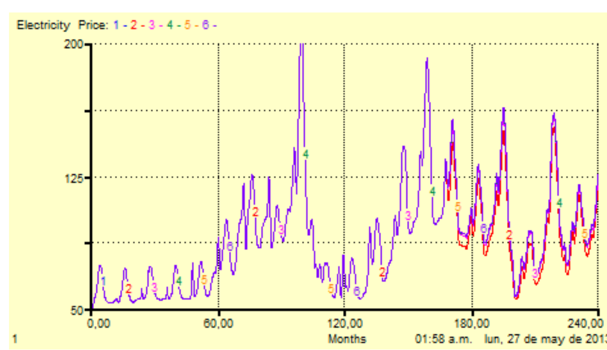

Fig. 54.f: Electricity Price, under a low demand scenario, and the hydrologic scenario 1

Figure 55: Results of the model under a low demand scenario, and under the hydrologic scenario 3

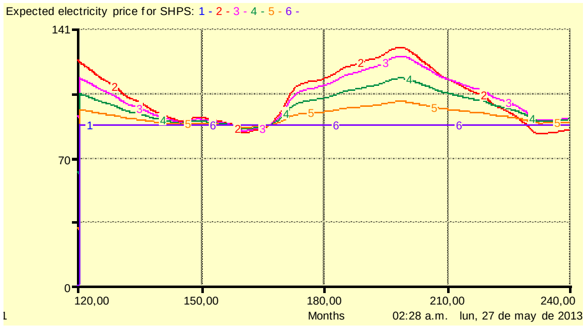

Fig. 55.a: Expected Electricity Price under a low demand scenario, and the hydrologic scenario 3

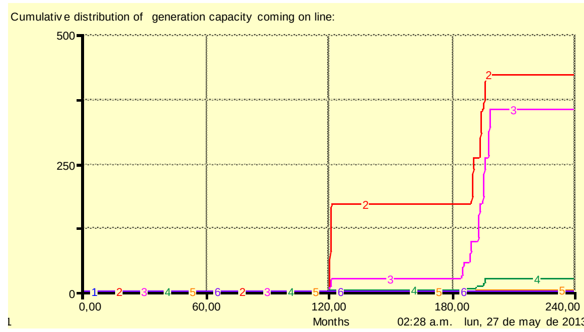

Fig. 55.b: Cumulative Distribution of Generation capacity under a low demand scenario, and the hydrologic scenario 3

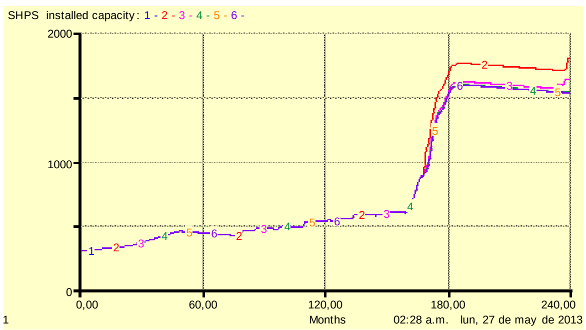

Fig. 55.c: SHPS Installed Capacity, under a low demand scenario, and the hydrologic scenario 3

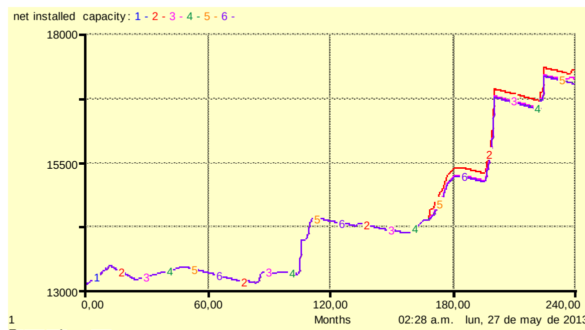

Fig. 55.d: Net Installed Capacity, under a low demand scenario, and the hydrologic scenario 3

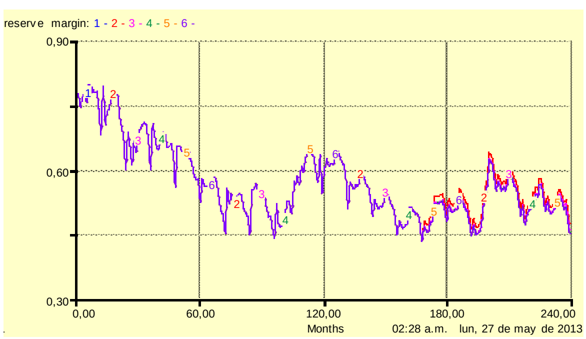

Fig. 55.e: Reserve Margin, under a low demand scenario, and the hydrologic scenario 3

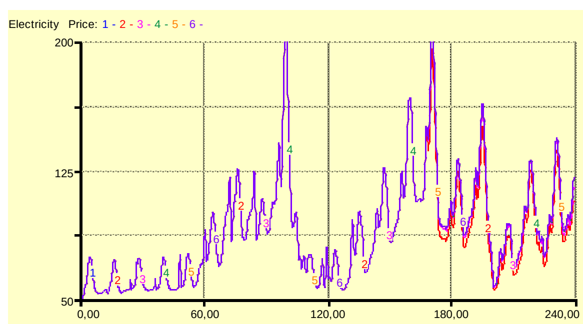

Fig. 55.f: Electricity Price, under a low demand scenario, and the hydrologic scenario 3

Figure 56: Results of the model under a moderate demand scenario, and under the hydrologic scenario 1

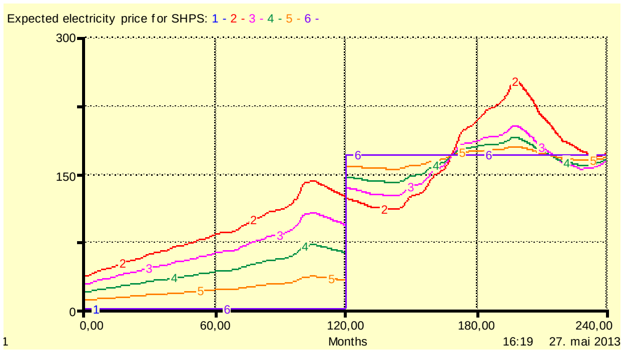

Fig. 56.a: Expected Electricity Price under a moderate demand scenario, and the hydrologic scenario 1

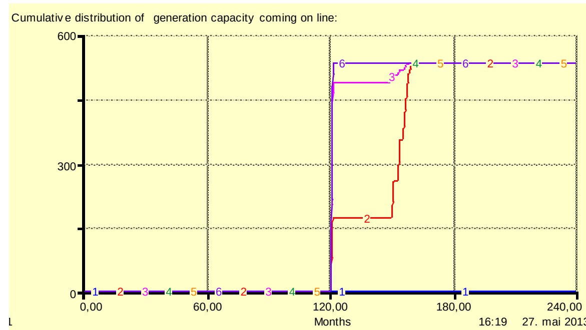

Fig. 56.b: Cumulative Distribution of Generation capacity under a moderate demand scenario, and the hydrologic scenario 1

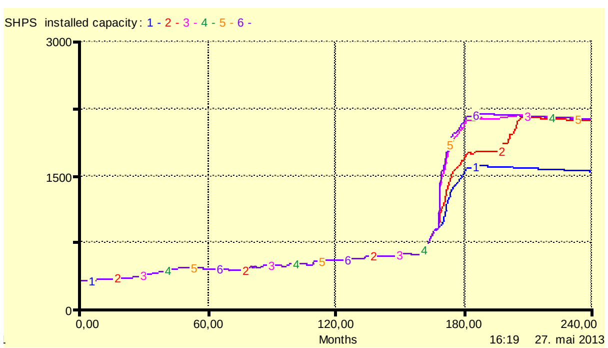

Fig. 56.c: SHPS Installed Capacity, under a moderate demand scenario, and the hydrologic scenario 1

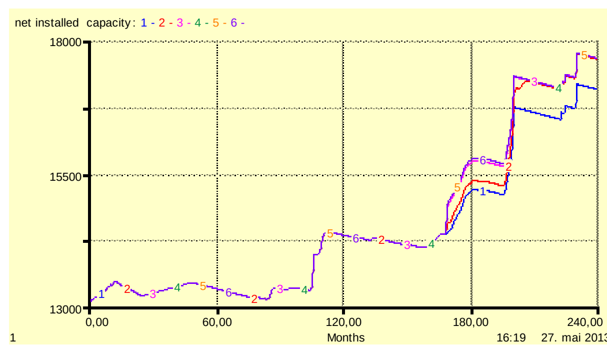

Fig. 56.d: Net Installed Capacity, under a moderate demand scenario, and the hydrologic scenario 1

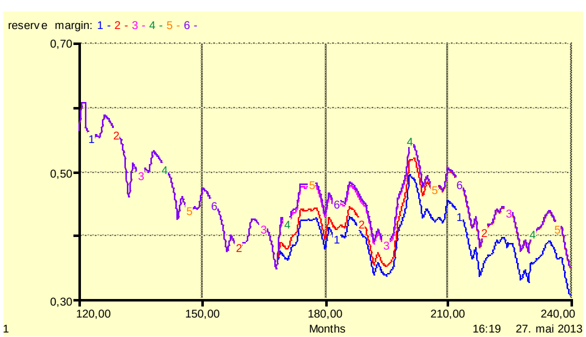

Fig. 56.e: Reserve Margin, under a moderate demand scenario, and the hydrologic scenario 1

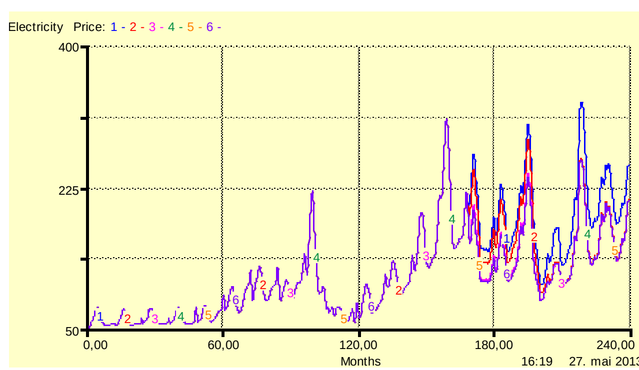

Fig. 56.f: Electricity Price, under a moderate demand scenario, and the hydrologic scenario 1

Figure 57: Results of the model under a moderate demand scenario, and under the hydrologic scenario 2

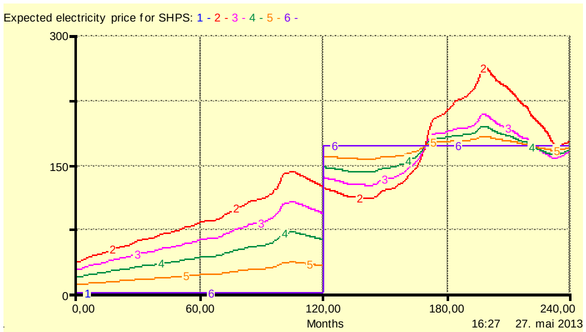

Fig. 57.a: Expected Electricity Price under a moderate demand scenario, and the hydrologic scenario 2

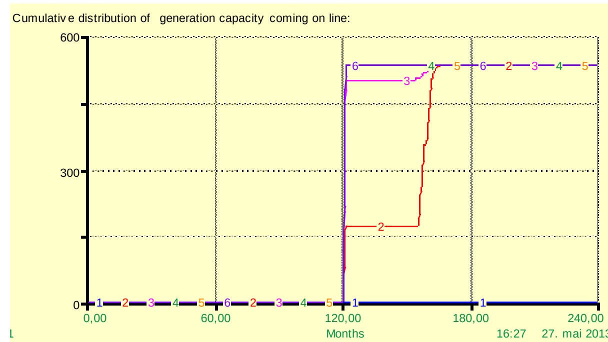

Fig. 57.b: Cumulative Distribution of Generation capacity under a moderate demand scenario, and the hydrologic scenario 2

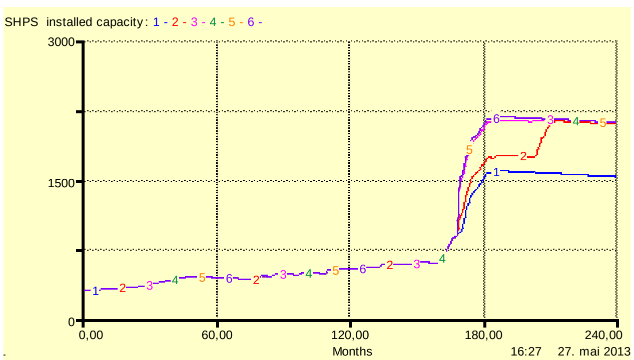

Fig. 57.c: SHPS Installed Capacity, under a moderate demand scenario, and the hydrologic scenario 2

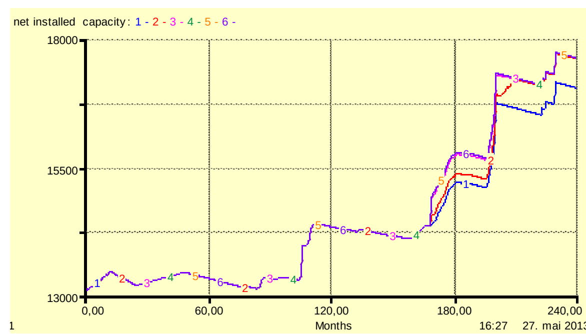

Fig. 57.d: Net Installed Capacity, under a moderate demand scenario, and the hydrologic scenario 2

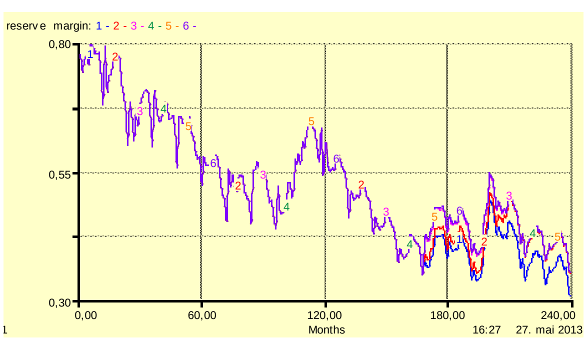

Fig. 57.e: Reserve Margin, under a moderate demand scenario, and the hydrologic scenario 2

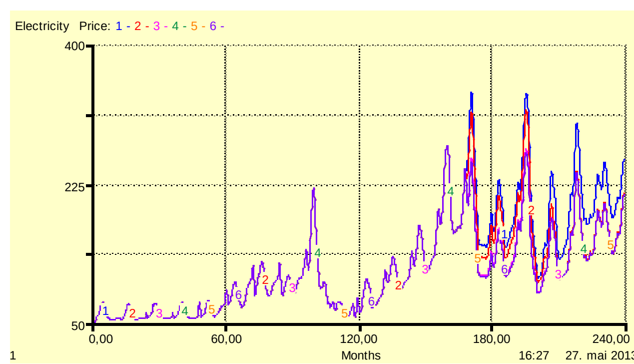

Fig. 57.f: Electricity Price, under a moderate demand scenario, and the hydrologic scenario 2

Figure 58: Results of the model under a high demand scenario, and under the hydrologic scenario 2

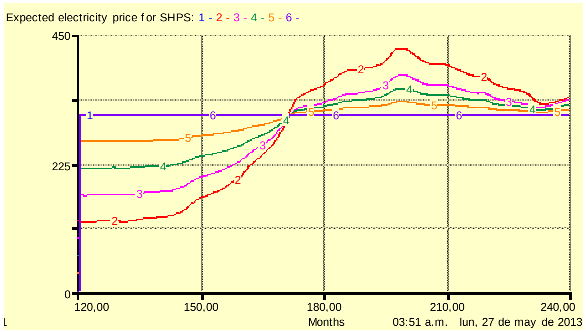

Fig. 58.a: Expected Electricity Price under a high demand scenario, and the hydrologic scenario 2

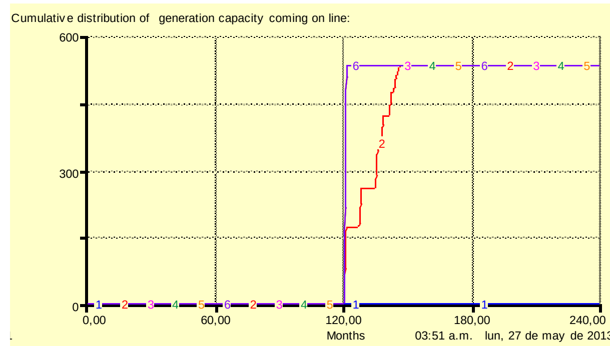

Fig. 58.b: Cumulative Distribution of Generation under a high demand scenario, and the hydrologic scenario 2

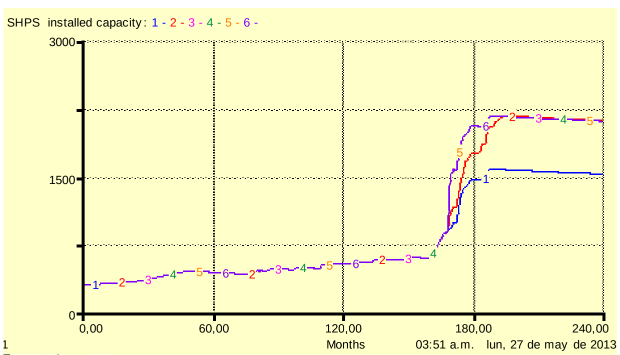

Fig. 58.c: SHPS Installed Capacity, under a high demand scenario, and the hydrologic scenario 2

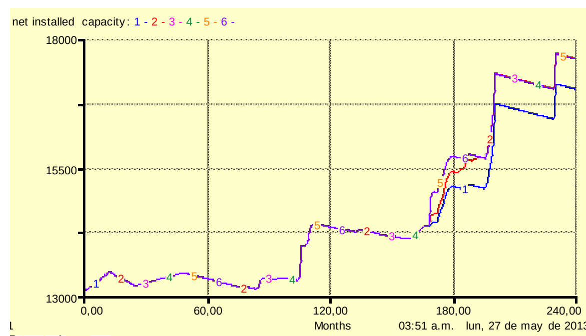

Fig. 58.d: Net Installed Capacity, under a high demand scenario, and the hydrologic scenario 2

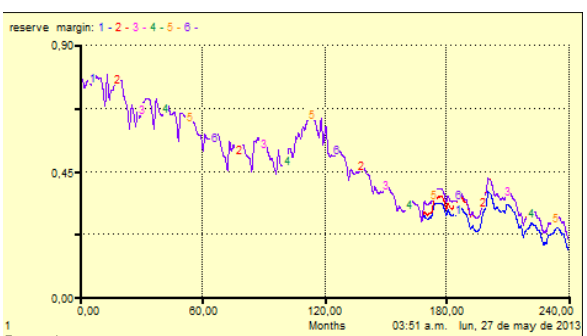

Fig. 58.e: Reserve Margin, under a high demand scenario, and the hydrologic scenario 2

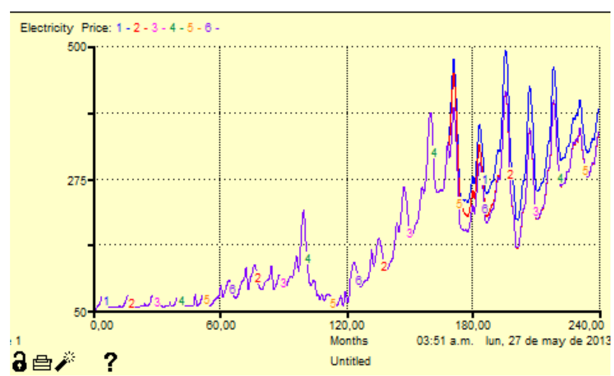

Fig. 58.f: Electricity Price, under a high demand scenario, and the hydrologic scenario 2

Figure 59: Results of the model under a high demand scenario, and under the hydrologic scenario 3

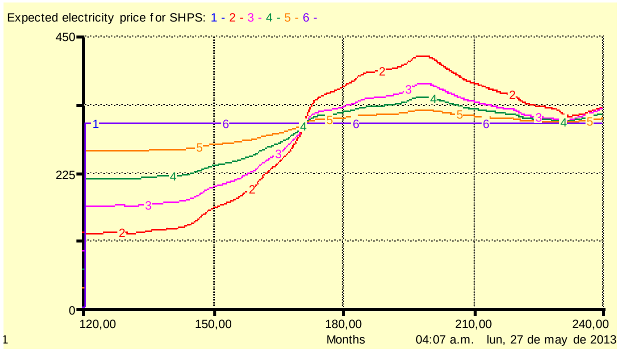

Fig. 59.a: Expected Electricity Price under a high demand scenario, and the hydrologic scenario 3

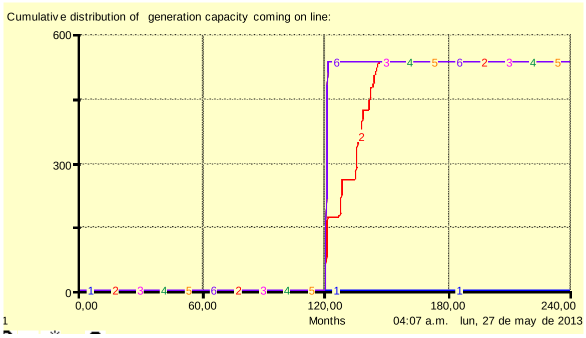

Fig. 59.b: Cumulative Distribution of Generation under a high demand scenario, and the hydrologic scenario 3

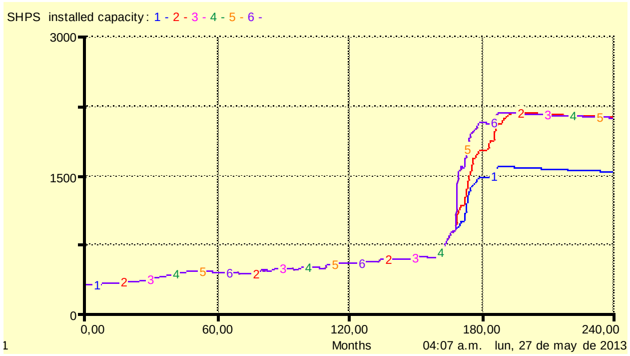

Fig. 59.c: SHPS Installed Capacity, under a high demand scenario, and the hydrologic scenario 3

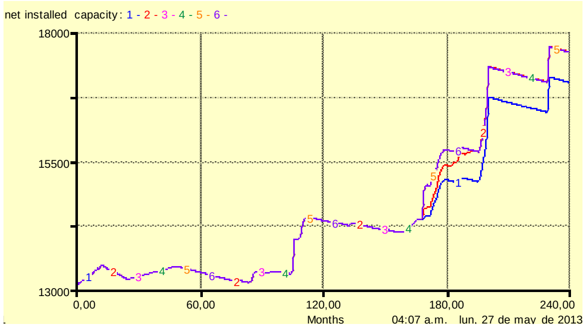

Fig. 59.d: Net Installed Capacity, under a high demand scenario, and the hydrologic scenario 3

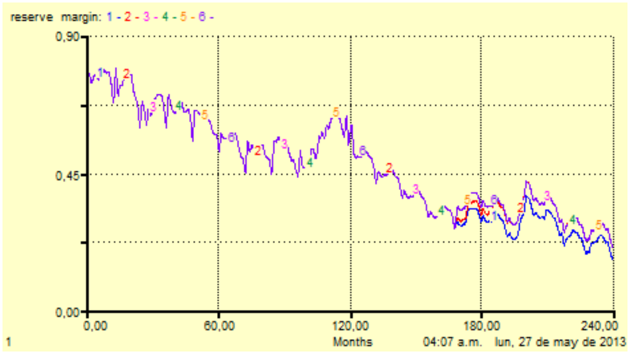

Fig. 59.e: Reserve Margin, under a high demand scenario, and the hydrologic scenario 3

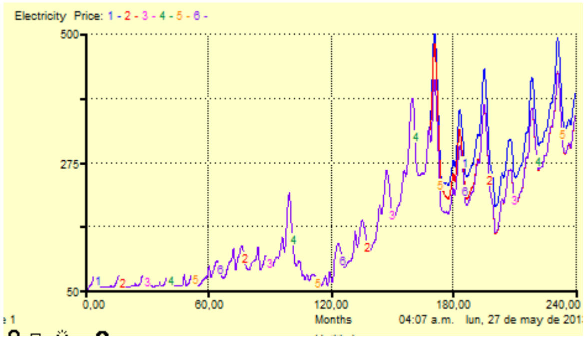

Fig. 59.f: Electricity Price, under a high demand scenario, and the hydrologic scenario 3

Appendix 2

List of equations

installed_capacity__of_dams_in_Gwh(t) = installed_capacity__of_dams_in_Gwh(t - dt) + (dam_completion_rate) * dt

INIT installed_capacity__of_dams_in_Gwh = 16377

UNITS: Gwh

INFLOWS:

dam_completion_rate = CONVEYOR OUTFLOW

UNITS: gwh/mo

large_hydro_power__station_with_DAM_installed_capacity(t) = large_hydro_power__station_with_DAM_installed_capacity(t - dt) + (large_hydro_power_station_with_DAM_completion_rate) * dt

INIT large_hydro_power__station_with_DAM_installed_capacity = 6823

UNITS: MW

INFLOWS:

large_hydro_power_station_with_DAM_completion_rate = CONVEYOR OUTFLOW

UNITS: mw/mo

MEDIUM_hydro_power__station_with_DAM_installed_capacity(t) = MEDIUM_hydro_power__station_with_DAM_installed_capacity(t - dt) + (MEDIUM_hydro_power_station_with_DAM_completion_rate) * dt

INIT MEDIUM_hydro_power__station_with_DAM_installed_capacity = 820

UNITS: MW

INFLOWS:

MEDIUM_hydro_power_station_with_DAM_completion_rate = CONVEYOR OUTFLOW

UNITS: mw/mo

coal_fired_thermal__power_station_projects__under_consideration(t) = coal_fired_thermal__power_station_projects__under_consideration(t - dt) + (coal_fired_thermal__power_station__under__consideration_inflow - coal_fired_thermal__power_station__under__consideration_outflow) * dt

INIT coal_fired_thermal__power_station_projects__under_consideration = 0

UNITS: MW

INFLOWS:

coal_fired_thermal__power_station__under__consideration_inflow = (List_of_registered__coal_fired_thermal__power_stations_projects+Registered_coal_thermal_projects_stage_1_for_supply_forecast)/AT

UNITS: mw/mo

OUTFLOWS:

coal_fired_thermal__power_station__under__consideration_outflow = IF(decision_rule_for_coal_fired_thermal_power_stations=1)THEN(coal_fired_thermal__power_station_projects__under_consideration)ELSE(0)

UNITS: mw/mo

Coal_thermal_power_station_total_cost_in_US_per_Kwh_WITHOUT_FUEL(t) = Coal_thermal_power_station_total_cost_in_US_per_Kwh_WITHOUT_FUEL(t - dt) + (change_in_coal_thermal_PS_total_cost__per_Kwh_withouth_fuel) * dt

INIT Coal_thermal_power_station_total_cost_in_US_per_Kwh_WITHOUT_FUEL = Coal_thermal_power_station_total_cost_USper_Kwh_WITHOUT_FUEL

UNITS: US Dollars/Kw-hour

INFLOWS:

change_in_coal_thermal_PS_total_cost__per_Kwh_withouth_fuel = Coal_thermal_power_station_total_cost_in_US_per_Kwh_WITHOUT_FUEL*inflation_rate

UNITS: us dollars/hour-kw-mo

Cumulative_distribution_of_generation_capac_ARRAY[Dim_Name_1](t) = Cumulative_distribution_of_generation_capac_ARRAY[Dim_Name_1](t - dt) + (Cumulative_distribution_of_generation_capacity_by_segment_inflow[Dim_Name_1]) * dt

INIT Cumulative_distribution_of_generation_capac_ARRAY[Dim_Name_1] = 0

UNITS: MW

INFLOWS:

Cumulative_distribution_of_generation_capacity_by_segment_inflow[Dim_Name_1] = (if(Cumulative_distribution_of_generation_capac_ARRAY>=Density_distribution_of_additional_generation_capacity_by_segment)then(0)else(Density_distribution_of_additional_generation_capacity_by_segment))

UNITS: mw/mo

dam_level(t) = dam_level(t - dt) + (hydrologic__contribution__to_DAM - electricity_generated_from_hydro_power_stations_with_DAM - water__spillage__rate) * dt

INIT dam_level = 12413

UNITS: Gwh

INFLOWS:

hydrologic__contribution__to_DAM = hydro_contribution_to_power_stations_with_DAM

UNITS: gwh/mo

OUTFLOWS:

electricity_generated_from_hydro_power_stations_with_DAM = if(dam_level<=technical_minimum__volumen_in_Gwh)then(0)else(MIN(available_electricity__from_dam,Demand_to_be_satisfied_through_power_stations_with_DAM))

UNITS: gwh/mo

water__spillage__rate = MAX(0,dam_level-installed_capacity__of_dams_in_Gwh)/water_spillage__adjustmet_time

UNITS: gwh/mo

Electricity__Price(t) = Electricity__Price(t - dt) + (Change_in__Electricity_Price) * dt

INIT Electricity__Price = 35

UNITS: COP/Kw-hour

INFLOWS:

Change_in__Electricity_Price = (indicated_price*(effect_of_dam_filling_fraction_on_price)-Electricity__Price)/Electricity_Price_Adjustment_time

UNITS: cop/hour-kw-mo

gas_fired_thermal__power_station_projects__under_consideration(t) = gas_fired_thermal__power_station_projects__under_consideration(t - dt) + (gas_fired_thermal__power_station__under__consideration_inflow - gas_fired_thermal__power_station__under__consideration_outflow) * dt

INIT gas_fired_thermal__power_station_projects__under_consideration = 0

UNITS: MW

INFLOWS:

gas_fired_thermal__power_station__under__consideration_inflow = List_of_registered__gas_fired_thermal__power_stations/AT

UNITS: mw/mo

OUTFLOWS:

gas_fired_thermal__power_station__under__consideration_outflow = IF(Decision_rule_for_gas_fired_thermal__power_stations=1)THEN(gas_fired_thermal__power_station_projects__under_consideration)ELSE(0)

UNITS: mw/mo

Gas_thermal_power_station__total_cost_US_per_Kwh_WITHOUT_FUEL(t) = Gas_thermal_power_station__total_cost_US_per_Kwh_WITHOUT_FUEL(t - dt) + (Change_in_gas_thermal_PS_total_cost_per_Kwh_without_fuel) * dt

INIT Gas_thermal_power_station__total_cost_US_per_Kwh_WITHOUT_FUEL = Gas_thermal_PS__total_cost_US2002_per_Kwh__WITHOUT_FUEL

UNITS: US Dollars/Kw-hour

INFLOWS:

Change_in_gas_thermal_PS_total_cost_per_Kwh_without_fuel = Gas_thermal_power_station__total_cost_US_per_Kwh_WITHOUT_FUEL*inflation_rate

UNITS: us dollars/hour-kw-mo

large_hydro_power__station_with_DAM__under_consideration(t) = large_hydro_power__station_with_DAM__under_consideration(t - dt) + (large_hydropower__station_with_DAM__under__consideration_inflow - large_hydro_power_station_with_DAM_initiation_rate) * dt

INIT large_hydro_power__station_with_DAM__under_consideration = 0

UNITS: MW

INFLOWS:

large_hydropower__station_with_DAM__under__consideration_inflow = (list_of_new_LARGE_hydro__power_stations_with_DAM+Registered_large_HPS_Stage_1_projects_for_supply_forecast)/AT

UNITS: mw/mo

OUTFLOWS:

large_hydro_power_station_with_DAM_initiation_rate = (IF(Decision_rule__for_large_hydro__power__stations_with_DAM=1)THEN(DELAY(large_hydro_power__station_with_DAM__under_consideration,Power_stations_with_DAM_planning__and_approval_time))ELSE(0))

UNITS: mw/mo

MEDIUM_hydro_power__station_with_DAM__under_consideration(t) = MEDIUM_hydro_power__station_with_DAM__under_consideration(t - dt) + (MEDIUM_hydro_power__station__with_DAM__under__consideration_inflow - MEDIUM_hydro_power_station_with_DAM_initiation_rate) * dt

INIT MEDIUM_hydro_power__station_with_DAM__under_consideration = 0

UNITS: MW

INFLOWS:

MEDIUM_hydro_power__station__with_DAM__under__consideration_inflow = (list_of_new_MEDIUM_hydro__power_stations_with_DAM+Registered_medium_HPS_Stage_1_projects_for_supply_forecast)/AT

UNITS: mw/mo

OUTFLOWS:

MEDIUM_hydro_power_station_with_DAM_initiation_rate = (delay(IF(Decision_rule__for_medium_hydro__power_stations_with_DAM=1)THEN(MEDIUM_hydro_power__station_with_DAM__under_consideration)ELSE(0),Power_stations_with_DAM_planning__and_approval_time))

UNITS: mw/mo

MEDIUM_river__power___station_under_consideration(t) = MEDIUM_river__power___station_under_consideration(t - dt) + (MEDIUM_river_power__station__under__consideration_inflow - MEDIUM_river_power__station__under__consideration_outflow) * dt

INIT MEDIUM_river__power___station_under_consideration = 0

UNITS: MW

INFLOWS:

MEDIUM_river_power__station__under__consideration_inflow = list_of_new_MEDIUM_river_power_stations/AT

UNITS: mw/mo

OUTFLOWS:

MEDIUM_river_power__station__under__consideration_outflow = IF(Decision_rule__for_medium_river__power_stations=1)THEN(MEDIUM_river__power___station_under_consideration)ELSE(0)

UNITS: mw/mo

SHPS__under_consideration(t) = SHPS__under_consideration(t - dt) + (SHPS_under__consideration_inflow - SHPS_under__consideration_outflow) * dt

INIT SHPS__under_consideration = 0

UNITS: MW

INFLOWS:

SHPS_under__consideration_inflow = (List_of_new__SHPS+Registered_SHPS_Stage_1_projects_for_supply_forecast)/AT

UNITS: mw/mo

OUTFLOWS:

SHPS_under__consideration_outflow = IF(Decision_rule__for_SHPS=1)THEN(SHPS__under_consideration)ELSE(0)

UNITS: mw/mo

average_electricity_price(t) = average_electricity_price(t - dt) + (average_electricity_price_inflow - average_electricity_price_outflow) * dt

INIT average_electricity_price = 35

TRANSIT TIME = 60

CAPACITY = INF

INFLOW LIMIT = INF

UNITS: COP/Kw-hour

INFLOWS:

average_electricity_price_inflow = Electricity__Price/60

UNITS: cop/hour-kw-mo

OUTFLOWS:

average_electricity_price_outflow = CONVEYOR OUTFLOW

UNITS: cop/hour-kw-mo

coal_fired_thermal__power_stations__under_construction(t) = coal_fired_thermal__power_stations__under_construction(t - dt) + (coal_fired_thermal__power_stations___initiation_rate - coal_fired_thermal_power_stations_completion_rate) * dt

INIT coal_fired_thermal__power_stations__under_construction = 80

TRANSIT TIME = 24

CAPACITY = INF

INFLOW LIMIT = INF

UNITS: MW

INFLOWS:

coal_fired_thermal__power_stations___initiation_rate = delay(coal_fired_thermal__power_station__under__consideration_outflow,coal_fired_thermal_power_stations_planning_and_approval_time)

UNITS: mw/mo

OUTFLOWS:

coal_fired_thermal_power_stations_completion_rate = CONVEYOR OUTFLOW

UNITS: mw/mo

coal_fired__thermal_power_stations__installed_capacity(t) = coal_fired__thermal_power_stations__installed_capacity(t - dt) + (coal_fired_thermal_power_stations_completion_rate - coal_fired_thermal_power_stations_depreciation_rate) * dt

INIT coal_fired__thermal_power_stations__installed_capacity = 993

TRANSIT TIME = 480

CAPACITY =

INFLOW LIMIT =

UNITS: MW

INFLOWS:

coal_fired_thermal_power_stations_completion_rate = CONVEYOR OUTFLOW

UNITS: mw/mo

OUTFLOWS:

coal_fired_thermal_power_stations_depreciation_rate = CONVEYOR OUTFLOW

UNITS: mw/mo

dam__under__construction(t) = dam__under__construction(t - dt) + (dam_initiation__rate - dam_completion_rate) * dt

INIT dam__under__construction = 250

TRANSIT TIME = 84

CAPACITY = INF

INFLOW LIMIT = INF

UNITS: Gwh

INFLOWS:

dam_initiation__rate = (large_hydro_power_station_with_DAM_initiation_rate+MEDIUM_hydro_power_station_with_DAM_initiation_rate)*equivalent_Gwh_of_dam_per_MW_of_installed_capacity

UNITS: gwh/mo

OUTFLOWS:

dam_completion_rate = CONVEYOR OUTFLOW

UNITS: gwh/mo

gas_fired_thermal__power_stations__under_construction(t) = gas_fired_thermal__power_stations__under_construction(t - dt) + (gas_fired_thermal__power_stations___initiation_rate - gas_fired_thermal_power_stations_completion_rate) * dt

INIT gas_fired_thermal__power_stations__under_construction = 100

TRANSIT TIME = 24

CAPACITY = INF

INFLOW LIMIT = INF

UNITS: MW

INFLOWS:

gas_fired_thermal__power_stations___initiation_rate = delay(gas_fired_thermal__power_station__under__consideration_outflow,gas_fired_thermal_power_stations_planning_and_approval_time,15)+DELAY(Registered_gas_thermal_projects_stage_2_for_supply_forecast,delay_for_projects_in_stage_2)

UNITS: mw/mo

OUTFLOWS:

gas_fired_thermal_power_stations_completion_rate = CONVEYOR OUTFLOW

UNITS: mw/mo

gas_fired__thermal_power_station__installed_capacity(t) = gas_fired__thermal_power_station__installed_capacity(t - dt) + (gas_fired_thermal_power_stations_completion_rate - gas_fired_thermal_power_stations_depreciation_rate) * dt

INIT gas_fired__thermal_power_station__installed_capacity = 3431

TRANSIT TIME = 480

CAPACITY =

INFLOW LIMIT =

UNITS: MW

INFLOWS:

gas_fired_thermal_power_stations_completion_rate = CONVEYOR OUTFLOW

UNITS: mw/mo

OUTFLOWS:

gas_fired_thermal_power_stations_depreciation_rate = CONVEYOR OUTFLOW

UNITS: mw/mo

large_hydro_power__station_with_DAM_under_construction(t) = large_hydro_power__station_with_DAM_under_construction(t - dt) + (large_hydro_power_station_with_DAM_initiation_rate - large_hydro_power_station_with_DAM_completion_rate) * dt

INIT large_hydro_power__station_with_DAM_under_construction = 650

TRANSIT TIME = IF(time<=12)then 12 else 80

CAPACITY = INF

INFLOW LIMIT = INF

UNITS: MW

INFLOWS:

large_hydro_power_station_with_DAM_initiation_rate = (IF(Decision_rule__for_large_hydro__power__stations_with_DAM=1)THEN(DELAY(large_hydro_power__station_with_DAM__under_consideration,Power_stations_with_DAM_planning__and_approval_time))ELSE(0))

UNITS: mw/mo

OUTFLOWS:

large_hydro_power_station_with_DAM_completion_rate = CONVEYOR OUTFLOW

UNITS: mw/mo

LARGE_river__power_station__installed_capacity(t) = LARGE_river__power_station__installed_capacity(t - dt) + (LARGE__RIVER_power_station_completion_rate - LARGE_RIVER__power_station__depreciation_rate) * dt

INIT LARGE_river__power_station__installed_capacity = 544

TRANSIT TIME = 24

CAPACITY =

INFLOW LIMIT =

UNITS: MW

INFLOWS:

LARGE__RIVER_power_station_completion_rate = CONVEYOR OUTFLOW

UNITS: mw/mo

OUTFLOWS:

LARGE_RIVER__power_station__depreciation_rate = CONVEYOR OUTFLOW

UNITS: mw/mo

LARGE_RIVER__power_station__under_construction(t) = LARGE_RIVER__power_station__under_construction(t - dt) + (LARGE__RIVER_power_station_initiation_rate - LARGE__RIVER_power_station_completion_rate) * dt

INIT LARGE_RIVER__power_station__under_construction = 0

TRANSIT TIME = 48

CAPACITY = INF

INFLOW LIMIT = INF

UNITS: MW

INFLOWS:

LARGE__RIVER_power_station_initiation_rate = delay(list_of_new_large_river_power_stations,river_power__station's__planning__and_approval_time,0)

UNITS: mw/mo

OUTFLOWS:

LARGE__RIVER_power_station_completion_rate = CONVEYOR OUTFLOW

UNITS: mw/mo

MEDIUM_hydro_power_station_with_DAM__under_construction(t) = MEDIUM_hydro_power_station_with_DAM__under_construction(t - dt) + (MEDIUM_hydro_power_station_with_DAM_initiation_rate - MEDIUM_hydro_power_station_with_DAM_completion_rate) * dt

INIT MEDIUM_hydro_power_station_with_DAM__under_construction = 14

TRANSIT TIME = 60

CAPACITY = INF

INFLOW LIMIT = INF

UNITS: MW

INFLOWS:

MEDIUM_hydro_power_station_with_DAM_initiation_rate = (delay(IF(Decision_rule__for_medium_hydro__power_stations_with_DAM=1)THEN(MEDIUM_hydro_power__station_with_DAM__under_consideration)ELSE(0),Power_stations_with_DAM_planning__and_approval_time))

UNITS: mw/mo

OUTFLOWS:

MEDIUM_hydro_power_station_with_DAM_completion_rate = CONVEYOR OUTFLOW

UNITS: mw/mo

MEDIUM_river__power_station_installed_capacity(t) = MEDIUM_river__power_station_installed_capacity(t - dt) + (MEDIUM_RIVER_power_station_completion_rate - MEDIUM_RIVER__power_station__depreciation_rate) * dt

INIT MEDIUM_river__power_station_installed_capacity = 165

TRANSIT TIME = 2400

CAPACITY =

INFLOW LIMIT =

UNITS: MW

INFLOWS:

MEDIUM_RIVER_power_station_completion_rate = CONVEYOR OUTFLOW

UNITS: mw/mo

OUTFLOWS:

MEDIUM_RIVER__power_station__depreciation_rate = CONVEYOR OUTFLOW

UNITS: mw/mo

MEDIUM_RIVER__power_station__under_construction(t) = MEDIUM_RIVER__power_station__under_construction(t - dt) + (MEDIUM_RIVER_power_station_initiation_rate - MEDIUM_RIVER_power_station_completion_rate) * dt

INIT MEDIUM_RIVER__power_station__under_construction = 0

TRANSIT TIME = 48

CAPACITY = INF

INFLOW LIMIT = INF

UNITS: MW

INFLOWS:

MEDIUM_RIVER_power_station_initiation_rate = GRAPH(DELAY(MEDIUM_river_power__station__under__consideration_outflow,river_power__station's__planning__and_approval_time,0))

(0.00, 0.00), (10.0, 0.00), (20.0, 0.00), (30.0, 0.00), (40.0, 0.00), (50.0, 0.00), (60.0, 0.00), (70.0, 0.00), (80.0, 0.00), (90.0, 0.00), (100, 0.00)

UNITS: mw/mo

OUTFLOWS:

MEDIUM_RIVER_power_station_completion_rate = CONVEYOR OUTFLOW

UNITS: mw/mo

SHPS__installed_capacity(t) = SHPS__installed_capacity(t - dt) + (SHPS__power_station_completion_rate - SHPS_depreciation_rate) * dt

INIT SHPS__installed_capacity = 293

TRANSIT TIME = 240

CAPACITY =

INFLOW LIMIT =

UNITS: MW

INFLOWS:

SHPS__power_station_completion_rate = CONVEYOR OUTFLOW

UNITS: mw/mo

OUTFLOWS:

SHPS_depreciation_rate = CONVEYOR OUTFLOW

UNITS: mw/mo

SHPS__under_construction(t) = SHPS__under_construction(t - dt) + (SHPS__initiation_rate - SHPS__power_station_completion_rate) * dt

INIT SHPS__under_construction = 71

TRANSIT TIME = 24

CAPACITY = INF

INFLOW LIMIT = INF

UNITS: MW

INFLOWS:

SHPS__initiation_rate = delay(SHPS_under__consideration_outflow+SHPS_generation_capacity_initiation_rate,SHPS_planning__and_approval_time,6)+DELAY(Registered_SHPS_Stage_2_projects_for_supply_forecast,delay_for_projects_in_stage_2)

UNITS: mw/mo

OUTFLOWS:

SHPS__power_station_completion_rate = CONVEYOR OUTFLOW

UNITS: mw/mo

UNATTACHED:

Electricity_generated_from_SHPS = SHPS__installed_capacity*Gwh_in_a_MW*effect_of_seasonality__on_rainfall__SHPS*(if(time<=120)then(ENSO)else(ENSO_FORECAST))*(1-unavailability_factor__for_small_hydro__power_stations)

UNATTACHED:

hydro_contribution_to_LARGE_river_power_station = LARGE_river__power_station__installed_capacity*Gwh_in_a_MW*effect_of__seasonality__on_rainfall*(if(time<=120)then(ENSO)else(ENSO_FORECAST))*(1-unavailability_factor__for_LARGE_river__power_station)*0.5

UNATTACHED:

hydro_contribution_to_MEDIUM_river_power_station = MEDIUM_river__power_station_installed_capacity*Gwh_in_a_MW*effect_of_seasonality__on_rainfall__MEDIUM_RIVER_PS*(if(time<=120)then(ENSO)else(ENSO_FORECAST))*(1-unavailability_factor__for_MEDIUM_river__power_station)*.3

administrative_building = 7889428.9

UNITS: US Dollars (USD)

amortization__time = 20

UNITS: year

AT = 1

UNITS: month

available_electricity__from_dam = min(max_available_electricity__from_dam,Max_generation__according_to_the__installed_capacity)*(1-unavailability_factor_for__hydro_power_stations_with_DAM)

UNITS: gwh/mo

bioler = 18158191

UNITS: US Dollars (USD)

capacity_in_MW_of_Coal___fired_thermal_power_station = 300

UNITS: MW

capacity_in_MW_of_gas__fired_thermal_power_station = 200

UNITS: MW

change_on_relative_fraction_gas_hydro = relative_fraction__gas_hydro_power_stations_'_installed_capacity/init(relative_fraction__gas_hydro_power_stations_'_installed_capacity)

UNITS: Unitless

coal_fired_thermal_power_stations_planning_and_approval_time = 24

coal_fired_thermal_power_stations_time_horizon = 48

UNITS: month

coal_fired_thermal_power_station_installed_HISTORICAL_capacity = GRAPH(time)

(0.00, 993), (12.0, 992), (24.0, 994), (36.0, 994), (48.0, 996), (60.0, 976), (72.0, 976), (84.0, 976), (96.0, 990), (108, 990), (120, 990)

coal_participation__on_generation = generation_from_coal_fired_thermal_power_stations/total_electricity__generated

UNITS: Unitless

Coal_price_in_US_per_Kwh = GRAPH(time)

(0.00, 0.00163), (1.00, 0.00163), (2.01, 0.00163), (3.01, 0.00163), (4.02, 0.00163), (5.02, 0.00163), (6.03, 0.00163), (7.03, 0.00163), (8.03, 0.00163), (9.04, 0.00163), (10.0, 0.00163), (11.0, 0.00163), (12.1, 0.00177), (13.1, 0.00177), (14.1, 0.00177), (15.1, 0.00177), (16.1, 0.00177), (17.1, 0.00177), (18.1, 0.00177), (19.1, 0.00177), (20.1, 0.00177), (21.1, 0.00177), (22.1, 0.00177), (23.1, 0.00177), (24.1, 0.00351), (25.1, 0.00351), (26.1, 0.00351), (27.1, 0.00351), (28.1, 0.00351), (29.1, 0.00351), (30.1, 0.00351), (31.1, 0.00351), (32.1, 0.00351), (33.1, 0.00351), (34.1, 0.00351), (35.1, 0.00351), (36.2, 0.00254), (37.2, 0.00254), (38.2, 0.00254), (39.2, 0.00254), (40.2, 0.00254), (41.2, 0.00254), (42.2, 0.00254), (43.2, 0.00254), (44.2, 0.00254), (45.2, 0.00254), (46.2, 0.00254), (47.2, 0.00254), (48.2, 0.00676), (49.2, 0.00676), (50.2, 0.00676), (51.2, 0.00676), (52.2, 0.00676), (53.2, 0.00676), (54.2, 0.00676), (55.2, 0.00676), (56.2, 0.00676), (57.2, 0.00676), (58.2, 0.00676), (59.2, 0.00676), (60.3, 0.00455), (61.3, 0.00455), (62.3, 0.00455), (63.3, 0.00455), (64.3, 0.00455), (65.3, 0.00455), (66.3, 0.00455), (67.3, 0.00455), (68.3, 0.00455), (69.3, 0.00455), (70.3, 0.00455), (71.3, 0.00455), (72.3, 0.00583), (73.3, 0.00583), (74.3, 0.00583), (75.3, 0.00583), (76.3, 0.00583), (77.3, 0.00583), (78.3, 0.00583), (79.3, 0.00583), (80.3, 0.00583), (81.3, 0.00583), (82.3, 0.00583), (83.3, 0.00583), (84.4, 0.0053), (85.4, 0.0053), (86.4, 0.0053), (87.4, 0.0053), (88.4, 0.0053), (89.4, 0.0053), (90.4, 0.0053), (91.4, 0.0053), (92.4, 0.0053), (93.4, 0.0053), (94.4, 0.0053), (95.4, 0.0053), (96.4, 0.00645), (97.4, 0.00645), (98.4, 0.00645), (99.4, 0.00645), (100, 0.00645), (101, 0.00645), (102, 0.00645), (103, 0.00645), (104, 0.00645), (105, 0.00645), (106, 0.00645), (107, 0.00645), (108, 0.00742), (109, 0.00742), (110, 0.00742), (111, 0.00742), (112, 0.00742), (113, 0.00742), (114, 0.00742), (115, 0.00742), (116, 0.00742), (117, 0.00742), (118, 0.00742), (119, 0.00742), (121, 0.0118), (122, 0.0111), (123, 0.0109), (124, 0.0108), (125, 0.00979), (126, 0.00967), (127, 0.00997), (128, 0.0105), (129, 0.00996), (130, 0.00952), (131, 0.00969), (132, 0.01), (133, 0.00965), (134, 0.00992), (135, 0.00952), (136, 0.0088), (137, 0.0088), (138, 0.0088), (139, 0.0088), (140, 0.0088), (141, 0.0088), (142, 0.0088), (143, 0.0088), (144, 0.0088), (145, 0.0088), (146, 0.0088), (147, 0.0088), (148, 0.0088), (149, 0.0088), (150, 0.0088), (151, 0.0088), (152, 0.0088), (153, 0.0088), (154, 0.0088), (155, 0.0088), (156, 0.0088), (157, 0.00871), (158, 0.00871), (159, 0.00871), (160, 0.00871), (161, 0.00871), (162, 0.00871), (163, 0.00871), (164, 0.00871), (165, 0.00871), (166, 0.00871), (167, 0.00871), (168, 0.00871), (169, 0.00865), (170, 0.00865), (171, 0.00865), (172, 0.00865), (173, 0.00865), (174, 0.00865), (175, 0.00865), (176, 0.00865), (177, 0.00865), (178, 0.00865), (179, 0.00865), (180, 0.00865), (181, 0.00865), (182, 0.00865), (183, 0.00865), (184, 0.00865), (185, 0.00865), (186, 0.00865), (187, 0.00865), (188, 0.00865), (189, 0.00865), (190, 0.00865), (191, 0.00865), (192, 0.00865), (193, 0.00865), (194, 0.00865), (195, 0.00865), (196, 0.00865), (197, 0.00865), (198, 0.00865), (199, 0.00865), (200, 0.00865), (201, 0.00865), (202, 0.00865), (203, 0.00865), (204, 0.00865), (205, 0.00865), (206, 0.00865), (207, 0.00865), (208, 0.00865), (209, 0.00865), (210, 0.00865), (211, 0.00865), (212, 0.00865), (213, 0.00865), (214, 0.00865), (215, 0.00865), (216, 0.00865), (217, 0.00869), (218, 0.00869), (219, 0.00869), (220, 0.00869), (221, 0.00869), (222, 0.00869), (223, 0.00869), (224, 0.00869), (225, 0.00869), (226, 0.00869), (227, 0.00869), (228, 0.00869), (229, 0.00872), (230, 0.00872), (231, 0.00872), (232, 0.00872), (233, 0.00872), (234, 0.00872), (235, 0.00872), (236, 0.00872), (237, 0.00872), (238, 0.00872), (239, 0.00872), (240, 0.00872)

UNITS: US Dollars/Kw-hour

Coal_thermal_power_station_conexions_lines = 1374249

UNITS: US Dollars (USD)

Coal_thermal_power_station_Critical_price__in_COP_per_Kwh = Coal_thermal_power_station_total_cost__in_US_per_Kwh*exchange_rate_COP_per_US

UNITS: COP/Kw-hour

Coal_thermal_power_station_enviromental_investment = 1064085

UNITS: US Dollars (USD)

Coal_thermal_power_station_FIXED_adm_operation_and__maint_cost = 7895682.98

UNITS: US Dollars/year

Coal_thermal_power_station_land_cost = 291507.2829

UNITS: US Dollars (USD)

Coal_thermal_power_station_preoperating_charges_by_law = 120625.71

UNITS: US Dollars (USD)

Coal_thermal_power_station_total_cost_USper_Kwh_WITHOUT_FUEL = Coal_thermal_PS__investment_cost___US$_Kwh+Coal__thermal__power_station_operating_cost_per_Kwh_without_fuel

UNITS: US Dollars/Kw-hour

Coal_thermal_power_station_total_cost__in_US_per_Kwh = Coal_thermal_power_station_total_cost_in_US_per_Kwh_WITHOUT_FUEL+Coal_price_in_US_per_Kwh

UNITS: US Dollars/Kw-hour

Coal_thermal_power_station__civil_works_or_fundations_cost = bioler+pumping+administrative_building

UNITS: US Dollars (USD)

Coal_thermal_power_station__electricity_generated__kWH_per_year = capacity_in_MW_of_Coal___fired_thermal_power_station*KW_in_a_MW_2*Coal_thermal_power_station__hours_per_year_of_operation

UNITS: Kw-hour/year

Coal_thermal_power_station__enviromental_managment = 364352.45

UNITS: US Dollars/year

Coal_thermal_power_station__hours_per_year_of_operation = 7306

UNITS: hour/year

Coal_thermal_power_station__unexpected_events'_cost = 29089261.9

UNITS: US Dollars (USD)

Coal_thermal_power__station_imported__equipment_cost = 135950667.97

UNITS: US Dollars (USD)

Coal_thermal_power__station_road_cost = 4166680.17

UNITS: US Dollars (USD)

Coal_thermal_PS__investment_cost___US$_Kwh = Coal_thermal__power_station__annual_investment_cost/Coal_thermal_power_station__electricity_generated__kWH_per_year

UNITS: US Dollars/Kw-hour

Coal_thermal__power_station__annual_investment_cost = Coal_thermal__power_station__investment_cost*((rate_of_return*(1+rate_of_return)^amortization__time)/((1+rate_of_return)^amortization__time-1))

UNITS: US Dollars/year

Coal_thermal__power_station__investment_cost = Coal_thermal_power_station_land_cost+Coal_thermal__power__station__infrastructure_cost+Coal_thermal_power_station__civil_works_or_fundations_cost+Coal_thermal_power__station_imported__equipment_cost+Coal_thermal_power_station_enviromental_investment+Coal__thermal_power_station__Engineering_cost+Coal_thermal_power_station__unexpected_events'_cost+Coal_thermal_power_station_preoperating_charges_by_law+Coal__thermal_power_station_preoperating_financial_cost

UNITS: US Dollars (USD)

Coal_thermal__power__station__infrastructure_cost = Coal_thermal_power__station_road_cost+offices+Coal_thermal_power_station_conexions_lines

UNITS: US Dollars (USD)

coal__generation_perc = generation_from_coal_fired_thermal_power_stations/total_electricty_demand_in_Gwh_month

UNITS: Unitless

Coal__thermal_power_station_charges_by_law = 1984376.38

UNITS: US Dollars/year

Coal__thermal_power_station_insurances = 2241995.84

UNITS: US Dollars/year

Coal__thermal_power_station_operating_cost_without_gas = Coal__thermal__power_station_FIXED_operating_cost+Coal__thermal_power_station__Variable_operation_and__maint_cost

UNITS: US Dollars/year

Coal__thermal_power_station_operation_time = 20

UNITS: month

Coal__thermal_power_station_preoperating_financial_cost = 40795983.66

UNITS: US Dollars (USD)

Coal__thermal_power_station__Engineering_cost = 19408823

UNITS: US Dollars (USD)

Coal__thermal_power_station__Variable_operation_and__maint_cost = 1395362.08

UNITS: US Dollars/year

Coal__thermal__power_station_FIXED_operating_cost =
Coal_thermal_power_station_FIXED_adm_operation_and__maint_cost+Coal_thermal_power_station__enviromental_managment+Coal__thermal_power_station_insurances+Coal__thermal_power_station_charges_by_law

UNITS: US Dollars/year

Coal__thermal__power_station_operating_cost_per_Kwh_without_fuel =
Coal__thermal_power_station_operating_cost_without_gas/Coal_thermal_power_station__electricity_generated__kWH_per_year

UNITS: US Dollars/Kw-hour

Critical_price_per_segment_of_density_distribution_of_investors[1] =
minim_critical+0*price_increase_per_segment_of_normal_distribution

UNITS: COP/Kw-hour

Critical_price_per_segment_of_density_distribution_of_investors[2] =
minim_critical+1*price_increase_per_segment_of_normal_distribution

UNITS: COP/Kw-hour

Critical_price_per_segment_of_density_distribution_of_investors[3] =
minim_critical+2*price_increase_per_segment_of_normal_distribution

UNITS: COP/Kw-hour

Critical_price_per_segment_of_density_distribution_of_investors[4] =
minim_critical+3*price_increase_per_segment_of_normal_distribution

UNITS: COP/Kw-hour

Critical_price_per_segment_of_density_distribution_of_investors[5] =
minim_critical+4*price_increase_per_segment_of_normal_distribution

UNITS: COP/Kw-hour

Critical_price_per_segment_of_density_distribution_of_investors[6] =
minim_critical+5*price_increase_per_segment_of_normal_distribution

UNITS: COP/Kw-hour

Critical_price_per_segment_of_density_distribution_of_investors[7] =
minim_critical+6*price_increase_per_segment_of_normal_distribution

UNITS: COP/Kw-hour

Critical_price_per_segment_of_density_distribution_of_investors[8] =
minim_critical+7*price_increase_per_segment_of_normal_distribution

UNITS: COP/Kw-hour

Critical_price_per_segment_of_density_distribution_of_investors[9] =
minim_critical+8*price_increase_per_segment_of_normal_distribution

UNITS: COP/Kw-hour

Critical_price_per_segment_of_density_distribution_of_investors[10] =
minim_critical+9*price_increase_per_segment_of_normal_distribution

UNITS: COP/Kw-hour

Critical_price_per_segment_of_density_distribution_of_investors[11] =
minim_critical+10*price_increase_per_segment_of_normal_distribution

UNITS: COP/Kw-hour

Critical_price_per_segment_of_density_distribution_of_investors[12] =
minim_critical+11*price_increase_per_segment_of_normal_distribution

UNITS: COP/Kw-hour

Critical_price_per_segment_of_density_distribution_of_investors[13] =
minim_critical+12*price_increase_per_segment_of_normal_distribution

UNITS: COP/Kw-hour

Critical_price_per_segment_of_density_distribution_of_investors[14] =
minim_critical+13*price_increase_per_segment_of_normal_distribution

UNITS: COP/Kw-hour

Critical_price_per_segment_of_density_distribution_of_investors[15] =
minim_critical+14*price_increase_per_segment_of_normal_distribution

UNITS: COP/Kw-hour

Critical_price_per_segment_of_density_distribution_of_investors[16] =
minim_critical+15*price_increase_per_segment_of_normal_distribution

UNITS: COP/Kw-hour

Critical_price_per_segment_of_density_distribution_of_investors[17] =
minim_critical+16*price_increase_per_segment_of_normal_distribution

UNITS: COP/Kw-hour

Critical_price_per_segment_of_density_distribution_of_investors[18] =
minim_critical+17*price_increase_per_segment_of_normal_distribution

UNITS: COP/Kw-hour

Critical_price_per_segment_of_density_distribution_of_investors[19] =
minim_critical+18*price_increase_per_segment_of_normal_distribution

UNITS: COP/Kw-hour

Critical_price_per_segment_of_density_distribution_of_investors[20] =
minim_critical+19*price_increase_per_segment_of_normal_distribution

UNITS: COP/Kw-hour

Critical_price_per_segment_of_density_distribution_of_investors[21] =
minim_critical+20*price_increase_per_segment_of_normal_distribution

UNITS: COP/Kw-hour

Cumulative_distribution_of__generation_capacity_coming_on_line =
SUM(Cumulative_distribution_of_generation_capac_ARRAY)

UNITS: MW

dam_filling_fraction = dam_level/installed_capacity__of_dams_in_Gwh

UNITS: Unitless

DAM_power__stations_participacion__on_generation = electricity_generated_from_hydro_power_stations_with_DAM/total_electricty_demand_in_Gwh_month

UNITS: Unitless

decision_rule_for_coal_fired_thermal_power_stations = IF(Coal_thermal_power_station_Critical_price__in_COP_per_Kwh<=Expected_electricity__price_for_coal_fired_thermal_power_stations)then(1)ELSE(0)

UNITS: Unitless

Decision_rule_for_gas_fired_thermal__power_stations = IF(Gas_thermal_power_station_critical_price__in_COP_per_Kwh<=Expected_electricity_price_for_gas_fired_thermal_power_stations)then(1)ELSE(0)

UNITS: Unitless

Decision_rule__for_large_hydro__power__stations_with_DAM = if(Hydro_power__station_critical__price_in_COP_per_Kwh<=Expected_electricity_price_for_LARGE_hydro_power_with_DAM)then(1)else(0)

UNITS: Unitless

Decision_rule__for_medium_hydro__power_stations_with_DAM = if(Hydro_power__station_critical__price_in_COP_per_Kwh<=Expected_electricity_price_for_MEDIUM_hydro_power_with_DAM)then(1)else(0)

UNITS: Unitless

Decision_rule__for_medium_river__power_stations = if(Hydro_power__station_critical__price_in_COP_per_Kwh<=Expected_electricity_price_for_MEDIUM_RIVER_power_station)then(1)else(0)

UNITS: Unitless

Decision_rule__for_SHPS = if(Electricity__Price<=Expected_electricity_price_for_SHPS1)then(1)else(0)

UNITS: Unitless

delay_for_projects_in_stage_2 = 12

Demand_satisfied_through_hydro_power_stations_WITHOUT_dam = Electricity_generated_from_SHPS+hydro_contribution_to_LARGE_river_power_station+hydro_contribution_to_MEDIUM_river_power_station

UNITS: gwh/mo

demand_to_be_satisfied_by_gas_fired_thermal_power_stations = min(demand_to_be__satisfied_by_thermal__power_stations,max_generation__from_gas_power_stations__according_to_history)

UNITS: gwh/mo

demand_to_be_satisfied_by__coal_power_stations = min(demand_to_be__satisfied_by_thermal__power_stations-generation_from__gas_fired_thermal__power_stations,max_generation_from_coal_power_stations_according_to_history)

UNITS: Unitless

Demand_to_be_satisfied_through_power_stations_with_DAM = total_electricty_demand_in_Gwh_month-Demand_satisfied_through_hydro_power_stations_WITHOUT_dam

demand_to_be__satisfied_by_thermal__power_stations = max(0,Demand_to_be_satisfied_through_power_stations_with_DAM-electricity_generated_from_hydro_power_stations_with_DAM)

UNITS: gwh/mo

Density_distribution_of_additional_generation_capacity_by_segment[1] = if(Expected_electricity_price_for_SHPS*Policy_switch_for_early_investors>=Critical_price_per_segment_of_density_distribution_of_investors[1])then(0)else(0)

UNITS: MW

Density_distribution_of_additional_generation_capacity_by_segment[2] = if(Expected_electricity_price_for_SHPS*Policy_switch_for_early_investors>=Critical_price_per_segment_of_density_distribution_of_investors[2])then(1.072144)else(0)

UNITS: MW

Density_distribution_of_additional_generation_capacity_by_segment[3] = if(Expected_electricity_price_for_SHPS*Policy_switch_for_early_investors>=Critical_price_per_segment_of_density_distribution_of_investors[3])then(1.072144)else(0)

UNITS: MW

Density_distribution_of_additional_generation_capacity_by_segment[4] = if(Expected_electricity_price_for_SHPS*Policy_switch_for_early_investors>=Critical_price_per_segment_of_density_distribution_of_investors[4])then(0)else(0)

UNITS: MW

Density_distribution_of_additional_generation_capacity_by_segment[5] = if(Expected_electricity_price_for_SHPS*Policy_switch_for_early_investors>=Critical_price_per_segment_of_density_distribution_of_investors[5])then(2.144289)else(0)

UNITS: MW

Density_distribution_of_additional_generation_capacity_by_segment[6] = if(Expected_electricity_price_for_SHPS*Policy_switch_for_early_investors>=Critical_price_per_segment_of_density_distribution_of_investors[6])then(5.360721)else(0)

UNITS: MW

Density_distribution_of_additional_generation_capacity_by_segment[7] = if(Expected_electricity_price_for_SHPS*Policy_switch_for_early_investors>=Critical_price_per_segment_of_density_distribution_of_investors[7])then(13.93788)else(0)

UNITS: MW

Density_distribution_of_additional_generation_capacity_by_segment[8] = if(Expected_electricity_price_for_SHPS*Policy_switch_for_early_investors>=Critical_price_per_segment_of_density_distribution_of_investors[8])then(30.02004)else(0)

UNITS: MW

Density_distribution_of_additional_generation_capacity_by_segment[9] = if(Expected_electricity_price_for_SHPS*Policy_switch_for_early_investors>=Critical_price_per_segment_of_density_distribution_of_investors[9])then(42.88577)else(0)

UNITS: MW

Density_distribution_of_additional_generation_capacity_by_segment[10] = if(Expected_electricity_price_for_SHPS*Policy_switch_for_early_investors>=Critical_price_per_segment_of_density_distribution_of_investors[10])then(72.90581)else(0)

UNITS: MW

Density_distribution_of_additional_generation_capacity_by_segment[11] = if(Expected_electricity_price_for_SHPS*Policy_switch_for_early_investors>=Critical_price_per_segment_of_density_distribution_of_investors[11])then(90.06012)else(0)

UNITS: MW

Density_distribution_of_additional_generation_capacity_by_segment[12] = if(Expected_electricity_price_for_SHPS*Policy_switch_for_early_investors>=Critical_price_per_segment_of_density_distribution_of_investors[12])then(94.3487)else(0)

UNITS: MW

Density_distribution_of_additional_generation_capacity_by_segment[13] = if(Expected_electricity_price_for_SHPS*Policy_switch_for_early_investors>=Critical_price_per_segment_of_density_distribution_of_investors[13])then(67.54509)else(0)

UNITS: MW

Density_distribution_of_additional_generation_capacity_by_segment[14] = if(Expected_electricity_price_for_SHPS*Policy_switch_for_early_investors>=Critical_price_per_segment_of_density_distribution_of_investors[14])then(52.53507)else(0)

UNITS: MW

Density_distribution_of_additional_generation_capacity_by_segment[15] = if(Expected_electricity_price_for_SHPS*Policy_switch_for_early_investors>=Critical_price_per_segment_of_density_distribution_of_investors[15])then(33.23647)else(0)

UNITS: MW

Density_distribution_of_additional_generation_capacity_by_segment[16] = if(Expected_electricity_price_for_SHPS*Policy_switch_for_early_investors>=Critical_price_per_segment_of_density_distribution_of_investors[16])then(10.72144)else(0)

UNITS: MW

Density_distribution_of_additional_generation_capacity_by_segment[17] = if(Expected_electricity_price_for_SHPS*Policy_switch_for_early_investors>=Critical_price_per_segment_of_density_distribution_of_investors[17])then(10.72144)else(0)

UNITS: MW

Density_distribution_of_additional_generation_capacity_by_segment[18] = if(Expected_electricity_price_for_SHPS*Policy_switch_for_early_investors>=Critical_price_per_segment_of_density_distribution_of_investors[18])then(5.360721)else(0)

UNITS: MW

Density_distribution_of_additional_generation_capacity_by_segment[19] = if(Expected_electricity_price_for_SHPS*Policy_switch_for_early_investors>=Critical_price_per_segment_of_density_distribution_of_investors[19])then(1.072144)else(0)

UNITS: MW

Density_distribution_of_additional_generation_capacity_by_segment[20] = if(Expected_electricity_price_for_SHPS*Policy_switch_for_early_investors>=Critical_price_per_segment_of_density_distribution_of_investors[20])then(0)else(0)

UNITS: MW

Density_distribution_of_additional_generation_capacity_by_segment[21] = if(Expected_electricity_price_for_SHPS*Policy_switch_for_early_investors>=Critical_price_per_segment_of_density_distribution_of_investors[21])then(0)else(0)

UNITS: MW

effect_of_dam_filling_fraction_on_price = GRAPH(dam_filling_fraction)

(0.00, 3.75), (0.1, 3.50), (0.2, 2.83), (0.3, 2.00), (0.4, 1.45), (0.5, 1.15), (0.6, 1.00), (0.7, 0.953), (0.8, 0.931)

UNITS: Unitless

effect_of_hydro_generation_on_coal_plants_participation = GRAPH(Effect_of_hydro__generation_on__gas_generation/3)

(0.4, 0.615), (0.455, 0.52), (0.51, 0.465), (0.565, 0.435), (0.62, 0.4), (0.675, 0.375), (0.73, 0.36), (0.785, 0.34), (0.84, 0.325), (0.895, 0.325), (0.95, 0.32)

UNITS: Unitless

Effect_of_hydro__generation_on__gas_generation = GRAPH(DAM_power__stations_participacion__on_generation)

(0.2, 0.8), (0.275, 0.758), (0.35, 0.616), (0.425, 0.491), (0.5, 0.393), (0.575, 0.302), (0.65, 0.195), (0.725, 0.152), (0.8, 0.122), (0.875, 0.113), (0.95, 0.109)

UNITS: Unitless

effect_of_seasonality__on_rainfall__MEDIUM_RIVER_PS = GRAPH(month)

(0.00, 1.48), (1.00, 1.47), (2.00, 1.37), (3.00, 1.05), (4.00, 1.26), (5.00, 1.37), (6.00, 1.48), (7.00, 1.43), (8.00, 1.17), (9.00, 0.964), (10.0, 1.16), (11.0, 1.35), (12.0, 1.37)

UNITS: Unitless

effect_of_seasonality__on_rainfall__SHPS = GRAPH(month)

(0.00, 0.421), (1.00, 0.462), (2.00, 0.466), (3.00, 0.526), (4.00, 0.628), (5.00, 0.686), (6.00, 0.742), (7.00, 0.634), (8.00, 0.494), (9.00, 0.67), (10.0, 0.694), (11.0, 0.73), (12.0, 0.421)

UNITS: Unitless

effect_of__seasonality__on_rainfall = GRAPH(month)

(0.00, 0.527), (1.00, 0.416), (2.00, 0.509), (3.00, 0.831), (4.00, 1.26), (5.00, 1.59), (6.00, 1.72), (7.00, 1.40), (8.00, 1.19), (9.00, 1.52), (10.0, 1.19), (11.0, 0.842), (12.0, 0.527)

UNITS: Unitless/month

Electricity_Price_Adjustment_time = 0.5

UNITS: month

Electricity__Demand_Scenario = if(Scenario_Dda=1)THEN(Low_Growth_Demand_Scenario_Gwh_month)ELSE(IF(Scenario_Dda=2)THEN(Medium_Growth_Demand_Scenario_Gwh_month)ELSE(High_Growth_Demand_Scenario_Gwh_month))

UNITS: gwh/mo

ENSO = GRAPH(TIME)

(0.00, 1.00), (5.22, 1.00), (10.4, 1.00), (15.7, 1.00), (20.9, 1.00), (26.1, 1.00), (31.3, 1.00), (36.5, 1.00), (41.7, 1.00), (47.0, 1.00), (52.2, 1.00), (57.4, 1.10), (62.6, 1.00), (67.8, 1.00), (73.0, 1.00), (78.3, 1.00), (83.5, 1.00), (88.7, 0.8), (93.9, 0.7), (99.1, 1.00), (104, 1.00), (110, 1.00), (115, 1.00), (120, 1.00)

UNITS: Unitless

ENSO_FORECAST = if(ENSO_SCENARIO=1)THEN(Enso_forecast_1)ELSE(IF(ENSO_SCENARIO=2)then(Enso_forecast_2)else(Enso_forecast_3))

UNITS: Unitless

Enso_forecast_1 = GRAPH(time)

(120, 1.00), (121, 1.00), (122, 1.00), (123, 1.00), (124, 1.00), (125, 1.00), (126, 1.00), (127, 1.00), (128, 1.00), (129, 1.00), (130, 1.00), (131, 1.00), (132, 1.00), (133, 1.00), (134, 1.00), (135, 1.00), (136, 1.00), (137, 1.00), (138, 1.00), (139, 1.00), (140, 1.00), (141, 1.00), (142, 1.00), (143, 1.00), (144, 1.00), (145, 1.00), (146, 0.7), (147, 0.7), (148, 0.7), (149, 0.7), (150, 0.7), (151, 0.7), (152, 0.7), (153, 0.7), (154, 0.7), (155, 0.7), (156, 0.7), (157, 1.00), (158, 1.00), (159, 1.00), (160, 1.00), (161, 1.00), (162, 1.00), (163, 1.00), (164, 1.00), (165, 1.00), (166, 1.00), (167, 1.00), (168, 1.00), (169, 1.00), (170, 1.00), (171, 1.00), (172, 1.00), (173, 1.00), (174, 1.00), (175, 1.00), (176, 1.00), (177, 1.00), (178, 1.00), (179, 1.00), (180, 1.00), (181, 1.00), (182, 1.00), (183, 1.00), (184, 1.00), (185, 1.00), (186, 1.00), (187, 1.00), (188, 1.00), (189, 1.00), (190, 1.00), (191, 1.00), (192, 1.00), (193, 1.00), (194, 1.00), (195, 1.00), (196, 1.00), (197, 1.00), (198, 1.00), (199, 1.00), (200, 1.00), (201, 1.00), (202, 1.00), (203, 1.00), (204, 1.00), (205, 1.00), (206, 1.00), (207, 0.7), (208, 0.7), (209, 0.7), (210, 0.7), (211, 0.7), (212, 0.7), (213, 0.7), (214, 0.7), (215, 0.7), (216, 0.7), (217, 0.7), (218, 0.7), (219, 0.7), (220, 0.7), (221, 0.7), (222, 1.00), (223, 1.00), (224, 1.00), (225, 1.00), (226, 1.00), (227, 1.00), (228, 1.00), (229, 1.00), (230, 1.00), (231, 1.00), (232, 1.00), (233, 1.00), (234, 1.00), (235, 1.00), (236, 1.00), (237, 1.00), (238, 1.00), (239, 1.00), (240, 1.00)

UNITS: Unitless

Enso_forecast_2 = GRAPH(time)

(120, 1.00), (121, 1.00), (122, 1.00), (123, 1.00), (124, 1.00), (125, 1.00), (126, 1.00), (127, 1.00), (128, 1.00), (129, 1.00), (130, 1.00), (131, 1.00), (132, 1.00), (133, 1.00), (134, 1.00), (135, 1.00), (136, 1.00), (137, 1.00), (138, 1.00), (139, 1.00), (140, 1.00), (141, 1.00), (142, 1.00), (143, 1.00), (144, 1.00), (145, 1.00), (146, 1.00), (147, 1.00), (148, 1.00), (149, 1.00), (150, 1.00), (151, 1.00), (152, 1.00), (153, 1.00), (154, 1.00), (155, 1.00), (156, 1.00), (157, 1.00), (158, 0.7), (159, 0.7), (160, 0.7), (161, 0.7), (162, 0.7), (163, 0.7), (164, 0.7), (165, 0.7), (166, 0.7), (167, 0.7), (168, 0.7), (169, 1.00), (170, 1.00), (171, 1.00), (172, 1.00), (173, 1.00), (174, 1.00), (175, 1.00), (176, 1.00), (177, 1.00), (178, 1.00), (179, 1.00), (180, 1.00), (181, 1.00), (182, 1.00), (183, 1.00), (184, 1.00), (185, 1.00), (186, 1.00), (187, 1.00), (188, 1.00), (189, 1.00), (190, 1.00), (191, 1.00), (192, 1.00), (193, 1.00), (194, 0.7), (195, 0.7), (196, 0.7), (197, 0.7), (198, 0.7), (199, 0.7), (200, 0.7), (201, 0.7), (202, 0.7), (203, 0.7), (204, 0.7), (205, 0.7), (206, 0.7), (207, 0.7), (208, 0.7), (209, 0.7), (210, 0.7), (211, 0.7), (212, 0.7), (213, 0.7), (214, 0.7), (215, 0.7), (216, 0.7), (217, 1.00), (218, 1.00), (219, 1.00), (220, 1.00), (221, 1.00), (222, 1.00), (223, 1.00), (224, 1.00), (225, 1.00), (226, 1.00), (227, 1.00), (228, 1.00), (229, 1.00), (230, 1.00), (231, 1.00), (232, 1.00), (233, 1.00), (234, 1.00), (235, 1.00), (236, 1.00), (237, 1.00), (238, 1.00), (239, 1.00), (240, 1.00)

UNITS: Unitless

Enso_forecast_3 = GRAPH(time)

(120, 1.00), (121, 1.00), (122, 1.00), (123, 1.00), (124, 1.00), (125, 1.00), (126, 1.00), (127, 1.00), (128, 1.00), (129, 1.00), (130, 1.00), (131, 1.00), (132, 1.00), (133, 1.00), (134, 1.00), (135, 1.00), (136, 1.00), (137, 1.00), (138, 1.00), (139, 1.00), (140, 1.00), (141, 1.00), (142, 1.00), (143, 1.00), (144, 1.00), (145, 1.00), (146, 1.00), (147, 1.00), (148, 1.00), (149, 1.00), (150, 1.00), (151, 1.00), (152, 1.00), (153, 1.00), (154, 1.00), (155, 1.00), (156, 1.00), (157, 1.00), (158, 0.7), (159, 0.7), (160, 0.7), (161, 0.7), (162, 0.7), (163, 0.7), (164, 0.7), (165, 0.7), (166, 0.7), (167, 0.7), (168, 0.7), (169, 0.7), (170, 1.00), (171, 1.00), (172, 1.00), (173, 1.00), (174, 1.00), (175, 1.00), (176, 1.00), (177, 1.00), (178, 1.00), (179, 1.00), (180, 1.00), (181, 1.00), (182, 1.00), (183, 1.00), (184, 1.00), (185, 1.00), (186, 1.00), (187, 1.00), (188, 1.00), (189, 1.00), (190, 1.00), (191, 1.00), (192, 1.00), (193, 1.00), (194, 1.00), (195, 1.00), (196, 1.00), (197, 1.00), (198, 1.00), (199, 1.00), (200, 1.00), (201, 1.00), (202, 1.00), (203, 1.00), (204, 1.00), (205, 1.00), (206, 1.00), (207, 0.7), (208, 0.7), (209, 0.7), (210, 0.7), (211, 0.7), (212, 0.7), (213, 0.7), (214, 0.7), (215, 1.00), (216, 1.00), (217, 1.00), (218, 1.00), (219, 1.00), (220, 1.00), (221, 1.00), (222, 1.00), (223, 1.00), (224, 1.00), (225, 1.00), (226, 1.00), (227, 0.7), (228, 0.7), (229, 0.7), (230, 0.7), (231, 0.7), (232, 0.7), (233, 0.7), (234, 0.7), (235, 0.7), (236, 0.7), (237, 1.00), (238, 1.00), (239, 1.00), (240, 1.00)

UNITS: Unitless

ENSO_SCENARIO = 1

UNITS: Unitless

equivalent_Gwh_of_dam_per_MW_of_installed_capacity = 0.72

exchange_rate_COP_per_US = GRAPH(TIME)

(0.00, 2275), (1.00, 2287), (2.01, 2282), (3.01, 2263), (4.02, 2310), (5.02, 2364), (6.03, 2507), (7.03, 2647), (8.03, 2751), (9.04, 2828), (10.0, 2727), (11.0, 2815), (12.1, 2913), (13.1, 2952), (14.1, 2959), (15.1, 2927), (16.1, 2859), (17.1, 2827), (18.1, 2859), (19.1, 2867), (20.1, 2840), (21.1, 2876), (22.1, 2845), (23.1, 2807), (24.1, 2749), (25.1, 2718), (26.1, 2671), (27.1, 2640), (28.1, 2719), (29.1, 2717), (30.1, 2653), (31.1, 2599), (32.1, 2553), (33.1, 2581), (34.1, 2530), (35.1, 2411), (36.2, 2363), (37.2, 2340), (38.2, 2354), (39.2, 2350), (40.2, 2339), (41.2, 2332), (42.2, 2323), (43.2, 2306), (44.2, 2295), (45.2, 2293), (46.2, 2280), (47.2, 2279), (48.2, 2274), (49.2, 2256), (50.2, 2262), (51.2, 2334), (52.2, 2418), (53.2, 2542), (54.2, 2512), (55.2, 2390), (56.2, 2399), (57.2, 2364), (58.2, 2290), (59.2, 2261), (60.3, 2237), (61.3, 2228), (62.3, 2201), (63.3, 2145), (64.3, 2008), (65.3, 1924), (66.3, 1951), (67.3, 2058), (68.3, 2117), (69.3, 2003), (70.3, 2048), (71.3, 2014), (72.3, 1981), (73.3, 1903), (74.3, 1847), (75.3, 1796), (76.3, 1778), (77.3, 1712), (78.3, 1783), (79.3, 1844), (80.3, 2066), (81.3, 2289), (82.3, 2329), (83.3, 2253), (84.4, 2253), (85.4, 2514), (86.4, 2477), (87.4, 2379), (88.4, 2230), (89.4, 2090), (90.4, 2053), (91.4, 2019), (92.4, 1981), (93.4, 1905), (94.4, 1974), (95.4, 2017), (96.4, 1978), (97.4, 1953), (98.4, 1909), (99.4, 1940), (100, 1984), (101, 1926), (102, 1875), (103, 1819), (104, 1806), (105, 1808), (106, 1864), (107, 1926), (108, 1867), (109, 1883), (110, 1884), (111, 1813), (112, 1802), (113, 1783), (114, 1762), (115, 1785), (116, 1836), (117, 1910), (118, 1918), (119, 1934), (121, 1934), (122, 1934), (123, 1934), (124, 1934), (125, 1934), (126, 1934), (127, 1934), (128, 1934), (129, 1934), (130, 1934), (131, 1934), (132, 1934), (133, 1934), (134, 1934), (135, 1934), (136, 1934), (137, 1934), (138, 1934), (139, 1934), (140, 1934), (141, 1934), (142, 1934), (143, 1934), (144, 1934), (145, 1934), (146, 1934), (147, 1934), (148, 1934), (149, 1934), (150, 1934), (151, 1934), (152, 1934), (153, 1934), (154, 1934), (155, 1934), (156, 1934), (157, 1934), (158, 1934), (159, 1934), (160, 1934), (161, 1934), (162, 1934), (163, 1934), (164, 1934), (165, 1934), (166, 1934), (167, 1934), (168, 1934), (169, 1934), (170, 1934), (171, 1934), (172, 1934), (173, 1934), (174, 1934), (175, 1934), (176, 1934), (177, 1934), (178, 1934), (179, 1934), (180, 1934), (181, 1934), (182, 1934), (183, 1934), (184, 1934), (185, 1934), (186, 1934), (187, 1934), (188, 1934), (189, 1934), (190, 1934), (191, 1934), (192, 1934), (193, 1934), (194, 1934), (195, 1934), (196, 1934), (197, 1934), (198, 1934), (199, 1934), (200, 1934), (201, 1934), (202, 1934), (203, 1934), (204, 1934), (205, 1934), (206, 1934), (207, 1934), (208, 1934), (209, 1934), (210, 1934), (211, 1934), (212, 1934), (213, 1934), (214, 1934), (215, 1934), (216, 1934), (217, 1934), (218, 1934), (219, 1934), (220, 1934), (221, 1934), (222, 1934), (223, 1934), (224, 1934), (225, 1934), (226, 1934), (227, 1934), (228, 1934), (229, 1934), (230, 1934), (231, 1934), (232, 1934), (233, 1934), (234, 1934), (235, 1934), (236, 1934), (237, 1934), (238, 1934), (239, 1934), (240, 1934)

UNITS: COP/US Dollars

Expected_electricity_price_for_gas_fired_thermal_power_stations = FORCST(average_electricity_price,36,gas_fired_thermal_power_stations_time_horizon)

UNITS: COP/Kw-hour

Expected_electricity_price_for_LARGE_hydro_power_with_DAM = FORCST(average_electricity_price,36,large_hydro_power_with_DAM_time_horizon)

UNITS: COP/Kw-hour

Expected_electricity_price_for_MEDIUM_hydro_power_with_DAM = FORCST(average_electricity_price,36,MEDIUM_hydro_power_with_DAM_time_horizon)

UNITS: COP/Kw-hour

Expected_electricity_price_for_MEDIUM_RIVER_power_station = FORCST(average_electricity_price,36,MEDIUM_RIVER_power_station_time_horizon)

UNITS: COP/Kw-hour

Expected_electricity_price_for_SHPS = Weight_to_historical_Electricity_price*Expected_electricity_price_for_SHPS1+Forecasted__Electricity_Price*Weight_to_forecasted_electricity_price

UNITS: COP/Kw-hour

Expected_electricity_price_for_SHPS1 = FORCST(average_electricity_price,36,SHPS__time_horizon)

UNITS: COP/Kw-hour

Expected_electricity__price_for_coal_fired_thermal_power_stations = FORCST(average_electricity_price,36,coal_fired_thermal_power_stations_time_horizon)

UNITS: COP/Kw-hour

Forecasted__Electricity_Price = HISTORY(Electricity_Price_Forecast.average_forecasted_electricity_price,120)

UNITS: COP/Kw-hour

fundations = 406823

UNITS: US Dollars (USD)

fundations__vapor_turbine = 2973971

UNITS: US Dollars (USD)

gas_fired_thermal_power_stations_planning_and_approval_time = 24

gas_fired_thermal_power_stations_time_horizon = 48

UNITS: month

gas_fired_thermal_power_station_installed_HISTORICAL_capacity = GRAPH(time)

(0.00, 3431), (12.0, 3377), (24.0, 3354), (36.0, 3464), (48.0, 3380), (60.0, 3309), (72.0, 3399), (84.0, 3463), (96.0, 3469), (108, 3638), (120, 3638)

gas_generation__perc = generation_from__gas_fired_thermal__power_stations/total_electricty_demand_in_Gwh_month

gas_participation__on_generation = generation_from__gas_fired_thermal__power_stations/total_electricity__generated

UNITS: Unitless

gas_pipeline = 687124

UNITS: US Dollars (USD)

gas_price_US_per_Kwh = GRAPH(time

)

(0.00, 0.00397), (1.00, 0.00341), (2.01, 0.00341), (3.01, 0.00341), (4.02, 0.00341), (5.02, 0.00341), (6.03, 0.00341), (7.03, 0.00444), (8.03, 0.00444), (9.04, 0.00444), (10.0, 0.00444), (11.0, 0.00444), (12.1, 0.00444), (13.1, 0.00549), (14.1, 0.00549), (15.1, 0.00549), (16.1, 0.00549), (17.1, 0.00549), (18.1, 0.00549), (19.1, 0.00502), (20.1, 0.00502), (21.1, 0.00502), (22.1, 0.00502), (23.1, 0.00502), (24.1, 0.00502), (25.1, 0.00519), (26.1, 0.00519), (27.1, 0.00519), (28.1, 0.00519), (29.1, 0.00519), (30.1, 0.00519), (31.1, 0.00513), (32.1, 0.00513), (33.1, 0.00513), (34.1, 0.00513), (35.1, 0.00513), (36.2, 0.00513), (37.2, 0.00535), (38.2, 0.00535), (39.2, 0.00535), (40.2, 0.00535), (41.2, 0.00535), (42.2, 0.00535), (43.2, 0.00728), (44.2, 0.00728), (45.2, 0.00728), (46.2, 0.00728), (47.2, 0.00728), (48.2, 0.00728), (49.2, 0.0093), (50.2, 0.0093), (51.2, 0.0093), (52.2, 0.0093), (53.2, 0.0093), (54.2, 0.0093), (55.2, 0.00945), (56.2, 0.00945), (57.2, 0.00945), (58.2, 0.00945), (59.2, 0.00945), (60.3, 0.00945), (61.3, 0.00803), (62.3, 0.00803), (63.3, 0.00803), (64.3, 0.00803), (65.3, 0.00803), (66.3, 0.00803), (67.3, 0.00945), (68.3, 0.00945), (69.3, 0.00945), (70.3, 0.00945), (71.3, 0.00945), (72.3, 0.00945), (73.3, 0.0126), (74.3, 0.0126), (75.3, 0.0126), (76.3, 0.0126), (77.3, 0.0126), (78.3, 0.0126), (79.3, 0.017), (80.3, 0.017), (81.3, 0.017), (82.3, 0.017), (83.3, 0.017), (84.4, 0.017), (85.4, 0.0113), (86.4, 0.0113), (87.4, 0.0113), (88.4, 0.0113), (89.4, 0.0113), (90.4, 0.0113), (91.4, 0.00944), (92.4, 0.00944), (93.4, 0.00944), (94.4, 0.00944), (95.4, 0.00944), (96.4, 0.00944), (97.4, 0.0133), (98.4, 0.0133), (99.4, 0.0133), (100, 0.0133), (101, 0.0133), (102, 0.0133), (103, 0.0137), (104, 0.0137), (105, 0.0137), (106, 0.0137), (107, 0.0137), (108, 0.0137), (109, 0.0145), (110, 0.0145), (111, 0.0145), (112, 0.0145), (113, 0.0145), (114, 0.0145), (115, 0.0198), (116, 0.0198), (117, 0.0198), (118, 0.0198), (119, 0.0198), (121, 0.0199), (122, 0.0199), (123, 0.02), (124, 0.02), (125, 0.02), (126, 0.0201), (127, 0.0201), (128, 0.0202), (129, 0.0202), (130, 0.0202), (131, 0.0203), (132, 0.0203), (133, 0.0204), (134, 0.0204), (135, 0.0204), (136, 0.0205), (137, 0.0205), (138, 0.0206), (139, 0.0206), (140, 0.0207), (141, 0.0207), (142, 0.0207), (143, 0.0208), (144, 0.0208), (145, 0.0209), (146, 0.0209), (147, 0.0209), (148, 0.021), (149, 0.021), (150, 0.0211), (151, 0.0211), (152, 0.0212), (153, 0.0212), (154, 0.0212), (155, 0.0213), (156, 0.0213), (157, 0.0214), (158, 0.0214), (159, 0.0215), (160, 0.0215), (161, 0.0216), (162, 0.0216), (163, 0.0216), (164, 0.0217), (165, 0.0217), (166, 0.0218), (167, 0.0218), (168, 0.0219), (169, 0.0219), (170, 0.0219), (171, 0.022), (172, 0.022), (173, 0.0221), (174, 0.0221), (175, 0.0222), (176, 0.0222), (177, 0.0223), (178, 0.0223), (179, 0.0224), (180, 0.0224), (181, 0.0224), (182, 0.0225), (183, 0.0225), (184, 0.0226), (185, 0.0226), (186, 0.0227), (187, 0.0227), (188, 0.0228), (189, 0.0228), (190, 0.0229), (191, 0.0229), (192, 0.023), (193, 0.023), (194, 0.023), (195, 0.0231), (196, 0.0231), (197, 0.0232), (198, 0.0232), (199, 0.0233), (200, 0.0233), (201, 0.0234), (202, 0.0234), (203, 0.0235), (204, 0.0235), (205, 0.0943), (206, 0.0945), (207, 0.0947), (208, 0.0948), (209, 0.095), (210, 0.0952), (211, 0.0954), (212, 0.0956), (213, 0.0958), (214, 0.096), (215, 0.0962), (216, 0.0964), (217, 0.0966), (218, 0.0968), (219, 0.097), (220, 0.0972), (221, 0.0974), (222, 0.0976), (223, 0.0978), (224, 0.098), (225, 0.0982), (226, 0.0984), (227, 0.0986), (228, 0.0988), (229, 0.099), (230, 0.0992), (231, 0.0994), (232, 0.0996), (233, 0.0998), (234, 0.1), (235, 0.1), (236, 0.1), (237, 0.101), (238, 0.101), (239, 0.101), (240, 0.101)

UNITS: US Dollars/Kw-hour

Gas_thermal_power_station_charges_by_law = 2011520

UNITS: US Dollars/year

Gas_thermal_power_station_conexions_lines = 687124

UNITS: US Dollars (USD)

Gas_thermal_power_station_critical_price__in_COP_per_Kwh = Gas_thermal_power_station_total_cost_in_US_per_Kwh*exchange_rate_COP_per_US

UNITS: COP/Kw-hour

Gas_thermal_power_station_enviromental_investment = 554410

UNITS: US Dollars (USD)

Gas_thermal_power_station_FIXED_adm_operation_and__maint_cost = 2095521

UNITS: US Dollars/year

Gas_thermal_power_station_insurances = 771471

UNITS: US Dollars/year

Gas_thermal_power_station_land_cost = 87452

UNITS: US Dollars (USD)

Gas_thermal_power_station_operating_cost_without_gas = Gas_thermal__power_station_FIXED_operating_cost+Gas_thermal_power_station__Variable_operation_and_maint_cost

UNITS: US Dollars/year

Gas_thermal_power_station_operation_time = 20

UNITS: month

Gas_thermal_power_station_preoperating_charges_by_law = 36188

UNITS: US Dollars (USD)

Gas_thermal_power_station_preoperating_financial_cost = 14477271

UNITS: US Dollars (USD)

Gas_thermal_power_station_road_cost = 626158

UNITS: US Dollars (USD)

Gas_thermal_power_station_total_cost_in_US_per_Kwh = Gas_thermal_power_station__total_cost_US_per_Kwh_WITHOUT_FUEL+gas_price_US_per_Kwh+gas_transport_price_in_US_per_Kwh

UNITS: US Dollars/Kw-hour

Gas_thermal_power_station__civil_works_or_fundations_cost = fundations__vapor_turbine+fundations+water_plant__and_others

UNITS: US Dollars (USD)

Gas_thermal_power_station__electricity_generated__kWH_per_year = capacity_in_MW_of_gas__fired_thermal_power_station*KW_in_a_MW*Gas_thermal_power_station__hours_per_year_of_operation

UNITS: Kw-hour/year

Gas_thermal_power_station__Engineering_cost = 7352216

UNITS: US Dollars (USD)

Gas_thermal_power_station__enviromental_managment = 117947

UNITS: US Dollars/year

Gas_thermal_power_station__hours_per_year_of_operation = 7306

UNITS: hour/year

Gas_thermal_power_station__preoperating_investment_cost = Gas_thermal_power_station_land_cost+Gas__thermal__power__station__infrastructure_cost+Gas_thermal_power_station__civil_works_or_fundations_cost+Gas_thermal_power__station_imported__equipment_cost+Gas_thermal_power_station_enviromental_investment+Gas_thermal_power_station__Engineering_cost+Gas_thermal_power_station__unexpected_events'_cost+Gas_thermal_power_station_preoperating_charges_by_law+Gas_thermal_power_station_preoperating_financial_cost

UNITS: US Dollars (USD)

Gas_thermal_power_station__unexpected_events'_cost = 11808804

UNITS: US Dollars (USD)

Gas_thermal_power_station__Variable_operation_and_maint_cost = 2145027

UNITS: US Dollars/year

Gas_thermal_power__station_imported__equipment_cost = 52849566

UNITS: US Dollars (USD)

Gas_thermal_PS_Investment_cost_in_US2OO2_per_Kwh = gas_thermal__power_station__annual_investment_cost/Gas_thermal_power_station__electricity_generated__kWH_per_year

UNITS: US Dollars/Kw-hour

Gas_thermal_PS__total_cost_US2002_per_Kwh__WITHOUT_FUEL = Gas_thermal_PS_Investment_cost_in_US2OO2_per_Kwh+Gas_thermal__power_station_operating_cost_per_Kwh_without_fuel

UNITS: US Dollars/Kw-hour

Gas_thermal__power_station_FIXED_operating_cost = Gas_thermal_power_station_FIXED_adm_operation_and__maint_cost+Gas_thermal_power_station__enviromental_managment+Gas_thermal_power_station_insurances+Gas_thermal_power_station_charges_by_law

UNITS: US Dollars/year

Gas_thermal__power_station_operating_cost_per_Kwh_without_fuel = Gas_thermal_power_station_operating_cost_without_gas/Gas_thermal_power_station__electricity_generated__kWH_per_year

UNITS: US Dollars/Kw-hour

gas_thermal__power_station__annual_investment_cost = Gas_thermal_power_station__preoperating_investment_cost*((rate_of_return*(1+rate_of_return)^amortization__time)/((1+rate_of_return)^amortization__time-1))

UNITS: US Dollars/year

gas_transport_price_in_US_per_Kwh = GRAPH(time)

(0.00, 0.00355), (1.00, 0.00359), (2.01, 0.00362), (3.01, 0.00365), (4.02, 0.00367), (5.02, 0.00369), (6.03, 0.00369), (7.03, 0.00369), (8.03, 0.00371), (9.04, 0.00373), (10.0, 0.00376), (11.0, 0.00377), (12.1, 0.00381), (13.1, 0.00385), (14.1, 0.0039), (15.1, 0.00394), (16.1, 0.00396), (17.1, 0.00396), (18.1, 0.00395), (19.1, 0.00396), (20.1, 0.00397), (21.1, 0.00398), (22.1, 0.00399), (23.1, 0.00401), (24.1, 0.00405), (25.1, 0.0041), (26.1, 0.00414), (27.1, 0.00416), (28.1, 0.00418), (29.1, 0.0042), (30.1, 0.0042), (31.1, 0.0042), (32.1, 0.00421), (33.1, 0.00421), (34.1, 0.00422), (35.1, 0.00424), (36.2, 0.00427), (37.2, 0.00432), (38.2, 0.00435), (39.2, 0.00437), (40.2, 0.00439), (41.2, 0.0044), (42.2, 0.00441), (43.2, 0.00441), (44.2, 0.00443), (45.2, 0.00444), (46.2, 0.00444), (47.2, 0.00444), (48.2, 0.00447), (49.2, 0.0045), (50.2, 0.00453), (51.2, 0.00455), (52.2, 0.00456), (53.2, 0.00458), (54.2, 0.0046), (55.2, 0.00462), (56.2, 0.00463), (57.2, 0.00462), (58.2, 0.00463), (59.2, 0.00464), (60.3, 0.00468), (61.3, 0.00474), (62.3, 0.00479), (63.3, 0.00484), (64.3, 0.00485), (65.3, 0.00486), (66.3, 0.00487), (67.3, 0.00486), (68.3, 0.00486), (69.3, 0.00486), (70.3, 0.00489), (71.3, 0.00491), (72.3, 0.00496), (73.3, 0.00504), (74.3, 0.00508), (75.3, 0.00512), (76.3, 0.00517), (77.3, 0.00521), (78.3, 0.00524), (79.3, 0.00525), (80.3, 0.00524), (81.3, 0.00525), (82.3, 0.00527), (83.3, 0.00529), (84.4, 0.00532), (85.4, 0.00537), (86.4, 0.0054), (87.4, 0.00541), (88.4, 0.00541), (89.4, 0.00541), (90.4, 0.00541), (91.4, 0.00541), (92.4, 0.0054), (93.4, 0.0054), (94.4, 0.00539), (95.4, 0.0054), (96.4, 0.00543), (97.4, 0.00548), (98.4, 0.00549), (99.4, 0.00552), (100, 0.00552), (101, 0.00553), (102, 0.00553), (103, 0.00553), (104, 0.00553), (105, 0.00552), (106, 0.00553), (107, 0.00557), (108, 0.00562), (109, 0.00565), (110, 0.00567), (111, 0.00568), (112, 0.00569), (113, 0.00571), (114, 0.00572), (115, 0.00572), (116, 0.00573), (117, 0.00575), (118, 0.00575), (119, 0.00578), (121, 0.00579), (122, 0.00581), (123, 0.00582), (124, 0.00584), (125, 0.00585), (126, 0.00586), (127, 0.00588), (128, 0.00589), (129, 0.00591), (130, 0.00592), (131, 0.00594), (132, 0.00595), (133, 0.00597), (134, 0.00598), (135, 0.006), (136, 0.00601), (137, 0.00603), (138, 0.00604), (139, 0.00606), (140, 0.00607), (141, 0.00609), (142, 0.0061), (143, 0.00612), (144, 0.00613), (145, 0.00615), (146, 0.00617), (147, 0.00618), (148, 0.0062), (149, 0.00621), (150, 0.00623), (151, 0.00624), (152, 0.00626), (153, 0.00627), (154, 0.00629), (155, 0.00631), (156, 0.00632), (157, 0.00634), (158, 0.00635), (159, 0.00637), (160, 0.00638), (161, 0.0064), (162, 0.00642), (163, 0.00643), (164, 0.00645), (165, 0.00646), (166, 0.00648), (167, 0.0065), (168, 0.00651), (169, 0.00653), (170, 0.00655), (171, 0.00656), (172, 0.00658), (173, 0.0066), (174, 0.00661), (175, 0.00663), (176, 0.00664), (177, 0.00666), (178, 0.00668), (179, 0.00669), (180, 0.00671), (181, 0.00673), (182, 0.00674), (183, 0.00676), (184, 0.00678), (185, 0.0068), (186, 0.00681), (187, 0.00683), (188, 0.00685), (189, 0.00686), (190, 0.00688), (191, 0.0069), (192, 0.00692), (193, 0.00693), (194, 0.00695), (195, 0.00697), (196, 0.00698), (197, 0.007), (198, 0.00702), (199, 0.00704), (200, 0.00706), (201, 0.00707), (202, 0.00709), (203, 0.00711), (204, 0.00713), (205, 0.00714), (206, 0.00716), (207, 0.00718), (208, 0.0072), (209, 0.00722), (210, 0.00723), (211, 0.00725), (212, 0.00727), (213, 0.00729), (214, 0.00731), (215, 0.00732), (216, 0.00734), (217, 0.00736), (218, 0.00738), (219, 0.0074), (220, 0.00742), (221, 0.00743), (222, 0.00745), (223, 0.00747), (224, 0.00749), (225, 0.00751), (226, 0.00753), (227, 0.00755), (228, 0.00757), (229, 0.00758), (230, 0.0076), (231, 0.00762), (232, 0.00764), (233, 0.00766), (234, 0.00768), (235, 0.0077), (236, 0.00772), (237, 0.00774), (238, 0.00776), (239, 0.00778), (240, 0.0078)

UNITS: US Dollars/Kw-hour

Gas__thermal__power__station__infrastructure_cost =
Gas_thermal_power_station_road_cost+gas_pipeline+Gas_thermal_power_station_conexions_lines

UNITS: US Dollars (USD)

generation_from_coal_fired_thermal_power_stations =
min(max_offer__of_electricity_from_coal__fired_thermal_power_stations,demand_to_be_satisfied_by__coal_power_stations)

UNITS: gwh/mo

generation_from_thermal_power_stations =
generation_from_coal_fired_thermal_power_stations+generation_from__gas_fired_thermal__power_stations

UNITS: gwh/mo

generation_from__gas_fired_thermal__power_stations =
min(demand_to_be_satisfied_by_gas_fired_thermal_power_stations,max_offer_of__electricity_from_gas__fired_thermal_power_stations)

UNITS: gwh/mo

generation_from__large_and_medium__HYDRO_PS =
hydro_contribution_to_LARGE_river_power_station+hydro_contribution_to_MEDIUM_river_power_station+electricity_generated_from_hydro_power_stations_with_DAM

Gwh_in_a_MW = 0.72

UNITS: Gwh/MW

High_Growth_Demand_Scenario_Gwh_month = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.01, 0.00), (3.01, 0.00), (4.02, 0.00), (5.02, 0.00), (6.03, 0.00), (7.03, 0.00), (8.03, 0.00), (9.04, 0.00), (10.0, 0.00), (11.0, 0.00), (12.1, 0.00), (13.1, 0.00), (14.1, 0.00), (15.1, 0.00), (16.1, 0.00), (17.1, 0.00), (18.1, 0.00), (19.1, 0.00), (20.1, 0.00), (21.1, 0.00), (22.1, 0.00), (23.1, 0.00), (24.1, 0.00), (25.1, 0.00), (26.1, 0.00), (27.1, 0.00), (28.1, 0.00), (29.1, 0.00), (30.1, 0.00), (31.1, 0.00), (32.1, 0.00), (33.1, 0.00), (34.1, 0.00), (35.1, 0.00), (36.2, 0.00), (37.2, 0.00), (38.2, 0.00), (39.2, 0.00), (40.2, 0.00), (41.2, 0.00), (42.2, 0.00), (43.2, 0.00), (44.2, 0.00), (45.2, 0.00), (46.2, 0.00), (47.2, 0.00), (48.2, 0.00), (49.2, 0.00), (50.2, 0.00), (51.2, 0.00), (52.2, 0.00), (53.2, 0.00), (54.2, 0.00), (55.2, 0.00), (56.2, 0.00), (57.2, 0.00), (58.2, 0.00), (59.2, 0.00), (60.3, 0.00), (61.3, 0.00), (62.3, 0.00), (63.3, 0.00), (64.3, 0.00), (65.3, 0.00), (66.3, 0.00), (67.3, 0.00), (68.3, 0.00), (69.3, 0.00), (70.3, 0.00), (71.3, 0.00), (72.3, 0.00), (73.3, 0.00), (74.3, 0.00), (75.3, 0.00), (76.3, 0.00), (77.3, 0.00), (78.3, 0.00), (79.3, 0.00), (80.3, 0.00), (81.3, 0.00), (82.3, 0.00), (83.3, 0.00), (84.4, 0.00), (85.4, 0.00), (86.4, 0.00), (87.4, 0.00), (88.4, 0.00), (89.4, 0.00), (90.4, 0.00), (91.4, 0.00), (92.4, 0.00), (93.4, 0.00), (94.4, 0.00), (95.4, 0.00), (96.4, 0.00), (97.4, 0.00), (98.4, 0.00), (99.4, 0.00), (100, 0.00), (101, 0.00), (102, 0.00), (103, 0.00), (104, 0.00), (105, 0.00), (106, 0.00), (107, 0.00), (108, 0.00), (109, 0.00), (110, 0.00), (111, 0.00), (112, 0.00), (113, 0.00), (114, 0.00), (115, 0.00), (116, 0.00), (117, 0.00), (118, 0.00), (119, 0.00), (121, 4955), (122, 4792), (123, 5105), (124, 4912), (125, 5118), (126, 4935), (127, 5080), (128, 5171), (129, 5058), (130, 5154), (131, 5100), (132, 5231), (133, 5114), (134, 4897), (135, 5170), (136, 5169), (137, 5286), (138, 5074), (139, 5254), (140, 5321), (141, 5240), (142, 5386), (143, 5251), (144, 5405), (145, 5430), (146, 5192), (147, 5564), (148, 5404), (149, 5626), (150, 5382), (151, 5639), (152, 5625), (153, 5582), (154, 5718), (155, 5827), (156, 5993), (157, 5717), (158, 5487), (159, 5890), (160, 5718), (161, 5886), (162, 5730), (163, 5965), (164, 5958), (165, 5950), (166, 6057), (167, 5912), (168, 6066), (169, 5960), (170, 5900), (171, 6090), (172, 6068), (173, 6164), (174, 6065), (175, 6175), (176, 6294), (177, 6224), (178, 6311), (179, 6209), (180, 6369), (181, 6302), (182, 6050), (183, 6486), (184, 6259), (185, 6494), (186, 6338), (187, 6484), (188, 6572), (189, 6528), (190, 6632), (191, 6522), (192, 6629), (193, 6596), (194, 6353), (195, 6785), (196, 6574), (197, 6803), (198, 6639), (199, 6803), (200, 6885), (201, 6818), (202, 6970), (203, 6837), (204, 6954), (205, 6912), (206, 6668), (207, 7081), (208, 6915), (209, 7158), (210, 6937), (211, 7157), (212, 7202), (213, 7152), (214, 7297), (215, 7156), (216, 7317), (217, 7260), (218, 7160), (219, 7442), (220, 7266), (221, 7447), (222, 7287), (223, 7539), (224, 7536), (225, 7533), (226, 7649), (227, 7501), (228, 7668), (229, 7610), (230, 7393), (231, 7851), (232, 7651), (233, 7844), (234, 7709), (235, 7888), (236, 7946), (237, 7926), (238, 8022), (239, 7919), (240, 8074)

UNITS: gwh/mo

High_Growth_Power_Demand_Scenario_MW = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.01, 0.00), (3.01, 0.00), (4.02, 0.00), (5.02, 0.00), (6.03, 0.00), (7.03, 0.00), (8.03, 0.00), (9.04, 0.00), (10.0, 0.00), (11.0, 0.00), (12.1, 0.00), (13.1, 0.00), (14.1, 0.00), (15.1, 0.00), (16.1, 0.00), (17.1, 0.00), (18.1, 0.00), (19.1, 0.00), (20.1, 0.00), (21.1, 0.00), (22.1, 0.00), (23.1, 0.00), (24.1, 0.00), (25.1, 0.00), (26.1, 0.00), (27.1, 0.00), (28.1, 0.00), (29.1, 0.00), (30.1, 0.00), (31.1, 0.00), (32.1, 0.00), (33.1, 0.00), (34.1, 0.00), (35.1, 0.00), (36.2, 0.00), (37.2, 0.00), (38.2, 0.00), (39.2, 0.00), (40.2, 0.00), (41.2, 0.00), (42.2, 0.00), (43.2, 0.00), (44.2, 0.00), (45.2, 0.00), (46.2, 0.00), (47.2, 0.00), (48.2, 0.00), (49.2, 0.00), (50.2, 0.00), (51.2, 0.00), (52.2, 0.00), (53.2, 0.00), (54.2, 0.00), (55.2, 0.00), (56.2, 0.00), (57.2, 0.00), (58.2, 0.00), (59.2, 0.00), (60.3, 0.00), (61.3, 0.00), (62.3, 0.00), (63.3, 0.00), (64.3, 0.00), (65.3, 0.00), (66.3, 0.00), (67.3, 0.00), (68.3, 0.00), (69.3, 0.00), (70.3, 0.00), (71.3, 0.00), (72.3, 0.00), (73.3, 0.00), (74.3, 0.00), (75.3, 0.00), (76.3, 0.00), (77.3, 0.00), (78.3, 0.00), (79.3, 0.00), (80.3, 0.00), (81.3, 0.00), (82.3, 0.00), (83.3, 0.00), (84.4, 0.00), (85.4, 0.00), (86.4, 0.00), (87.4, 0.00), (88.4, 0.00), (89.4, 0.00), (90.4, 0.00), (91.4, 0.00), (92.4, 0.00), (93.4, 0.00), (94.4, 0.00), (95.4, 0.00), (96.4, 0.00), (97.4, 0.00), (98.4, 0.00), (99.4, 0.00), (100, 0.00), (101, 0.00), (102, 0.00), (103, 0.00), (104, 0.00), (105, 0.00), (106, 0.00), (107, 0.00), (108, 0.00), (109, 0.00), (110, 0.00), (111, 0.00), (112, 0.00), (113, 0.00), (114, 0.00), (115, 0.00), (116, 0.00), (117, 0.00), (118, 0.00), (119, 0.00), (121, 9396), (122, 9487), (123, 9552), (124, 9498), (125, 9525), (126, 9310), (127, 9351), (128, 9420), (129, 9507), (130, 9533), (131, 9697), (132, 10090), (133, 9784), (134, 9898), (135, 9953), (136, 9884), (137, 9918), (138, 9697), (139, 9738), (140, 9807), (141, 9901), (142, 9925), (143, 10096), (144, 10398), (145, 10201), (146, 10322), (147, 10369), (148, 10313), (149, 10335), (150, 10116), (151, 10146), (152, 10225), (153, 10320), (154, 10347), (155, 10528), (156, 10840), (157, 10663), (158, 10794), (159, 10841), (160, 10783), (161, 10809), (162, 10576), (163, 10608), (164, 10689), (165, 10788), (166, 10814), (167, 11010), (168, 11332), (169, 11145), (170, 11255), (171, 11335), (172, 11255), (173, 11295), (174, 11046), (175, 11087), (176, 11165), (177, 11271), (178, 11301), (179, 11502), (180, 11776), (181, 11556), (182, 11701), (183, 11741), (184, 11687), (185, 11709), (186, 11459), (187, 11497), (188, 11579), (189, 11684), (190, 11720), (191, 11926), (192, 12217), (193, 12084), (194, 12237), (195, 12272), (196, 12223), (197, 12242), (198, 11981), (199, 12022), (200, 12105), (201, 12218), (202, 12249), (203, 12469), (204, 12774), (205, 12651), (206, 12775), (207, 12844), (208, 12774), (209, 12854), (210, 12537), (211, 12572), (212, 12639), (213, 12765), (214, 12801), (215, 13060), (216, 13362), (217, 13230), (218, 13690), (219, 13448), (220, 13343), (221, 13313), (222, 13107), (223, 13174), (224, 13167), (225, 13375), (226, 13361), (227, 13626), (228, 13942), (229, 13806), (230, 14054), (231, 14098), (232, 14011), (233, 13962), (234, 13795), (235, 13722), (236, 13821), (237, 14005), (238, 13954), (239, 14320), (240, 14620)

hydro_contribution_to_power_stations_with_DAM = Total_hydro_power_stations_with_DAM_installed_capacity*Gwh_in_a_MW*effect_of__seasonality__on_rainfall*(if(time<=120)then(ENSO)else(ENSO_FORECAST))*0.55

hydro_contribution_to_river_power_station = hydro_contribution_to_LARGE_river_power_station+hydro_contribution_to_MEDIUM_river_power_station+Electricity_generated_from_SHPS

hydro_participation_on_generation = generation_from__large_and_medium__HYDRO_PS/total_electricity__generated

UNITS: Unitless

Hydro_power__station_critical__price_in_COP_per_Kwh = (Electricity__Price-Gas_thermal_power_station_critical_price__in_COP_per_Kwh*gas_participation__on_generation-Coal_thermal_power_station_Critical_price__in_COP_per_Kwh*coal_participation__on_generation-Electricity__Price*SHPS_participation_on_generation)/hydro_participation_on_generation

UNITS: COP/Kw-hour

indicated_price = GRAPH(reserve__margin)

(0.4, 179), (0.438, 140), (0.475, 115), (0.512, 102), (0.55, 85.5), (0.588, 70.0), (0.625, 59.3), (0.663, 58.5), (0.7, 58.5), (0.738, 57.7), (0.775, 56.1), (0.813, 56.1), (0.85, 56.1)

inflation_rate = GRAPH(TIME)

(0.00, 0.008), (1.00, 0.0126), (2.01, 0.0071), (3.01, 0.0092), (4.02, 0.006), (5.02, 0.0043), (6.03, 0.0002), (7.03, 0.0009), (8.03, 0.0036), (9.04, 0.0056), (10.0, 0.0078), (11.0, 0.0027), (12.1, 0.0117), (13.1, 0.0111), (14.1, 0.0105), (15.1, 0.0115), (16.1, 0.0049), (17.1, -0.0005), (18.1, -0.0014), (19.1, 0.0031), (20.1, 0.0022), (21.1, 0.0006), (22.1, 0.0035), (23.1, 0.0061), (24.1, 0.0089), (25.1, 0.012), (26.1, 0.0098), (27.1, 0.0046), (28.1, 0.0038), (29.1, 0.006), (30.1, -0.0003), (31.1, 0.0003), (32.1, 0.003), (33.1, -0.0001), (34.1, 0.0028), (35.1, 0.003), (36.2, 0.0082), (37.2, 0.0102), (38.2, 0.0077), (39.2, 0.0044), (40.2, 0.0041), (41.2, 0.004), (42.2, 0.0005), (43.2, 0.00), (44.2, 0.0043), (45.2, 0.0023), (46.2, 0.0011), (47.2, 0.0007), (48.2, 0.0054), (49.2, 0.0066), (50.2, 0.007), (51.2, 0.0045), (52.2, 0.0033), (53.2, 0.003), (54.2, 0.0041), (55.2, 0.0039), (56.2, 0.0029), (57.2, -0.0014), (58.2, 0.0024), (59.2, 0.0023), (60.3, 0.0077), (61.3, 0.0117), (62.3, 0.0121), (63.3, 0.009), (64.3, 0.003), (65.3, 0.0012), (66.3, 0.0017), (67.3, -0.0013), (68.3, 0.0008), (69.3, 0.0001), (70.3, 0.0047), (71.3, 0.0049), (72.3, 0.0106), (73.3, 0.0151), (74.3, 0.0081), (75.3, 0.0071), (76.3, 0.0093), (77.3, 0.0086), (78.3, 0.0048), (79.3, 0.0019), (80.3, -0.0019), (81.3, 0.0035), (82.3, 0.0028), (83.3, 0.0044), (84.4, 0.0059), (85.4, 0.0084), (86.4, 0.005), (87.4, 0.0032), (88.4, 0.0001), (89.4, -0.0006), (90.4, -0.0004), (91.4, 0.0004), (92.4, -0.0011), (93.4, -0.0013), (94.4, -0.0007), (95.4, 0.0008), (96.4, 0.0069), (97.4, 0.0083), (98.4, 0.0025), (99.4, 0.0046), (100, 0.001), (101, 0.0011), (102, -0.0004), (103, 0.0011), (104, -0.0014), (105, -0.0009), (106, 0.0019), (107, 0.0065), (108, 0.0091), (109, 0.006), (110, 0.0027), (111, 0.0012), (112, 0.0028), (113, 0.0032), (114, 0.0014), (115, -0.0003), (116, 0.0031), (117, 0.0019), (118, 0.0014), (119, 0.0042), (121, 0.0025), (122, 0.00253), (123, 0.0025), (124, 0.0025), (125, 0.0025), (126, 0.0025), (127, 0.0025), (128, 0.0025), (129, 0.0025), (130, 0.0025), (131, 0.0025), (132, 0.0025), (133, 0.0025), (134, 0.0025), (135, 0.0025), (136, 0.0025), (137, 0.0025), (138, 0.0025), (139, 0.0025), (140, 0.0025), (141, 0.0025), (142, 0.0025), (143, 0.0025), (144, 0.0025), (145, 0.0025), (146, 0.0025), (147, 0.0025), (148, 0.0025), (149, 0.0025), (150, 0.0025), (151, 0.0025), (152, 0.0025), (153, 0.0025), (154, 0.0025), (155, 0.0025), (156, 0.0025), (157, 0.0025), (158, 0.0025), (159, 0.0025), (160, 0.0025), (161, 0.0025), (162, 0.0025), (163, 0.0025), (164, 0.0025), (165, 0.0025), (166, 0.0025), (167, 0.0025), (168, 0.0025), (169, 0.0025), (170, 0.0025), (171, 0.0025), (172, 0.0025), (173, 0.0025), (174, 0.0025), (175, 0.0025), (176, 0.0025), (177, 0.0025), (178, 0.0025), (179, 0.0025), (180, 0.0025), (181, 0.0025), (182, 0.0025), (183, 0.0025), (184, 0.0025), (185, 0.0025), (186, 0.0025), (187, 0.0025), (188, 0.0025), (189, 0.0025), (190, 0.0025), (191, 0.0025), (192, 0.0025), (193, 0.0025), (194, 0.0025), (195, 0.0025), (196, 0.0025), (197, 0.0025), (198, 0.0025), (199, 0.0025), (200, 0.0025), (201, 0.0025), (202, 0.0025), (203, 0.0025), (204, 0.0025), (205, 0.0025), (206, 0.0025), (207, 0.0025), (208, 0.0025), (209, 0.0025), (210, 0.0025), (211, 0.0025), (212, 0.0025), (213, 0.0025), (214, 0.0025), (215, 0.0025), (216, 0.0025), (217, 0.0025), (218, 0.0025), (219, 0.0025), (220, 0.0025), (221, 0.0025), (222, 0.0025), (223, 0.0025), (224, 0.0025), (225, 0.0025), (226, 0.0025), (227, 0.0025), (228, 0.0025), (229, 0.0025), (230, 0.0025), (231, 0.0025), (232, 0.0025), (233, 0.0025), (234, 0.0025), (235, 0.0025), (236, 0.0025), (237, 0.0025), (238, 0.0025), (239, 0.0025), (240, 0.0025)

UNITS: Unitless/month

KW_in_a_MW = 1000

UNITS: Kw/MW

KW_in_a_MW_2 = 1000

UNITS: Kw/MW

large_hydro_power_station_with_DAM_installed_HISTORICAL_capacity = GRAPH(time)

(0.00, 6823), (12.0, 7457), (24.0, 7479), (36.0, 7482), (48.0, 7483), (60.0, 7483), (72.0, 7526), (84.0, 7526), (96.0, 7526), (108, 8186), (120, 8186)

large_hydro_power_with_DAM_time_horizon = 108

UNITS: month

LARGE_river_power_station_installed_HISTORICAL_capacity = GRAPH(time)

(0.00, 544), (12.0, 241), (24.0, 0.00), (36.0, 0.00), (48.0, 0.00), (60.0, 0.00), (72.0, 0.00), (84.0, 0.00), (96.0, 0.00), (108, 0.00), (120, 0.00)

LARGE__RIVER_power_station_time_horizon = 72

UNITS: month

list_of_new_LARGE_hydro__power_stations_with_DAM = GRAPH(TIME)

(0.00, 750), (1.01, 0.00), (2.02, 0.00), (3.03, 0.00), (4.03, 0.00), (5.04, 0.00), (6.05, 0.00), (7.06, 0.00), (8.07, 0.00), (9.08, 0.00), (10.1, 0.00), (11.1, 0.00), (12.1, 0.00), (13.1, 0.00), (14.1, 0.00), (15.1, 0.00), (16.1, 0.00), (17.1, 0.00), (18.2, 0.00), (19.2, 0.00), (20.2, 0.00), (21.2, 0.00), (22.2, 0.00), (23.2, 0.00), (24.2, 0.00), (25.2, 0.00), (26.2, 0.00), (27.2, 0.00), (28.2, 0.00), (29.2, 0.00), (30.3, 0.00), (31.3, 0.00), (32.3, 0.00), (33.3, 0.00), (34.3, 0.00), (35.3, 0.00), (36.3, 0.00), (37.3, 0.00), (38.3, 0.00), (39.3, 0.00), (40.3, 0.00), (41.3, 0.00), (42.4, 0.00), (43.4, 0.00), (44.4, 0.00), (45.4, 0.00), (46.4, 0.00), (47.4, 0.00), (48.4, 0.00), (49.4, 0.00), (50.4, 0.00), (51.4, 0.00), (52.4, 0.00), (53.4, 0.00), (54.5, 0.00), (55.5, 0.00), (56.5, 0.00), (57.5, 0.00), (58.5, 0.00), (59.5, 0.00), (60.5, 0.00), (61.5, 0.00), (62.5, 0.00), (63.5, 0.00), (64.5, 0.00), (65.5, 0.00), (66.6, 0.00), (67.6, 0.00), (68.6, 0.00), (69.6, 0.00), (70.6, 0.00), (71.6, 0.00), (72.6, 0.00), (73.6, 0.00), (74.6, 0.00), (75.6, 0.00), (76.6, 0.00), (77.6, 0.00), (78.7, 0.00), (79.7, 0.00), (80.7, 0.00), (81.7, 0.00), (82.7, 0.00), (83.7, 0.00), (84.7, 0.00), (85.7, 0.00), (86.7, 0.00), (87.7, 0.00), (88.7, 0.00), (89.7, 0.00), (90.8, 0.00), (91.8, 0.00), (92.8, 0.00), (93.8, 0.00), (94.8, 0.00), (95.8, 0.00), (96.8, 0.00), (97.8, 0.00), (98.8, 0.00), (99.8, 0.00), (101, 0.00), (102, 0.00), (103, 0.00), (104, 0.00), (105, 0.00), (106, 0.00), (107, 0.00), (108, 0.00), (109, 0.00), (110, 0.00), (111, 0.00), (112, 0.00), (113, 0.00), (114, 0.00), (115, 0.00), (116, 0.00), (117, 0.00), (118, 0.00), (119, 0.00), (120, 0.00)

UNITS: MW

list_of_new_large_river_power_stations = GRAPH(time)

(0.00, 0.00), (12.0, 0.00), (24.0, 0.00), (36.0, 0.00), (48.0, 0.00), (60.0, 0.00), (72.0, 0.00), (84.0, 0.00), (96.0, 0.00), (108, 0.00), (120, 0.00)

list_of_new_MEDIUM_hydro__power_stations_with_DAM = GRAPH(TIME)

(0.00, 0.00), (12.0, 0.00), (24.0, 0.00), (36.0, 0.00), (48.0, 0.00), (60.0, 0.00), (72.0, 0.00), (84.0, 0.00), (96.0, 0.00), (108, 0.00), (120, 0.00)

UNITS: MW

list_of_new_MEDIUM_river_power_stations = GRAPH(time)

(0.00, 0.00), (12.0, 0.00), (24.0, 0.00), (36.0, 0.00), (48.0, 0.00), (60.0, 0.00), (72.0, 0.00), (84.0, 0.00), (96.0, 0.00), (108, 0.00), (120, 0.00)

UNITS: MW

List_of_new__SHPS = GRAPH(TIME)

(0.00, 20.0), (1.00, 0.00), (2.01, 0.00), (3.01, 0.00), (4.02, 0.00), (5.02, 0.00), (6.03, 0.00), (7.03, 0.00), (8.03, 0.00), (9.04, 0.00), (10.0, 0.00), (11.0, 0.00), (12.1, 10.0), (13.1, 0.00), (14.1, 0.00), (15.1, 0.00), (16.1, 0.00), (17.1, 0.00), (18.1, 0.00), (19.1, 0.00), (20.1, 0.00), (21.1, 0.00), (22.1, 0.00), (23.1, 0.00), (24.1, 14.5), (25.1, 0.00), (26.1, 0.00), (27.1, 0.00), (28.1, 0.00), (29.1, 0.00), (30.1, 0.00), (31.1, 0.00), (32.1, 0.00), (33.1, 0.00), (34.1, 0.00), (35.1, 0.00), (36.2, 28.5), (37.2, 0.00), (38.2, 0.00), (39.2, 0.00), (40.2, 0.00), (41.2, 0.00), (42.2, 0.00), (43.2, 0.00), (44.2, 0.00), (45.2, 0.00), (46.2, 0.00), (47.2, 0.00), (48.2, 30.0), (49.2, 0.00), (50.2, 0.00), (51.2, 0.00), (52.2, 0.00), (53.2, 0.00), (54.2, 0.00), (55.2, 0.00), (56.2, 0.00), (57.2, 0.00), (58.2, 0.00), (59.2, 0.00), (60.3, 62.0), (61.3, 0.00), (62.3, 0.00), (63.3, 0.00), (64.3, 0.00), (65.3, 0.00), (66.3, 0.00), (67.3, 0.00), (68.3, 0.00), (69.3, 0.00), (70.3, 0.00), (71.3, 0.00), (72.3, 37.5), (73.3, 0.00), (74.3, 0.00), (75.3, 0.00), (76.3, 0.00), (77.3, 0.00), (78.3, 0.00), (79.3, 0.00), (80.3, 0.00), (81.3, 0.00), (82.3, 0.00), (83.3, 0.00), (84.4, 38.5), (85.4, 0.00), (86.4, 0.00), (87.4, 0.00), (88.4, 0.00), (89.4, 0.00), (90.4, 0.00), (91.4, 0.00), (92.4, 0.00), (93.4, 0.00), (94.4, 0.00), (95.4, 0.00), (96.4, 38.5), (97.4, 0.00), (98.4, 0.00), (99.4, 0.00), (100, 0.00), (101, 0.00), (102, 0.00), (103, 0.00), (104, 0.00), (105, 0.00), (106, 0.00), (107, 0.00), (108, 0.00), (109, 0.00), (110, 0.00), (111, 0.00), (112, 0.00), (113, 0.00), (114, 0.00), (115, 0.00), (116, 0.00), (117, 0.00), (118, 0.00), (119, 0.00), (121, 0.00), (122, 0.00), (123, 0.00), (124, 0.00), (125, 0.00), (126, 0.00), (127, 0.00), (128, 0.00), (129, 0.00), (130, 0.00), (131, 0.00), (132, 0.00), (133, 0.00), (134, 0.00), (135, 0.00), (136, 0.00), (137, 0.00), (138, 0.00), (139, 0.00), (140, 0.00), (141, 0.00), (142, 0.00), (143, 0.00), (144, 0.00), (145, 0.00), (146, 0.00), (147, 0.00), (148, 0.00), (149, 0.00), (150, 0.00), (151, 0.00), (152, 0.00), (153, 0.00), (154, 0.00), (155, 0.00), (156, 0.00), (157, 0.00), (158, 0.00), (159, 0.00), (160, 0.00), (161, 0.00), (162, 0.00), (163, 0.00), (164, 0.00), (165, 0.00), (166, 0.00), (167, 0.00), (168, 0.00), (169, 0.00), (170, 0.00), (171, 0.00), (172, 0.00), (173, 0.00), (174, 0.00), (175, 0.00), (176, 0.00), (177, 0.00), (178, 0.00), (179, 0.00), (180, 0.00), (181, 0.00), (182, 0.00), (183, 0.00), (184, 0.00), (185, 0.00), (186, 0.00), (187, 0.00), (188, 0.00), (189, 0.00), (190, 0.00), (191, 0.00), (192, 0.00), (193, 0.00), (194, 0.00), (195, 0.00), (196, 0.00), (197, 0.00), (198, 0.00), (199, 0.00), (200, 0.00), (201, 0.00), (202, 0.00), (203, 0.00), (204, 0.00), (205, 0.00), (206, 0.00), (207, 0.00), (208, 0.00), (209, 0.00), (210, 0.00), (211, 0.00), (212, 0.00), (213, 0.00), (214, 0.00), (215, 0.00), (216, 0.00), (217, 0.00), (218, 0.00), (219, 0.00), (220, 0.00), (221, 0.00), (222, 0.00), (223, 0.00), (224, 0.00), (225, 0.00), (226, 0.00), (227, 0.00), (228, 0.00), (229, 0.00), (230, 0.00), (231, 0.00), (232, 0.00), (233, 0.00), (234, 0.00), (235, 0.00), (236, 0.00), (237, 0.00), (238, 0.00), (239, 0.00), (240, 0.00)

UNITS: MW

List_of_registered__coal_fired_thermal__power_stations_projects = GRAPH(time)

(0.00, 40.0), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 0.00), (14.0, 0.00), (15.0, 0.00), (16.0, 0.00), (17.0, 0.00), (18.0, 0.00), (19.0, 0.00), (20.0, 0.00), (21.0, 0.00), (22.0, 0.00), (23.0, 0.00), (24.0, 40.0), (25.0, 0.00), (26.0, 0.00), (27.0, 0.00), (28.0, 0.00), (29.0, 0.00), (30.0, 0.00), (31.0, 0.00), (32.0, 0.00), (33.0, 0.00), (34.0, 0.00), (35.0, 0.00), (36.0, 0.00), (37.0, 0.00), (38.0, 0.00), (39.0, 0.00), (40.0, 0.00), (41.0, 0.00), (42.0, 0.00), (43.0, 0.00), (44.0, 0.00), (45.0, 0.00), (46.0, 0.00), (47.0, 0.00), (48.0, 40.0), (49.0, 0.00), (50.0, 0.00), (51.0, 0.00), (52.0, 0.00), (53.0, 0.00), (54.0, 0.00), (55.0, 0.00), (56.0, 0.00), (57.0, 0.00), (58.0, 0.00), (59.0, 0.00), (60.0, 40.0), (61.0, 0.00), (62.0, 0.00), (63.0, 0.00), (64.0, 0.00), (65.0, 0.00), (66.0, 0.00), (67.0, 0.00), (68.0, 0.00), (69.0, 0.00), (70.0, 0.00), (71.0, 0.00), (72.0, 0.00), (73.0, 0.00), (74.0, 0.00), (75.0, 0.00), (76.0, 0.00), (77.0, 0.00), (78.0, 0.00), (79.0, 0.00), (80.0, 0.00), (81.0, 0.00), (82.0, 0.00), (83.0, 0.00), (84.0, 40.0), (85.0, 0.00), (86.0, 0.00), (87.0, 0.00), (88.0, 0.00), (89.0, 0.00), (90.0, 0.00), (91.0, 0.00), (92.0, 0.00), (93.0, 0.00), (94.0, 0.00), (95.0, 0.00), (96.0, 0.00), (97.0, 0.00), (98.0, 0.00), (99.0, 0.00), (100, 0.00), (101, 0.00), (102, 0.00), (103, 0.00), (104, 0.00), (105, 0.00), (106, 0.00), (107, 0.00), (108, 40.0), (109, 0.00), (110, 0.00), (111, 0.00), (112, 0.00), (113, 0.00), (114, 0.00), (115, 0.00), (116, 0.00), (117, 0.00), (118, 0.00), (119, 0.00), (120, 0.00)

UNITS: MW

List_of_registered__gas_fired_thermal__power_stations = GRAPH(time)

(0.00, 0.00), (1.00, 0.00), (2.00, 0.00), (3.00, 0.00), (4.00, 0.00), (5.00, 0.00), (6.00, 0.00), (7.00, 0.00), (8.00, 0.00), (9.00, 0.00), (10.0, 0.00), (11.0, 0.00), (12.0, 0.00), (13.0, 0.00), (14.0, 0.00), (15.0, 0.00), (16.0, 0.00), (17.0, 0.00), (18.0, 0.00), (19.0, 0.00), (20.0, 0.00), (21.0, 0.00), (22.0, 0.00), (23.0, 0.00), (24.0, 50.0), (25.0, 0.00), (26.0, 0.00), (27.0, 0.00), (28.0, 0.00), (29.0, 0.00), (30.0, 0.00), (31.0, 0.00), (32.0, 0.00), (33.0, 0.00), (34.0, 0.00), (35.0, 0.00), (36.0, 200), (37.0, 0.00), (38.0, 0.00), (39.0, 0.00), (40.0, 0.00), (41.0, 0.00), (42.0, 0.00), (43.0, 0.00), (44.0, 0.00), (45.0, 0.00), (46.0, 0.00), (47.0, 0.00), (48.0, 0.00), (49.0, 0.00), (50.0, 0.00), (51.0, 0.00), (52.0, 0.00), (53.0, 0.00), (54.0, 0.00), (55.0, 0.00), (56.0, 0.00), (57.0, 0.00), (58.0, 0.00), (59.0, 0.00), (60.0, 350), (61.0, 0.00), (62.0, 0.00), (63.0, 0.00), (64.0, 0.00), (65.0, 0.00), (66.0, 0.00), (67.0, 0.00), (68.0, 0.00), (69.0, 0.00), (70.0, 0.00), (71.0, 0.00), (72.0, 0.00), (73.0, 0.00), (74.0, 0.00), (75.0, 0.00), (76.0, 0.00), (77.0, 0.00), (78.0, 0.00), (79.0, 0.00), (80.0, 0.00), (81.0, 0.00), (82.0, 0.00), (83.0, 0.00), (84.0, 0.00), (85.0, 0.00), (86.0, 0.00), (87.0, 0.00), (88.0, 0.00), (89.0, 0.00), (90.0, 0.00), (91.0, 0.00), (92.0, 0.00), (93.0, 0.00), (94.0, 0.00), (95.0, 0.00), (96.0, 0.00), (97.0, 0.00), (98.0, 0.00), (99.0, 0.00), (100, 0.00), (101, 0.00), (102, 0.00), (103, 0.00), (104, 0.00), (105, 0.00), (106, 0.00), (107, 0.00), (108, 0.00), (109, 0.00), (110, 0.00), (111, 0.00), (112, 0.00), (113, 0.00), (114, 0.00), (115, 0.00), (116, 0.00), (117, 0.00), (118, 0.00), (119, 0.00), (120, 0.00)

UNITS: MW

Low_Growth_Demand_Scenario_Gwh_month = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.01, 0.00), (3.01, 0.00), (4.02, 0.00), (5.02, 0.00), (6.03, 0.00), (7.03, 0.00), (8.03, 0.00), (9.04, 0.00), (10.0, 0.00), (11.0, 0.00), (12.1, 0.00), (13.1, 0.00), (14.1, 0.00), (15.1, 0.00), (16.1, 0.00), (17.1, 0.00), (18.1, 0.00), (19.1, 0.00), (20.1, 0.00), (21.1, 0.00), (22.1, 0.00), (23.1, 0.00), (24.1, 0.00), (25.1, 0.00), (26.1, 0.00), (27.1, 0.00), (28.1, 0.00), (29.1, 0.00), (30.1, 0.00), (31.1, 0.00), (32.1, 0.00), (33.1, 0.00), (34.1, 0.00), (35.1, 0.00), (36.2, 0.00), (37.2, 0.00), (38.2, 0.00), (39.2, 0.00), (40.2, 0.00), (41.2, 0.00), (42.2, 0.00), (43.2, 0.00), (44.2, 0.00), (45.2, 0.00), (46.2, 0.00), (47.2, 0.00), (48.2, 0.00), (49.2, 0.00), (50.2, 0.00), (51.2, 0.00), (52.2, 0.00), (53.2, 0.00), (54.2, 0.00), (55.2, 0.00), (56.2, 0.00), (57.2, 0.00), (58.2, 0.00), (59.2, 0.00), (60.3, 0.00), (61.3, 0.00), (62.3, 0.00), (63.3, 0.00), (64.3, 0.00), (65.3, 0.00), (66.3, 0.00), (67.3, 0.00), (68.3, 0.00), (69.3, 0.00), (70.3, 0.00), (71.3, 0.00), (72.3, 0.00), (73.3, 0.00), (74.3, 0.00), (75.3, 0.00), (76.3, 0.00), (77.3, 0.00), (78.3, 0.00), (79.3, 0.00), (80.3, 0.00), (81.3, 0.00), (82.3, 0.00), (83.3, 0.00), (84.4, 0.00), (85.4, 0.00), (86.4, 0.00), (87.4, 0.00), (88.4, 0.00), (89.4, 0.00), (90.4, 0.00), (91.4, 0.00), (92.4, 0.00), (93.4, 0.00), (94.4, 0.00), (95.4, 0.00), (96.4, 0.00), (97.4, 0.00), (98.4, 0.00), (99.4, 0.00), (100, 0.00), (101, 0.00), (102, 0.00), (103, 0.00), (104, 0.00), (105, 0.00), (106, 0.00), (107, 0.00), (108, 0.00), (109, 0.00), (110, 0.00), (111, 0.00), (112, 0.00), (113, 0.00), (114, 0.00), (115, 0.00), (116, 0.00), (117, 0.00), (118, 0.00), (119, 0.00), (121, 4749), (122, 4574), (123, 4864), (124, 4707), (125, 4909), (126, 4717), (127, 4853), (128, 4943), (129, 4827), (130, 4948), (131, 4839), (132, 4960), (133, 4831), (134, 4609), (135, 4860), (136, 4883), (137, 5004), (138, 4779), (139, 4956), (140, 5017), (141, 4932), (142, 5072), (143, 4914), (144, 5054), (145, 4932), (146, 4716), (147, 5054), (148, 4909), (149, 5111), (150, 4889), (151, 5123), (152, 5110), (153, 5070), (154, 5194), (155, 5293), (156, 5444), (157, 5109), (158, 4904), (159, 5264), (160, 5110), (161, 5261), (162, 5121), (163, 5331), (164, 5325), (165, 5318), (166, 5413), (167, 5283), (168, 5422), (169, 5249), (170, 5196), (171, 5364), (172, 5344), (173, 5429), (174, 5341), (175, 5438), (176, 5543), (177, 5482), (178, 5558), (179, 5469), (180, 5609), (181, 5464), (182, 5245), (183, 5623), (184, 5426), (185, 5630), (186, 5495), (187, 5621), (188, 5698), (189, 5659), (190, 5750), (191, 5654), (192, 5747), (193, 5624), (194, 5417), (195, 5785), (196, 5605), (197, 5801), (198, 5661), (199, 5800), (200, 5871), (201, 5813), (202, 5943), (203, 5830), (204, 5929), (205, 5794), (206, 5590), (207, 5937), (208, 5797), (209, 6001), (210, 5815), (211, 6000), (212, 6038), (213, 5996), (214, 6118), (215, 5999), (216, 6134), (217, 5987), (218, 5905), (219, 6137), (220, 5992), (221, 6141), (222, 6009), (223, 6217), (224, 6215), (225, 6212), (226, 6308), (227, 6186), (228, 6324), (229, 6171), (230, 5996), (231, 6367), (232, 6205), (233, 6361), (234, 6252), (235, 6397), (236, 6444), (237, 6428), (238, 6505), (239, 6422), (240, 6548)

UNITS: gwh/mo

Low_Growth_Power_Demand_Scenario_MW = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.01, 0.00), (3.01, 0.00), (4.02, 0.00), (5.02, 0.00), (6.03, 0.00), (7.03, 0.00), (8.03, 0.00), (9.04, 0.00), (10.0, 0.00), (11.0, 0.00), (12.1, 0.00), (13.1, 0.00), (14.1, 0.00), (15.1, 0.00), (16.1, 0.00), (17.1, 0.00), (18.1, 0.00), (19.1, 0.00), (20.1, 0.00), (21.1, 0.00), (22.1, 0.00), (23.1, 0.00), (24.1, 0.00), (25.1, 0.00), (26.1, 0.00), (27.1, 0.00), (28.1, 0.00), (29.1, 0.00), (30.1, 0.00), (31.1, 0.00), (32.1, 0.00), (33.1, 0.00), (34.1, 0.00), (35.1, 0.00), (36.2, 0.00), (37.2, 0.00), (38.2, 0.00), (39.2, 0.00), (40.2, 0.00), (41.2, 0.00), (42.2, 0.00), (43.2, 0.00), (44.2, 0.00), (45.2, 0.00), (46.2, 0.00), (47.2, 0.00), (48.2, 0.00), (49.2, 0.00), (50.2, 0.00), (51.2, 0.00), (52.2, 0.00), (53.2, 0.00), (54.2, 0.00), (55.2, 0.00), (56.2, 0.00), (57.2, 0.00), (58.2, 0.00), (59.2, 0.00), (60.3, 0.00), (61.3, 0.00), (62.3, 0.00), (63.3, 0.00), (64.3, 0.00), (65.3, 0.00), (66.3, 0.00), (67.3, 0.00), (68.3, 0.00), (69.3, 0.00), (70.3, 0.00), (71.3, 0.00), (72.3, 0.00), (73.3, 0.00), (74.3, 0.00), (75.3, 0.00), (76.3, 0.00), (77.3, 0.00), (78.3, 0.00), (79.3, 0.00), (80.3, 0.00), (81.3, 0.00), (82.3, 0.00), (83.3, 0.00), (84.4, 0.00), (85.4, 0.00), (86.4, 0.00), (87.4, 0.00), (88.4, 0.00), (89.4, 0.00), (90.4, 0.00), (91.4, 0.00), (92.4, 0.00), (93.4, 0.00), (94.4, 0.00), (95.4, 0.00), (96.4, 0.00), (97.4, 0.00), (98.4, 0.00), (99.4, 0.00), (100, 0.00), (101, 0.00), (102, 0.00), (103, 0.00), (104, 0.00), (105, 0.00), (106, 0.00), (107, 0.00), (108, 0.00), (109, 0.00), (110, 0.00), (111, 0.00), (112, 0.00), (113, 0.00), (114, 0.00), (115, 0.00), (116, 0.00), (117, 0.00), (118, 0.00), (119, 0.00), (121, 8786), (122, 8847), (123, 8913), (124, 8854), (125, 8875), (126, 8660), (127, 8693), (128, 8754), (129, 8826), (130, 8851), (131, 8995), (132, 9474), (133, 9057), (134, 9137), (135, 9194), (136, 9121), (137, 9148), (138, 8930), (139, 8961), (140, 9021), (141, 9100), (142, 9123), (143, 9271), (144, 9541), (145, 9272), (146, 9355), (147, 9404), (148, 9344), (149, 9360), (150, 9147), (151, 9167), (152, 9235), (153, 9313), (154, 9337), (155, 9493), (156, 9767), (157, 9522), (158, 9612), (159, 9660), (160, 9599), (161, 9617), (162, 9395), (163, 9417), (164, 9486), (165, 9565), (166, 9589), (167, 9753), (168, 10031), (169, 9808), (170, 9877), (171, 9953), (172, 9873), (173, 9904), (174, 9670), (175, 9699), (176, 9763), (177, 9847), (178, 9874), (179, 10041), (180, 10272), (181, 10017), (182, 10114), (183, 10155), (184, 10098), (185, 10113), (186, 9881), (187, 9906), (188, 9974), (189, 10055), (190, 10086), (191, 10255), (192, 10497), (193, 10302), (194, 10403), (195, 10440), (196, 10387), (197, 10399), (198, 10161), (199, 10188), (200, 10255), (201, 10342), (202, 10368), (203, 10545), (204, 10795), (205, 10636), (206, 10710), (207, 10774), (208, 10705), (209, 10767), (210, 10484), (211, 10507), (212, 10558), (213, 10654), (214, 10685), (215, 10891), (216, 11135), (217, 10947), (218, 11297), (219, 11103), (220, 11005), (221, 10976), (222, 10789), (223, 10836), (224, 10827), (225, 10988), (226, 10977), (227, 11185), (228, 11435), (229, 11242), (230, 11411), (231, 11454), (232, 11372), (233, 11327), (234, 11174), (235, 11107), (236, 11183), (237, 11321), (238, 11281), (239, 11567), (240, 11800)

max_available_electricity__from_dam = max(0,dam_level-target_level__of_dam_in_Ghw)

UNITS: Gwh

max_critical_price = 150

UNITS: COP/Kw-hour

max_generation_from_coal_power_stations_according_to_history = total_electricty_demand_in_Gwh_month*effect_of_hydro_generation_on_coal_plants_participation*.1

UNITS: gwh/mo

Max_generation__according_to_the__installed_capacity = Total_hydro_power_stations_with_DAM_installed_capacity*Gwh_in_a_MW

UNITS: Gwh

max_generation__from_gas_power_stations__according_to_history = total_electricty_demand_in_Gwh_month*(Effect_of_hydro__generation_on__gas_generation)*(change_on_relative_fraction_gas_hydro)

UNITS: gwh/mo

max_offer_of__electricity_from_gas__fired_thermal_power_stations = gas_fired__thermal_power_station__installed_capacity*Gwh_in_a_MW*(1-unavailability_factor_for_gas_fired_thermal_power_stations)

UNITS: gwh/mo

max_offer__of_electricity_from_coal__fired_thermal_power_stations = coal_fired__thermal_power_stations__installed_capacity*Gwh_in_a_MW*(1-unavailability_factor_for_coal__fired_thermal_power_stations)

UNITS: gwh/mo

Max_power__demand_per_month = if(time<121)THEN(Max_power_demand_per_month_MW_historical)else(Max_power__demand_scenario)

Max_power__demand_scenario = if(Scenario_Dda=1)THEN(Low_Growth_Power_Demand_Scenario_MW)else(if(Scenario_Dda=2)THEN(Medium_Growth_Power_Demand_Scenario_MW)ELSE(High_Growth_Power_Demand_Scenario_MW))

MEDIUM_hydro_power_with_DAM_time_horizon = 84

UNITS: month

MEDIUM_river_power_station_installed_HISTORICAL_capacity = GRAPH(time)

(0.00, 165), (12.0, 165), (24.0, 165), (36.0, 165), (48.0, 165), (60.0, 165), (72.0, 165), (84.0, 165), (96.0, 165), (108, 165), (120, 165)

MEDIUM_RIVER_power_station_time_horizon = 72

UNITS: month

minim_critical = 96

UNITS: COP/Kw-hour

month = COUNTER(0,12)

UNITS: Unitless

net_installed__capacity = MEDIUM_hydro_power__station_with_DAM_installed_capacity+LARGE_river__power_station__installed_capacity+MEDIUM_river__power_station_installed_capacity+SHPS__installed_capacity+gas_fired__thermal_power_station__installed_capacity+coal_fired__thermal_power_stations__installed_capacity+large_hydro_power__station_with_DAM_installed_capacity

UNITS: MW

offices = 0

UNITS: US Dollars (USD)

others = GRAPH(time)

(0.00, 13.0), (12.0, 13.0), (24.0, 19.0), (36.0, 42.0), (48.0, 30.0), (60.0, 44.0), (72.0, 44.0), (84.0, 44.0), (96.0, 73.8), (108, 73.8), (120, 73.8)

Policiy_activation = 1

UNITS: Unitless

Policy_start_time = 120

UNITS: Unitless

Policy_switch_for_early_investors = (if(time>=Policy_start_time)then(1)ELSE(0))*Policiy_activation

UNITS: Unitless

Power_stations_with_DAM_planning__and_approval_time = 24

UNITS: month

price_increase_per_segment_of_normal_distribution = (max_critical_price-minim_critical)/20

UNITS: COP/Kw-hour

pumping = 3104774.11

UNITS: US Dollars (USD)

rate_of_return = 0.12

UNITS: Unitless/year

Registered_coal_thermal_projects_stage_1_for_supply_forecast = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.01, 0.00), (3.01, 0.00), (4.02, 0.00), (5.02, 0.00), (6.03, 0.00), (7.03, 0.00), (8.03, 0.00), (9.04, 0.00), (10.0, 0.00), (11.0, 0.00), (12.1, 0.00), (13.1, 0.00), (14.1, 0.00), (15.1, 0.00), (16.1, 0.00), (17.1, 0.00), (18.1, 0.00), (19.1, 0.00), (20.1, 0.00), (21.1, 0.00), (22.1, 0.00), (23.1, 0.00), (24.1, 0.00), (25.1, 0.00), (26.1, 0.00), (27.1, 0.00), (28.1, 0.00), (29.1, 0.00), (30.1, 0.00), (31.1, 0.00), (32.1, 0.00), (33.1, 0.00), (34.1, 0.00), (35.1, 0.00), (36.2, 0.00), (37.2, 0.00), (38.2, 0.00), (39.2, 0.00), (40.2, 0.00), (41.2, 0.00), (42.2, 0.00), (43.2, 0.00), (44.2, 0.00), (45.2, 0.00), (46.2, 0.00), (47.2, 0.00), (48.2, 0.00), (49.2, 0.00), (50.2, 0.00), (51.2, 0.00), (52.2, 0.00), (53.2, 0.00), (54.2, 0.00), (55.2, 0.00), (56.2, 0.00), (57.2, 0.00), (58.2, 0.00), (59.2, 0.00), (60.3, 0.00), (61.3, 0.00), (62.3, 0.00), (63.3, 0.00), (64.3, 0.00), (65.3, 0.00), (66.3, 0.00), (67.3, 0.00), (68.3, 0.00), (69.3, 0.00), (70.3, 0.00), (71.3, 0.00), (72.3, 0.00), (73.3, 0.00), (74.3, 0.00), (75.3, 0.00), (76.3, 0.00), (77.3, 0.00), (78.3, 0.00), (79.3, 0.00), (80.3, 0.00), (81.3, 0.00), (82.3, 0.00), (83.3, 0.00), (84.4, 0.00), (85.4, 0.00), (86.4, 0.00), (87.4, 0.00), (88.4, 0.00), (89.4, 0.00), (90.4, 0.00), (91.4, 0.00), (92.4, 0.00), (93.4, 0.00), (94.4, 0.00), (95.4, 0.00), (96.4, 0.00), (97.4, 0.00), (98.4, 0.00), (99.4, 0.00), (100, 0.00), (101, 0.00), (102, 0.00), (103, 0.00), (104, 0.00), (105, 0.00), (106, 0.00), (107, 0.00), (108, 0.00), (109, 0.00), (110, 0.00), (111, 0.00), (112, 0.00), (113, 0.00), (114, 0.00), (115, 0.00), (116, 0.00), (117, 0.00), (118, 0.00), (119, 0.00), (121, 0.00), (122, 0.00), (123, 0.00), (124, 0.00), (125, 0.00), (126, 0.00), (127, 200), (128, 99.0), (129, 0.00), (130, 0.00), (131, 0.00), (132, 0.00), (133, 0.00), (134, 0.00), (135, 0.00), (136, 0.00), (137, 0.00), (138, 0.00), (139, 0.00), (140, 0.00), (141, 0.00), (142, 0.00), (143, 0.00), (144, 0.00), (145, 0.00), (146, 0.00), (147, 0.00), (148, 0.00), (149, 0.00), (150, 0.00), (151, 0.00), (152, 0.00), (153, 0.00), (154, 0.00), (155, 0.00), (156, 0.00), (157, 0.00), (158, 0.00), (159, 0.00), (160, 0.00), (161, 0.00), (162, 0.00), (163, 0.00), (164, 0.00), (165, 0.00), (166, 0.00), (167, 0.00), (168, 0.00), (169, 0.00), (170, 0.00), (171, 0.00), (172, 0.00), (173, 0.00), (174, 0.00), (175, 0.00), (176, 0.00), (177, 0.00), (178, 0.00), (179, 0.00), (180, 0.00), (181, 0.00), (182, 0.00), (183, 0.00), (184, 0.00), (185, 0.00), (186, 0.00), (187, 0.00), (188, 0.00), (189, 0.00), (190, 0.00), (191, 0.00), (192, 0.00), (193, 0.00), (194, 0.00), (195, 0.00), (196, 0.00), (197, 0.00), (198, 0.00), (199, 0.00), (200, 0.00), (201, 0.00), (202, 0.00), (203, 0.00), (204, 0.00), (205, 0.00), (206, 0.00), (207, 0.00), (208, 0.00), (209, 0.00), (210, 0.00), (211, 0.00), (212, 0.00), (213, 0.00), (214, 0.00), (215, 0.00), (216, 0.00), (217, 0.00), (218, 0.00), (219, 0.00), (220, 0.00), (221, 0.00), (222, 0.00), (223, 0.00), (224, 0.00), (225, 0.00), (226, 0.00), (227, 0.00), (228, 0.00), (229, 0.00), (230, 0.00), (231, 0.00), (232, 0.00), (233, 0.00), (234, 0.00), (235, 0.00), (236, 0.00), (237, 0.00), (238, 0.00), (239, 0.00), (240, 0.00)

UNITS: MW

Registered_gas_thermal_projects_stage_2_for_supply_forecast = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.01, 0.00), (3.01, 0.00), (4.02, 0.00), (5.02, 0.00), (6.03, 0.00), (7.03, 0.00), (8.03, 0.00), (9.04, 0.00), (10.0, 0.00), (11.0, 0.00), (12.1, 0.00), (13.1, 0.00), (14.1, 0.00), (15.1, 0.00), (16.1, 0.00), (17.1, 0.00), (18.1, 0.00), (19.1, 0.00), (20.1, 0.00), (21.1, 0.00), (22.1, 0.00), (23.1, 0.00), (24.1, 0.00), (25.1, 0.00), (26.1, 0.00), (27.1, 0.00), (28.1, 0.00), (29.1, 0.00), (30.1, 0.00), (31.1, 0.00), (32.1, 0.00), (33.1, 0.00), (34.1, 0.00), (35.1, 0.00), (36.2, 0.00), (37.2, 0.00), (38.2, 0.00), (39.2, 0.00), (40.2, 0.00), (41.2, 0.00), (42.2, 0.00), (43.2, 0.00), (44.2, 0.00), (45.2, 0.00), (46.2, 0.00), (47.2, 0.00), (48.2, 0.00), (49.2, 0.00), (50.2, 0.00), (51.2, 0.00), (52.2, 0.00), (53.2, 0.00), (54.2, 0.00), (55.2, 0.00), (56.2, 0.00), (57.2, 0.00), (58.2, 0.00), (59.2, 0.00), (60.3, 0.00), (61.3, 0.00), (62.3, 0.00), (63.3, 0.00), (64.3, 0.00), (65.3, 0.00), (66.3, 0.00), (67.3, 0.00), (68.3, 0.00), (69.3, 0.00), (70.3, 0.00), (71.3, 0.00), (72.3, 0.00), (73.3, 0.00), (74.3, 0.00), (75.3, 0.00), (76.3, 0.00), (77.3, 0.00), (78.3, 0.00), (79.3, 0.00), (80.3, 0.00), (81.3, 0.00), (82.3, 0.00), (83.3, 0.00), (84.4, 0.00), (85.4, 0.00), (86.4, 0.00), (87.4, 0.00), (88.4, 0.00), (89.4, 0.00), (90.4, 0.00), (91.4, 0.00), (92.4, 0.00), (93.4, 0.00), (94.4, 0.00), (95.4, 0.00), (96.4, 0.00), (97.4, 0.00), (98.4, 0.00), (99.4, 0.00), (100, 0.00), (101, 0.00), (102, 0.00), (103, 0.00), (104, 0.00), (105, 0.00), (106, 0.00), (107, 0.00), (108, 0.00), (109, 0.00), (110, 0.00), (111, 0.00), (112, 0.00), (113, 0.00), (114, 0.00), (115, 0.00), (116, 0.00), (117, 0.00), (118, 0.00), (119, 0.00), (121, 0.00), (122, 0.00), (123, 0.00), (124, 34.5), (125, 0.00), (126, 0.00), (127, 0.00), (128, 0.00), (129, 0.00), (130, 0.00), (131, 0.00), (132, 0.00), (133, 0.00), (134, 0.00), (135, 0.00), (136, 0.00), (137, 0.00), (138, 0.00), (139, 0.00), (140, 0.00), (141, 0.00), (142, 0.00), (143, 0.00), (144, 0.00), (145, 0.00), (146, 0.00), (147, 0.00), (148, 0.00), (149, 0.00), (150, 0.00), (151, 0.00), (152, 0.00), (153, 0.00), (154, 0.00), (155, 0.00), (156, 0.00), (157, 0.00), (158, 0.00), (159, 0.00), (160, 0.00), (161, 0.00), (162, 0.00), (163, 0.00), (164, 0.00), (165, 0.00), (166, 0.00), (167, 0.00), (168, 0.00), (169, 0.00), (170, 0.00), (171, 0.00), (172, 0.00), (173, 0.00), (174, 0.00), (175, 0.00), (176, 0.00), (177, 0.00), (178, 0.00), (179, 0.00), (180, 0.00), (181, 0.00), (182, 0.00), (183, 0.00), (184, 0.00), (185, 0.00), (186, 0.00), (187, 0.00), (188, 0.00), (189, 0.00), (190, 0.00), (191, 0.00), (192, 0.00), (193, 0.00), (194, 0.00), (195, 0.00), (196, 0.00), (197, 0.00), (198, 0.00), (199, 0.00), (200, 0.00), (201, 0.00), (202, 0.00), (203, 0.00), (204, 0.00), (205, 0.00), (206, 0.00), (207, 0.00), (208, 0.00), (209, 0.00), (210, 0.00), (211, 0.00), (212, 0.00), (213, 0.00), (214, 0.00), (215, 0.00), (216, 0.00), (217, 0.00), (218, 0.00), (219, 0.00), (220, 0.00), (221, 0.00), (222, 0.00), (223, 0.00), (224, 0.00), (225, 0.00), (226, 0.00), (227, 0.00), (228, 0.00), (229, 0.00), (230, 0.00), (231, 0.00), (232, 0.00), (233, 0.00), (234, 0.00), (235, 0.00), (236, 0.00), (237, 0.00), (238, 0.00), (239, 0.00), (240, 0.00)

Registered_large_HPS_Stage_1_projects_for_supply_forecast = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.01, 0.00), (3.01, 0.00), (4.02, 0.00), (5.02, 0.00), (6.03, 0.00), (7.03, 0.00), (8.03, 0.00), (9.04, 0.00), (10.0, 0.00), (11.0, 0.00), (12.1, 0.00), (13.1, 0.00), (14.1, 0.00), (15.1, 0.00), (16.1, 0.00), (17.1, 0.00), (18.1, 0.00), (19.1, 0.00), (20.1, 0.00), (21.1, 0.00), (22.1, 0.00), (23.1, 0.00), (24.1, 0.00), (25.1, 0.00), (26.1, 0.00), (27.1, 0.00), (28.1, 0.00), (29.1, 0.00), (30.1, 0.00), (31.1, 0.00), (32.1, 0.00), (33.1, 0.00), (34.1, 0.00), (35.1, 0.00), (36.2, 0.00), (37.2, 0.00), (38.2, 0.00), (39.2, 0.00), (40.2, 0.00), (41.2, 0.00), (42.2, 0.00), (43.2, 0.00), (44.2, 0.00), (45.2, 0.00), (46.2, 0.00), (47.2, 0.00), (48.2, 0.00), (49.2, 0.00), (50.2, 0.00), (51.2, 0.00), (52.2, 0.00), (53.2, 0.00), (54.2, 0.00), (55.2, 0.00), (56.2, 0.00), (57.2, 0.00), (58.2, 0.00), (59.2, 0.00), (60.3, 0.00), (61.3, 0.00), (62.3, 0.00), (63.3, 0.00), (64.3, 0.00), (65.3, 0.00), (66.3, 0.00), (67.3, 0.00), (68.3, 0.00), (69.3, 0.00), (70.3, 0.00), (71.3, 0.00), (72.3, 0.00), (73.3, 0.00), (74.3, 0.00), (75.3, 0.00), (76.3, 0.00), (77.3, 0.00), (78.3, 0.00), (79.3, 0.00), (80.3, 0.00), (81.3, 0.00), (82.3, 0.00), (83.3, 0.00), (84.4, 0.00), (85.4, 0.00), (86.4, 0.00), (87.4, 0.00), (88.4, 0.00), (89.4, 0.00), (90.4, 0.00), (91.4, 0.00), (92.4, 0.00), (93.4, 0.00), (94.4, 0.00), (95.4, 0.00), (96.4, 0.00), (97.4, 0.00), (98.4, 0.00), (99.4, 0.00), (100, 0.00), (101, 0.00), (102, 0.00), (103, 0.00), (104, 0.00), (105, 0.00), (106, 0.00), (107, 0.00), (108, 0.00), (109, 0.00), (110, 0.00), (111, 0.00), (112, 0.00), (113, 0.00), (114, 0.00), (115, 0.00), (116, 0.00), (117, 0.00), (118, 738), (119, 0.00), (121, 0.00), (122, 0.00), (123, 0.00), (124, 0.00), (125, 0.00), (126, 0.00), (127, 0.00), (128, 0.00), (129, 0.00), (130, 0.00), (131, 0.00), (132, 0.00), (133, 0.00), (134, 0.00), (135, 0.00), (136, 0.00), (137, 0.00), (138, 0.00), (139, 0.00), (140, 0.00), (141, 0.00), (142, 0.00), (143, 0.00), (144, 0.00), (145, 0.00), (146, 0.00), (147, 0.00), (148, 0.00), (149, 0.00), (150, 0.00), (151, 0.00), (152, 0.00), (153, 0.00), (154, 0.00), (155, 0.00), (156, 0.00), (157, 0.00), (158, 0.00), (159, 0.00), (160, 0.00), (161, 0.00), (162, 0.00), (163, 0.00), (164, 0.00), (165, 0.00), (166, 0.00), (167, 0.00), (168, 0.00), (169, 0.00), (170, 0.00), (171, 0.00), (172, 0.00), (173, 0.00), (174, 0.00), (175, 0.00), (176, 0.00), (177, 0.00), (178, 0.00), (179, 0.00), (180, 0.00), (181, 0.00), (182, 0.00), (183, 0.00), (184, 0.00), (185, 0.00), (186, 0.00), (187, 0.00), (188, 0.00), (189, 0.00), (190, 0.00), (191, 0.00), (192, 0.00), (193, 0.00), (194, 0.00), (195, 0.00), (196, 0.00), (197, 0.00), (198, 0.00), (199, 0.00), (200, 0.00), (201, 0.00), (202, 0.00), (203, 0.00), (204, 0.00), (205, 0.00), (206, 0.00), (207, 0.00), (208, 0.00), (209, 0.00), (210, 0.00), (211, 0.00), (212, 0.00), (213, 0.00), (214, 0.00), (215, 0.00), (216, 0.00), (217, 0.00), (218, 0.00), (219, 0.00), (220, 0.00), (221, 0.00), (222, 0.00), (223, 0.00), (224, 0.00), (225, 0.00), (226, 0.00), (227, 0.00), (228, 0.00), (229, 0.00), (230, 0.00), (231, 0.00), (232, 0.00), (233, 0.00), (234, 0.00), (235, 0.00), (236, 0.00), (237, 0.00), (238, 0.00), (239, 0.00), (240, 0.00)

UNITS: MW

Registered_medium_HPS_Stage_1_projects_for_supply_forecast = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.01, 0.00), (3.01, 0.00), (4.02, 0.00), (5.02, 0.00), (6.03, 0.00), (7.03, 0.00), (8.03, 0.00), (9.04, 0.00), (10.0, 0.00), (11.0, 0.00), (12.1, 0.00), (13.1, 0.00), (14.1, 0.00), (15.1, 0.00), (16.1, 0.00), (17.1, 0.00), (18.1, 0.00), (19.1, 0.00), (20.1, 0.00), (21.1, 0.00), (22.1, 0.00), (23.1, 0.00), (24.1, 0.00), (25.1, 0.00), (26.1, 0.00), (27.1, 0.00), (28.1, 0.00), (29.1, 0.00), (30.1, 0.00), (31.1, 0.00), (32.1, 0.00), (33.1, 0.00), (34.1, 0.00), (35.1, 0.00), (36.2, 0.00), (37.2, 0.00), (38.2, 0.00), (39.2, 0.00), (40.2, 0.00), (41.2, 0.00), (42.2, 0.00), (43.2, 0.00), (44.2, 0.00), (45.2, 0.00), (46.2, 0.00), (47.2, 0.00), (48.2, 0.00), (49.2, 0.00), (50.2, 0.00), (51.2, 0.00), (52.2, 0.00), (53.2, 0.00), (54.2, 0.00), (55.2, 0.00), (56.2, 0.00), (57.2, 0.00), (58.2, 0.00), (59.2, 0.00), (60.3, 0.00), (61.3, 0.00), (62.3, 0.00), (63.3, 0.00), (64.3, 0.00), (65.3, 0.00), (66.3, 0.00), (67.3, 0.00), (68.3, 0.00), (69.3, 0.00), (70.3, 0.00), (71.3, 0.00), (72.3, 0.00), (73.3, 0.00), (74.3, 0.00), (75.3, 0.00), (76.3, 0.00), (77.3, 0.00), (78.3, 0.00), (79.3, 0.00), (80.3, 0.00), (81.3, 0.00), (82.3, 0.00), (83.3, 0.00), (84.4, 0.00), (85.4, 0.00), (86.4, 0.00), (87.4, 0.00), (88.4, 0.00), (89.4, 0.00), (90.4, 0.00), (91.4, 0.00), (92.4, 0.00), (93.4, 0.00), (94.4, 0.00), (95.4, 0.00), (96.4, 0.00), (97.4, 0.00), (98.4, 0.00), (99.4, 0.00), (100, 0.00), (101, 0.00), (102, 0.00), (103, 0.00), (104, 0.00), (105, 0.00), (106, 0.00), (107, 0.00), (108, 0.00), (109, 0.00), (110, 0.00), (111, 234), (112, 0.00), (113, 0.00), (114, 189), (115, 661), (116, 0.00), (117, 0.00), (118, 0.00), (119, 0.00), (121, 0.00), (122, 0.00), (123, 550), (124, 0.00), (125, 122), (126, 0.00), (127, 52.5), (128, 11.3), (129, 0.00), (130, 0.00), (131, 0.00), (132, 0.00), (133, 0.00), (134, 0.00), (135, 0.00), (136, 0.00), (137, 0.00), (138, 0.00), (139, 0.00), (140, 0.00), (141, 0.00), (142, 0.00), (143, 0.00), (144, 0.00), (145, 0.00), (146, 0.00), (147, 0.00), (148, 0.00), (149, 0.00), (150, 0.00), (151, 0.00), (152, 0.00), (153, 0.00), (154, 0.00), (155, 0.00), (156, 0.00), (157, 0.00), (158, 0.00), (159, 0.00), (160, 0.00), (161, 0.00), (162, 0.00), (163, 0.00), (164, 0.00), (165, 0.00), (166, 0.00), (167, 0.00), (168, 0.00), (169, 0.00), (170, 0.00), (171, 0.00), (172, 0.00), (173, 0.00), (174, 0.00), (175, 0.00), (176, 0.00), (177, 0.00), (178, 0.00), (179, 0.00), (180, 0.00), (181, 0.00), (182, 0.00), (183, 0.00), (184, 0.00), (185, 0.00), (186, 0.00), (187, 0.00), (188, 0.00), (189, 0.00), (190, 0.00), (191, 0.00), (192, 0.00), (193, 0.00), (194, 0.00), (195, 0.00), (196, 0.00), (197, 0.00), (198, 0.00), (199, 0.00), (200, 0.00), (201, 0.00), (202, 0.00), (203, 0.00), (204, 0.00), (205, 0.00), (206, 0.00), (207, 0.00), (208, 0.00), (209, 0.00), (210, 0.00), (211, 0.00), (212, 0.00), (213, 0.00), (214, 0.00), (215, 0.00), (216, 0.00), (217, 0.00), (218, 0.00), (219, 0.00), (220, 0.00), (221, 0.00), (222, 0.00), (223, 0.00), (224, 0.00), (225, 0.00), (226, 0.00), (227, 0.00), (228, 0.00), (229, 0.00), (230, 0.00), (231, 0.00), (232, 0.00), (233, 0.00), (234, 0.00), (235, 0.00), (236, 0.00), (237, 0.00), (238, 0.00), (239, 0.00), (240, 0.00)

UNITS: MW

Registered_SHPS_Stage_1_projects_for_supply_forecast = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.01, 0.00), (3.01, 0.00), (4.02, 0.00), (5.02, 0.00), (6.03, 0.00), (7.03, 0.00), (8.03, 0.00), (9.04, 0.00), (10.0, 0.00), (11.0, 0.00), (12.1, 0.00), (13.1, 0.00), (14.1, 0.00), (15.1, 0.00), (16.1, 0.00), (17.1, 0.00), (18.1, 0.00), (19.1, 0.00), (20.1, 0.00), (21.1, 0.00), (22.1, 0.00), (23.1, 0.00), (24.1, 0.00), (25.1, 0.00), (26.1, 0.00), (27.1, 0.00), (28.1, 0.00), (29.1, 0.00), (30.1, 0.00), (31.1, 0.00), (32.1, 0.00), (33.1, 0.00), (34.1, 0.00), (35.1, 0.00), (36.2, 0.00), (37.2, 0.00), (38.2, 0.00), (39.2, 0.00), (40.2, 0.00), (41.2, 0.00), (42.2, 0.00), (43.2, 0.00), (44.2, 0.00), (45.2, 0.00), (46.2, 0.00), (47.2, 0.00), (48.2, 0.00), (49.2, 0.00), (50.2, 0.00), (51.2, 0.00), (52.2, 0.00), (53.2, 0.00), (54.2, 0.00), (55.2, 0.00), (56.2, 0.00), (57.2, 0.00), (58.2, 0.00), (59.2, 0.00), (60.3, 0.00), (61.3, 0.00), (62.3, 0.00), (63.3, 0.00), (64.3, 0.00), (65.3, 0.00), (66.3, 0.00), (67.3, 0.00), (68.3, 0.00), (69.3, 0.00), (70.3, 0.00), (71.3, 0.00), (72.3, 0.00), (73.3, 0.00), (74.3, 0.00), (75.3, 0.00), (76.3, 0.00), (77.3, 0.00), (78.3, 0.00), (79.3, 0.00), (80.3, 0.00), (81.3, 0.00), (82.3, 0.00), (83.3, 0.00), (84.4, 0.00), (85.4, 0.00), (86.4, 0.00), (87.4, 0.00), (88.4, 0.00), (89.4, 0.00), (90.4, 0.00), (91.4, 0.00), (92.4, 0.00), (93.4, 0.00), (94.4, 0.00), (95.4, 0.00), (96.4, 0.00), (97.4, 0.00), (98.4, 0.00), (99.4, 0.00), (100, 0.00), (101, 0.00), (102, 0.00), (103, 0.00), (104, 0.00), (105, 0.00), (106, 0.00), (107, 0.00), (108, 0.00), (109, 0.00), (110, 0.00), (111, 56.9), (112, 0.00), (113, 0.00), (114, 93.4), (115, 56.5), (116, 0.00), (117, 9.90), (118, 0.00), (119, 6.00), (121, 29.6), (122, 133), (123, 169), (124, 4.40), (125, 95.1), (126, 39.3), (127, 0.00), (128, 15.9), (129, 52.4), (130, 45.1), (131, 27.5), (132, 60.0), (133, 0.00), (134, 4.81), (135, 12.9), (136, 0.00), (137, 0.00), (138, 0.00), (139, 0.00), (140, 0.00), (141, 0.00), (142, 0.00), (143, 0.00), (144, 0.00), (145, 0.00), (146, 0.00), (147, 0.00), (148, 0.00), (149, 0.00), (150, 0.00), (151, 0.00), (152, 0.00), (153, 0.00), (154, 0.00), (155, 0.00), (156, 0.00), (157, 0.00), (158, 0.00), (159, 0.00), (160, 0.00), (161, 0.00), (162, 0.00), (163, 0.00), (164, 0.00), (165, 0.00), (166, 0.00), (167, 0.00), (168, 0.00), (169, 0.00), (170, 0.00), (171, 0.00), (172, 0.00), (173, 0.00), (174, 0.00), (175, 0.00), (176, 0.00), (177, 0.00), (178, 0.00), (179, 0.00), (180, 0.00), (181, 0.00), (182, 0.00), (183, 0.00), (184, 0.00), (185, 0.00), (186, 0.00), (187, 0.00), (188, 0.00), (189, 0.00), (190, 0.00), (191, 0.00), (192, 0.00), (193, 0.00), (194, 0.00), (195, 0.00), (196, 0.00), (197, 0.00), (198, 0.00), (199, 0.00), (200, 0.00), (201, 0.00), (202, 0.00), (203, 0.00), (204, 0.00), (205, 0.00), (206, 0.00), (207, 0.00), (208, 0.00), (209, 0.00), (210, 0.00), (211, 0.00), (212, 0.00), (213, 0.00), (214, 0.00), (215, 0.00), (216, 0.00), (217, 0.00), (218, 0.00), (219, 0.00), (220, 0.00), (221, 0.00), (222, 0.00), (223, 0.00), (224, 0.00), (225, 0.00), (226, 0.00), (227, 0.00), (228, 0.00), (229, 0.00), (230, 0.00), (231, 0.00), (232, 0.00), (233, 0.00), (234, 0.00), (235, 0.00), (236, 0.00), (237, 0.00), (238, 0.00), (239, 0.00), (240, 0.00)

UNITS: MW

Registered_SHPS_Stage_2_projects_for_supply_forecast = GRAPH(TIME)

(0.00, 0.00), (1.00, 0.00), (2.01, 0.00), (3.01, 0.00), (4.02, 0.00), (5.02, 0.00), (6.03, 0.00), (7.03, 0.00), (8.03, 0.00), (9.04, 0.00), (10.0, 0.00), (11.0, 0.00), (12.1, 0.00), (13.1, 0.00), (14.1, 0.00), (15.1, 0.00), (16.1, 0.00), (17.1, 0.00), (18.1, 0.00), (19.1, 0.00), (20.1, 0.00), (21.1, 0.00), (22.1, 0.00), (23.1, 0.00), (24.1, 0.00), (25.1, 0.00), (26.1, 0.00), (27.1, 0.00), (28.1, 0.00), (29.1, 0.00), (30.1, 0.00), (31.1, 0.00), (32.1, 0.00), (33.1, 0.00), (34.1, 0.00), (35.1, 0.00), (36.2, 0.00), (37.2, 0.00), (38.2, 0.00), (39.2, 0.00), (40.2, 0.00), (41.2, 0.00), (42.2, 0.00), (43.2, 0.00), (44.2, 0.00), (45.2, 0.00), (46.2, 0.00), (47.2, 0.00), (48.2, 0.00), (49.2, 0.00), (50.2, 0.00), (51.2, 0.00), (52.2, 0.00), (53.2, 0.00), (54.2, 0.00), (55.2, 0.00), (56.2, 0.00), (57.2, 0.00), (58.2, 0.00), (59.2, 0.00), (60.3, 0.00), (61.3, 0.00), (62.3, 0.00), (63.3, 0.00), (64.3, 0.00), (65.3, 0.00), (66.3, 0.00), (67.3, 0.00), (68.3, 0.00), (69.3, 0.00), (70.3, 0.00), (71.3, 0.00), (72.3, 0.00), (73.3, 0.00), (74.3, 0.00), (75.3, 0.00), (76.3, 0.00), (77.3, 0.00), (78.3, 0.00), (79.3, 0.00), (80.3, 0.00), (81.3, 0.00), (82.3, 0.00), (83.3, 0.00), (84.4, 0.00), (85.4, 0.00), (86.4, 0.00), (87.4, 0.00), (88.4, 0.00), (89.4, 0.00), (90.4, 0.00), (91.4, 0.00), (92.4, 0.00), (93.4, 0.00), (94.4, 0.00), (95.4, 0.00), (96.4, 0.00), (97.4, 0.00), (98.4, 0.00), (99.4, 0.00), (100, 0.00), (101, 0.00), (102, 0.00), (103, 0.00), (104, 0.00), (105, 0.00), (106, 0.00), (107, 0.00), (108, 0.00), (109, 0.00), (110, 0.00), (111, 0.00), (112, 0.00), (113, 0.00), (114, 0.00), (115, 0.00), (116, 0.00), (117, 0.00), (118, 0.00), (119, 0.00), (121, 0.00), (122, 0.00), (123, 0.00), (124, 0.00), (125, 39.8), (126, 19.8), (127, 0.00), (128, 0.00), (129, 13.6), (130, 9.10), (131, 2.00), (132, 19.9), (133, 19.9), (134, 0.00), (135, 0.00), (136, 0.00), (137, 0.00), (138, 0.00), (139, 0.00), (140, 0.00), (141, 0.00), (142, 0.00), (143, 0.00), (144, 0.00), (145, 0.00), (146, 0.00), (147, 0.00), (148, 0.00), (149, 0.00), (150, 0.00), (151, 0.00), (152, 0.00), (153, 0.00), (154, 0.00), (155, 0.00), (156, 0.00), (157, 0.00), (158, 0.00), (159, 0.00), (160, 0.00), (161, 0.00), (162, 0.00), (163, 0.00), (164, 0.00), (165, 0.00), (166, 0.00), (167, 0.00), (168, 0.00), (169, 0.00), (170, 0.00), (171, 0.00), (172, 0.00), (173, 0.00), (174, 0.00), (175, 0.00), (176, 0.00), (177, 0.00), (178, 0.00), (179, 0.00), (180, 0.00), (181, 0.00), (182, 0.00), (183, 0.00), (184, 0.00), (185, 0.00), (186, 0.00), (187, 0.00), (188, 0.00), (189, 0.00), (190, 0.00), (191, 0.00), (192, 0.00), (193, 0.00), (194, 0.00), (195, 0.00), (196, 0.00), (197, 0.00), (198, 0.00), (199, 0.00), (200, 0.00), (201, 0.00), (202, 0.00), (203, 0.00), (204, 0.00), (205, 0.00), (206, 0.00), (207, 0.00), (208, 0.00), (209, 0.00), (210, 0.00), (211, 0.00), (212, 0.00), (213, 0.00), (214, 0.00), (215, 0.00), (216, 0.00), (217, 0.00), (218, 0.00), (219, 0.00), (220, 0.00), (221, 0.00), (222, 0.00), (223, 0.00), (224, 0.00), (225, 0.00), (226, 0.00), (227, 0.00), (228, 0.00), (229, 0.00), (230, 0.00), (231, 0.00), (232, 0.00), (233, 0.00), (234, 0.00), (235, 0.00), (236, 0.00), (237, 0.00), (238, 0.00), (239, 0.00), (240, 0.00)

relative_fraction__gas_hydro_power_stations_'_installed_capacity = gas_fired__thermal_power_station__installed_capacity/Total_hydro_power_stations_with_DAM_installed_capacity

UNITS: Unitless

reserve__margin = (net_installed__capacity-Max_power__demand_per_month)/Max_power__demand_per_month

river_power__station's__planning__and_approval_time = 24

Scenario_Dda = 1

UNITS: Unitless

SHPS_generation_capacity_initiation_rate = SUM(Cumulative_distribution_of_generation_capacity_by_segment_inflow)

UNITS: mw/mo

SHPS_Historical = GRAPH(time)

(0.00, 293), (12.0, 314), (24.0, 356), (36.0, 437), (48.0, 461), (60.0, 469), (72.0, 466), (84.0, 471), (96.0, 485), (108, 536), (120, 536)

SHPS_participation_on_generation = Electricity_generated_from_SHPS/total_electricity__generated

UNITS: Unitless

SHPS_planning__and_approval_time = 24

SHPS__time_horizon = 48

UNITS: month

target_level__of_dam_in_Ghw = dam_level*target_level__percentual__RIGHT

UNITS: Gwh

target_level__percentual__RIGHT = GRAPH(month)

(0.00, 0.724), (1.00, 0.697), (2.00, 0.574), (3.00, 0.592), (4.00, 0.618), (5.00, 0.655), (6.00, 0.678), (7.00, 0.687), (8.00, 0.713), (9.00, 0.71), (10.0, 0.717), (11.0, 0.717), (12.0, 0.724)

UNITS: Unitless

Technical_minimum__volumen_fraction = 0.065

UNITS: Unitless

technical_minimum__volumen_in_Gwh = installed_capacity__of_dams_in_Gwh*Technical_minimum__volumen_fraction

UNITS: Gwh

total_electricity__generated = Electricity_generated_from_SHPS+generation_from__large_and_medium__HYDRO_PS+generation_from_thermal_power_stations

total_electricty_demand_in_Gwh_month = if(time<121)THEN(total_historical_electricty_demand_in_Gwh_month)else(Electricity__Demand_Scenario)

UNITS: gwh/mo

total_historical_installed_capacity = LARGE_river_power_station_installed_HISTORICAL_capacity+MEDIUM_river_power_station_installed_HISTORICAL_capacity+SHPS_Historical+Medium_hydro_power_station_with_DAM_installed_HISTORICAL_capacity+large_hydro_power_station_with_DAM_installed_HISTORICAL_capacity+gas_fired_thermal_power_station_installed_HISTORICAL_capacity+coal_fired_thermal_power_station_installed_HISTORICAL_capacity+others

total_hydro_contribution = hydrologic__contribution__to_DAM+hydro_contribution_to_river_power_station

Total_hydro_power_stations_with_DAM_installed_capacity = large_hydro_power__station_with_DAM_installed_capacity+MEDIUM_hydro_power__station_with_DAM_installed_capacity

UNITS: MW

unavailability_factor_for_coal__fired_thermal_power_stations = 0.1

UNITS: Unitless/mo

unavailability_factor_for_gas_fired_thermal_power_stations = 0.1

UNITS: Unitless/mo

unavailability_factor_for__hydro_power_stations_with_DAM = 0.05

UNITS: Unitless/month

unavailability_factor__for_LARGE_river__power_station = 1

UNITS: Unitless/month

unavailability_factor__for_MEDIUM_river__power_station = 0.05

UNITS: Unitless/month

unavailability_factor__for_small_hydro__power_stations = 0.05

UNITS: Unitless/month

unsatisfied__demand = max(0,demand_to_be__satisfied_by_thermal__power_stations-generation_from_thermal_power_stations)

UNITS: gwh/mo

water_plant__and_others = 7619959

UNITS: US Dollars (USD)

water_spillage__adjustmet_time = 0.5

UNITS: month

Weight_to_forecasted_electricity_price = 1-Weight_to_historical_Electricity_price

UNITS: Unitless

Weight_to_historical_Electricity_price = 0

UNITS: Unitless

NOTE: This model is replicated when forecasting the electricity price in the scenario chapter. Therefore, in the model file, there is a module named as Electricity Price forecast. The differences, between the equations already displayed in this section and the equations in the Electricity Price forecast module, are the initial values of the stocks and the data used to set the graphs. These values are the ones calculated for the main model in the month 120.