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Analysis of the Electric Power Sector Restructuring in a Cost-Based Dispatch Environment

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Abstract: Introduction of competition in the electricity supply industry has required several adjustments or in some cases significant improvements, depending on the original design and its implementation. This study analyzes the impact of private ownerships on the spot prices and market power in a system dominated by hydroelectric capacity based on the Panamanian electricity market data. Besides, we apply the Cournot-Nash equilibrium model to evaluate the generating company's profit in an electricity market with cost-based dispatch. Despite the premise that competition in the wholesale market will lead to lower prices, it has been shown that the retail prices for residential consumers have gradually increased after the restructuring process.

Key words: Restructuring process, electricity market, spot market, economic dispatch and ancillary services

INTRODUCTION

Starting in 1978, when Chile privatized its electricity supply industry, but primarily since, the end of the 1990, there have been global trends to restructure the electricity markets. The main reasons of this electricity reform were to improve the efficiency of the network utilities, provide the means to transfer the gains to consumers as well as cutting cost by introducing competition (Newbery, 2000). However, until now there is no data indicating that domestic consumers had benefited from these changes (Lave *et al*., 2007) as well as the consumers have not been very active on the competitive market even though in many countries they have been given a freedom to choose their electricity suppliers.

There are many transition issues related to the electricity restructuring process that might be difficult to define the best industry structure at this moment. In view of this complication, it is more appropriate to point out the development of the key elements of a competitive model rather than specify a rigid industry structure. It is expected to find several differences between the electricity market models which have been implemented in each country under electricity reforms.

It has been widely analyzed the restructuring of the electricity supply industry on markets where the price is determined by the interaction between producers and consumers. Conversely, the use of cost-based dispatch and pricing in wholesale markets has not received that much attention, this scheme is frequently used in Latin American countries. In this study, we will evaluate the main features and results of the restructuring and privatization process of the Panamanian electricity market. The Panamanian regulatory framework is based on the competition on the wholesale market, while the distribution-retail companies maintain a natural monopoly over energy sales to the regulated consumers. Besides, the transmission company remains as the sate ownership.

RESTRUCTURING AND PRIVATIZATION PROCESS IN PANAMA

In 1997-98, the Panamanian government restructured the state-owned Instituto de Recursos Hidráulicos y Electrificación (IRHE, Institute of Hydraulic Resources and Electricity Supply), unbundling the generation from the transmission and the distribution. As result of these processes four generation companies (GENCOs), three distribution companies (DISCOs), one Transmission Company as well as contract and balancing/spot markets were created. Furthermore, an independent regulatory entity (ERSP) was established to oversee the tariff and service levels. The Panamanian competitive wholesale market began working on July 1st 1998.

After privatization, generating companies became competitive. Nonetheless, at the wholesale level some functions remain centralized such as the operation of the spot/balancing market by the national center of dispatch

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(CND), which is part of the state owned transmission company (ETESA). Besides, the operation of the transmission network is still under the control of the Panamanian government and the tariffs are regulated by ERSP. The retail level remains as natural monopoly. However, large consumers are allowed to directly negotiate for their power supplies with GENCOs and also to buy in the spot/balancing market.

In Panama, the first model of competition subsequent to the divestment of the state owned Electricity Company was the purchasing agency (Hunt, 1996). At this stage, the electricity supply industry was no longer integrated. During the first 5 years, after the creation of the energy law, ETESA was the company in charge to purchase energy. Though, DISCOs were permitted to buy from different GENCOs through ETESA or generate their own electric power until 15% of the demand in their service territory. From 2002, no central organization is responsible to procure electrical energy. Instead, DISCOs purchase the electrical energy consumed by their customers directly from GENCOs through bilateral contract or in the spot/balancing market.

SYSTEM SIZE, GENERATION AND DEMAND

In 2007, the total demand of energy in Panama was about 6,078 GWh with a peak load of 1,024 MW and installed capacity was 1,471 MW. The hydro generation is the dominant source for the electricity, it is about 57.2% of the total installed capacity.

After the introduction of competition in the generating sector, the hydro installed capacity increased in 35% and thermal capacity had a lower growth in 24%. As, it is shown on Fig. 1, three generating companies control 72.2% of the total generation capacity. However, the hydro capacity is concentrated on two companies (AES and Fortuna). During the period of January 2005 to December 2007, these three companies have set the market prices as follows Fortuna 36.2%, AES 34.1% and BLM 27.1%. Moreover, the companies AES and Fortuna have larger share of the electricity generated in the market 31 and 25%, respectively.

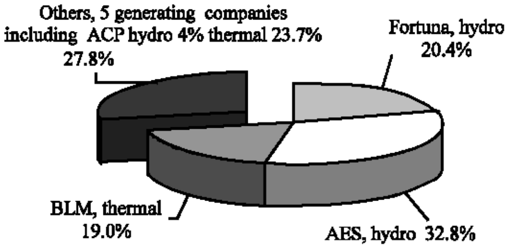

Fig. 1: Capacity ownership in the Panamanian electricity market

COURNOT-NASH EQUILIBRIUM MODEL

In the cournot model, each GENCO chooses an output quantity to maximize its profit. Consequently, we defined the profit of the generating company as the difference between revenues earned and costs incurred from providing electric service. The revenues rely on the generated energy, the real-time balancing market payments, contracted energy payments and ancillary services payments. Expenses include operating costs and outage costs. For simplicity, in this stage, no bilateral energy contracts are

$$\pi_i = p(Q_T)q_i + R_i - c_i(q_i) - O_i \quad (1)$$

$$Q_T = \sum_{i=1}^{i=M} q_i \quad (2)$$

$$O_i = C_{SMC} f_i q_i \quad (3)$$

where:

Q_t = The total energy production in the wholesale electricity market.
M = The total number of players in the game.
$p(Q_T)$ = The spot price.
q_i = The optimal production quantity.

In an economic dispatch system, the spot price is given by the marginal cost of the system on a short-term basis $p(Q_T) = C_{SMC}$, $p(Q_T)$ is also known as the inverse demand function, $c_i(q_i)$ is GENCO i's production cost curve, O_i is GENCO i's outage cost, f_i is the forced outage rate of GENCO i and R_i represents GENCO i's revenue for the provision of the ancillary service. The ancillary services payments are explained in detail in the next section. In fact, each player seeks to maximize its profit subject to operational and physical constraints.

$$\max_{q_i} \pi_i = \max_{q_i} \{p(q_i + Q_{-i})q_i + R_i - c_i(q_i) - O_i\} \quad (4)$$

The cournot model also assumes that all GENCOs in the wholesale market can be identified at the start of the game and that decision making by GENCO occurs simultaneously.

Then, a Cournot-Nash equilibrium is a vector of production quantities which maximizes the profit of each GENCO given all other GENCO quantity decisions. In mathematical terms, a Cournot-Nash equilibrium is a vector $(q_1^*, q_2^*,..., q_i^*, ..., q_M^*)$, which solves a collection of profit maximization problems of the form:

$$\max_{q_i} \pi_i\left(q_1^*, q_2^*, \ldots q_i^*, \ldots, q_M^*\right) \forall i \quad (5)$$

In other words, a Cournot-Nash equilibrium is a set of electricity production quantities, such that no GENCO can obtain better profits by unilaterally changing a different production quantity for its energy resources.

TRADING IN THE WHOLESALE ELECTRICITY MARKET

In a market with cost-based dispatch, GENCOs are required to declare their start-up, no-load and variable costs to the regulator. Once these costs are approved by the regulator, GENCOs are required to bid these costs into the market and then the Independent System Operator (ISO) implements the economic dispatch. The economic dispatch is the process of determining the most reliable, low-cost and efficient operation of the electric power system by allocating the required load demand between the available generation units (Wolak, 2003).

The ISO uses the following variables to make the economic dispatch:

c_{tg} = Variable cost of operation for thermal generation of unit g at period t (US$/MWh).
c_{tj} = Opportunity cost of water for hydro generation of unit j at period t (US$/MWh).
e_{tg} = Energy production of thermal unit g at period t (MWh).
e_{tj} = Energy production of hydro unit j at period t (MWh).
b_{CA} = Bid price to import energy to Panama which are submitted by the Central America electricity companies (US$/MWh).
b_{ACP} = Bid price to sell surpluses of energy from ACP auto-generator (US$/MWh).
q_{CA} = Imported energy quantity from Central America electricity companies (MWh).
q_{ACP} = Sold energy quantity from ACP (MWh).
x_{VOLL} = Value of lost load (VOLL) which is related to energy rationing costs (US$). These costs may be caused by the outage risk attributable to the lack of reserve.
N = Number of thermal units.
K = Number of hydro units.

On this set of assumption, the total cost of the electric power system at period t is given

$$C_t = \sum_{g=1}^{g=N} e_{tg} c_{tg} + \sum_{j=1}^{j=K} e_{tj} c_{tj} + q_{CA} b_{CA} + q_{ACP} b_{ACP} + x_{VOLL} \quad (6)$$

The primary objective of economic dispatch is to minimize the total cost of generation while keeping the reliability and security of the electric power system.

$$\min C_t = \min \left\{ \begin{array}{c} \sum_{g=1}^{g=N} e_{tg} c_{tg} + \sum_{j=1}^{j=K} e_{tj} c_{tj} + q_{CA} b_{CA} \\ + q_{ACP} b_{ACP} + x_{VOLL} \end{array} \right\} \quad (7)$$

Constraints

- Unit capacity limits

$$P_{g\,min} \le P_g \le P_{g\,max} \quad (8)$$

$$P_{j\,min} \le P_j \le P_{j\,max} \quad (9)$$

where:
P_g = The production power of the thermal unit g.
P_j = The production power of the hydro unit j.

- System constraints, demand and supply balance. In this calculation, the transmission loss were not taking into account:

$$D_t = \sum_{g=1}^{g=N} e_{tg} + \sum_{j=1}^{j=K} e_{tj} + q_{CA} + q_{ACP} \quad (10)$$

where:
D_t = The energy demand at period t.

Finally, GENCOs are paid market clearing prices based on the system marginal cost C_{SMC}.

Contract market analysis: Since the physical dispatch is centrally coordinated by the ISO, bilateral contracts are financial hedge against the spot prices. It has been shown that high level of energy trading in the contract market eliminates the incentive to induce high spot prices (Allaz and Vila, 1993).

If we take into account the level of ex-ante contracting, the profit of the GENCO i with cost curve $c_i(q_i)$ producing at a level equal to q_i and with a long position contract described by the commitment to sell s_i at the fixed price z_i is represented by,

$$\pi_i = C_{SMC} q_i + R_i - c_i(q_i) - O_i - s_i (C_{SMC} - z_i) \quad (11)$$

During the first 6 years of introducing competition in wholesale market, most of the energy trading occurred in the contract market. The average of traded energy in the contract market was 87.2%. However in 2005, the purchased energy in the contract market was decreased down to 62.8%. These changes were caused by many bilateral contracts were terminated in 2004. By this time, the spot market prices were lower than the contract market

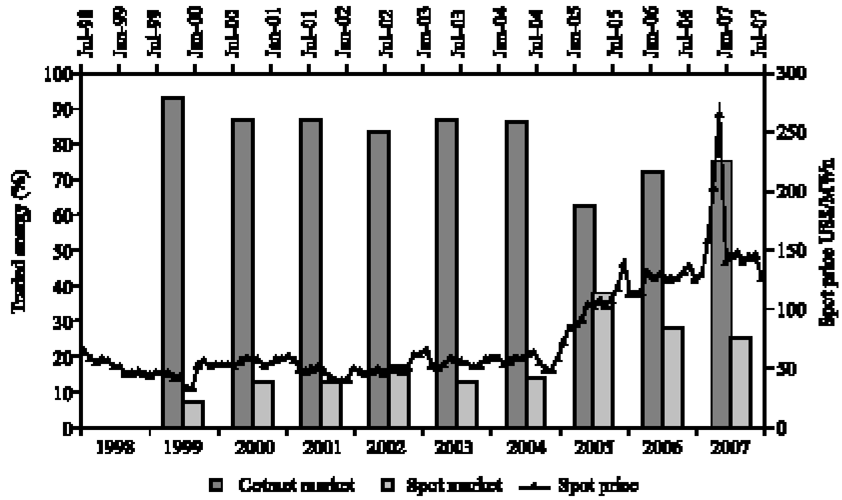

Fig. 2: Total energy traded in the spot and contract market and spot price

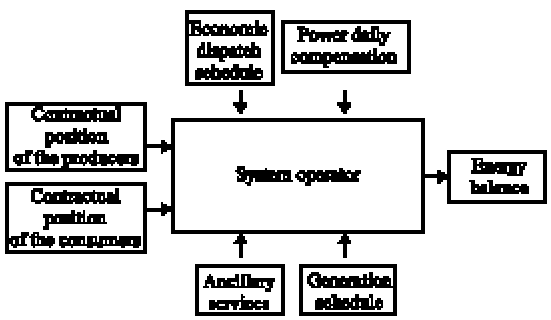

Fig. 3: Schematic diagram of the operation of Panamanian spot/balancing market

prices causing DISCOs to purchase less energy in the contract market and more in the spot market. This exercise of market power by generating companies implied significantly higher spot prices as it is shown on Fig. 2.

Spot market/balancing market analysis: The transactions in the spot market arise from the differences between the physical reality of the generation/ consumption and the commercial reality of the contracted commitments at a certain moment (Kirschen, 2004). These adjustments are hourly made by ISO and the spot price is determined by the last dispatched generating unit, the Fig. 3 summarizes the operation of the Panamanian spot/balancing market.

Spot price volatility: In spite of the cost-based dispatch, the spot market prices presented volatility behavior similar to the bid-based electricity markets where the price is determined by the interaction between producers and consumers. In the period 1998-2004, the monthly average

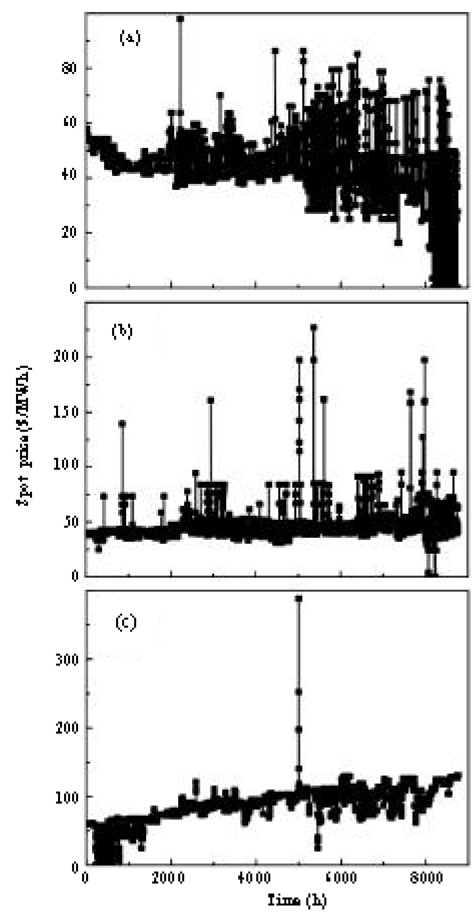

Fig. 4: Spike prices in the spot market in (a) 1999 (b) 2002 and (c) 2005. Source: CND

spot price was around to 40 - 65 US$/MWh. At the end of 1999, the spot prices were tended to zero since the purchase of energy in this market, was scarce (Fig. 4a). In 2002, 21 price spikes exceeded 150 US$/MWh as depicted on Fig. 4b. In this years, the spot prices increased up to 227.14 US$/MWh. However, the spot market prices tendency was lower than 65 US$/MWh. In 2005, a spike jump equal to 388.07 US$/MWh occurred (Fig. 4c). From this year the average spot price gradually started to increase until May 2007 when, it reached a maximum of 265.15 US$/MWh.

The principal reasons for this increasing tendency were the raise on energy trading in the spot market, creating more volatility in the spot market and the exercise of market power by hydroelectric companies. During the period 2005-2007, the hydro units have set the clearing market price 71 and the thermal units 29% as shown on Fig. 5. The higher prices observed during March 2007 to May 2007 were the result of the two largest hydropower plants had their reservoir capacities lower than average usage. As it was above mentioned, these two companies (AES and Fortuna) usually set the market price. Although, the hydro generation is the dominant source of electricity in Panama, the spot prices have tended to increase from 2005. That is due to the opportunity cost of water for hydro generation is based on the marginal cost of all thermal generators of the system. As shown on Fig. 6 and 7, the spot prices are more correlated with the opportunity cost of water than the oil prices especially during 2005-2007. Besides, in Panama, there is not a cap price for the spot market. The spot price can increase or decrease depending on the availability of the GENCOs to supply energy to the system.

Probability distribution of spot price: The spot price is given by the marginal cost of the system on a short-term basis. Moreover, this price is calculated by the system operator through an economical dispatch. We applied a distribution fitting to the historical spot price data (1999-2007) in order to determine the probability distribution and its parameter that best describe the characteristic of the data. The logistic distribution is the best fit to represent the spot price data as follows:

$$f(P) = \frac{e^{\frac{P-\bar{P}}{\sigma}}}{\sigma\left(1+e^{\frac{P-\bar{P}}{\sigma}}\right)^2} \tag{12}$$

where:

f (P)	=	The spot price probability at the spot price P.
σ	=	The scale parameter.
$\bar{P}$	=	The average spot price.

The results of the probability of the spot price at different price levels are shown on Table 1.

Ancillary services analysis: Recently there have been several proposals for creating competitive markets for Ancillary Services (Hirst and Kirby, 1997). In the case of Panama, there is not a specialized market where Ancillary Services (AS) are purchased or sold. AS are purchased by contracts or directly assigned by ISO, depending on the requirement of the real time demand in order to supply stable and reliable electricity.

The bids to provide special AS are annually submitted to ISO by the participants who want to supply these services. The offers are ranking in order ascendant according to the price. The value of the special ancillary services is equal to the last accepted offer. The Fig. 8 shows the scheme of the AS that are supplied in Panama. The system AS such as voltage control and reactive

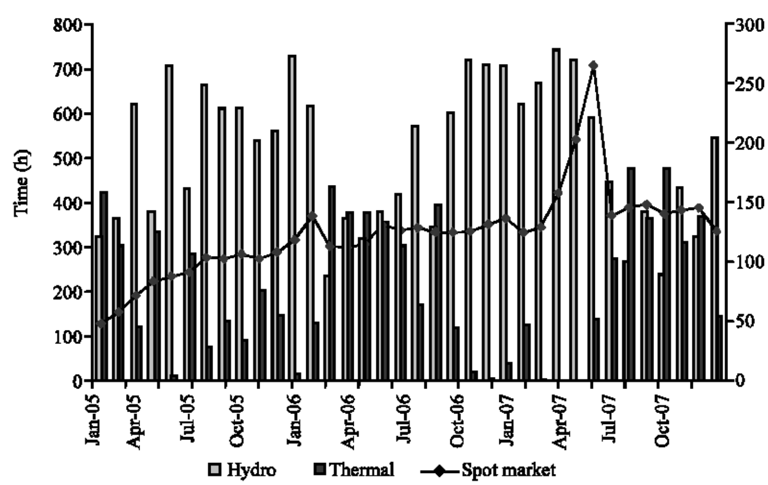

Fig. 5: Number of hour that the hydro and thermal units have set the market clearing price compared to the spot prices

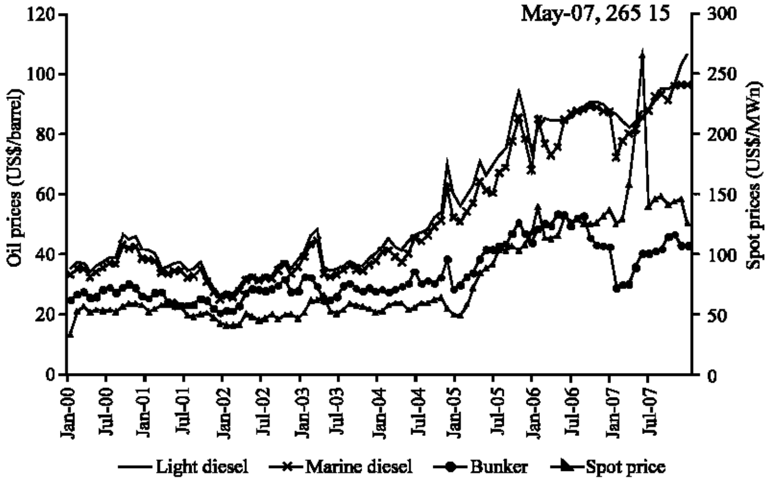

Fig. 6: Spot market price and oil prices

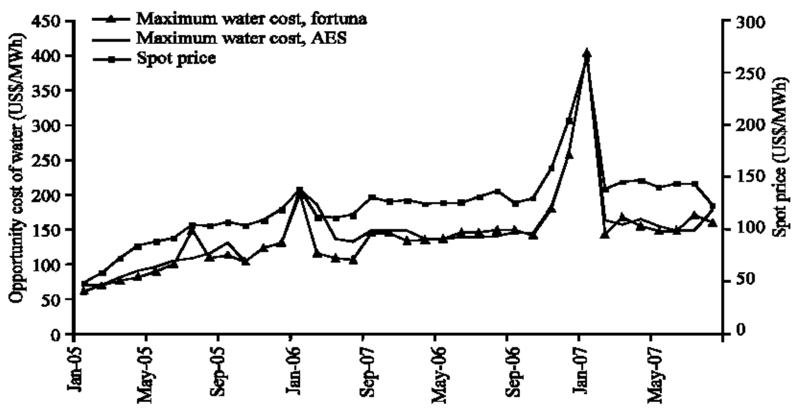

Fig. 7: Opportunity cost of water for hydro generation and spot prices

Table 1: Probability of the spot price at diferent price levels

Year	Price level (%) p<40	40≤p≤65	65<p	Mean US$/MWh
1999	31.30	65.70	3.00	43.19
2000	8.80	81.80	9.40	50.98
2001	1.40	93.90	4.70	49.99
2002	32.10	64.50	3.40	43.15
2003	0.80	93.40	5.80	53.96
2004	8.10	76.70	15.20	55.95
	p<100	100≤p≤150	150<p	
2005	66.40	32.30	1.30	90.8
2006	5.20	91.10	3.70	125.03
2007	10.90	41.90	47.20	154.45

P-Spot Price; US$/MWh

power support are compulsory services. There is not compensation for the participants who provide these services. Automatic Generation Control (AGC) or regulation service is provided by generating unit that can respond automatically to the system operator. There is not a premium for supply this service either.

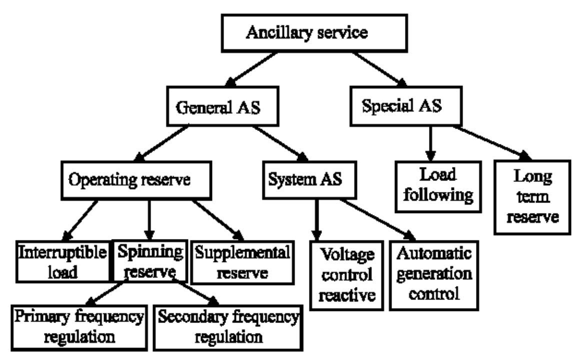

Fig. 8: Scheme of the ancillary services supplied in Panama

The operating reserve corrects the differences between the generation and demand so as to avoid contingencies and diminish the risk of collapse of the system. Additionally, the operating reserve is required during each hour to maintain the reliability and good operation of the electric grid. Besides, the regulatory entity has fixed the obligatory quantity of operating reserve equal to 5% of the scheduled peak demand.

The spinning reserve is provided by all the generating units, which are synchronized to the electric grid, they must start responding immediately to change in frequency. In primary frequency regulation, GENCOs must regulate the frequency in their generating units. Hence, there is not automatic control by ISO. No premium is paid to supply this service. In contrast, there is a premium for secondary frequency regulation service.

In a defined period, the contribution to the spinning reserve of a generating unit is calculated by the difference between the emergency maximum power and the dispatched power. The emergency maximum power is the maximum power that the generating units can supply in a period of 15 min when ISO requests for emergency reasons.

The generating unit providing supplemental reserve services must be able to synchronize to the electric grid in a period no bigger than 15 min.

ISO calculates monthly the maximum remuneration that must be paid for the provision of the general AS using the commercial percentage of general AS. This percentage is equal to 1% (established by ERSP) of the total energy provided to the grid (Eq. 13), valorized at the spot market price. Corresponding amount of money is distributed between the general AS. Thus, the general AS price (US$/MWh) is calculated dividing the maximum remuneration by the total energy provided to the consuming participants,

$$\text{General AS Price} = \frac{1\%\sum_{t=1}^{t=T} E_t P_t}{E_{CP}} \quad (13)$$

Where:
E_t = The total energy provided to the grid at the hour t.
P_t = The spot market price at the hour t.
E_{CP} = The total energy provided to the consuming participant in one month.
T = The total hour of the month.

Each consuming participant must monthly reimburse for the general AS a payment equal to the total energy supplied to the participant valorized at the general AS price.

The long term reserve ancillary service (SARLP) is an assurance to fulfill the commitments of available power in order to cover the requirement of electricity provision of the Panamanian consumers.

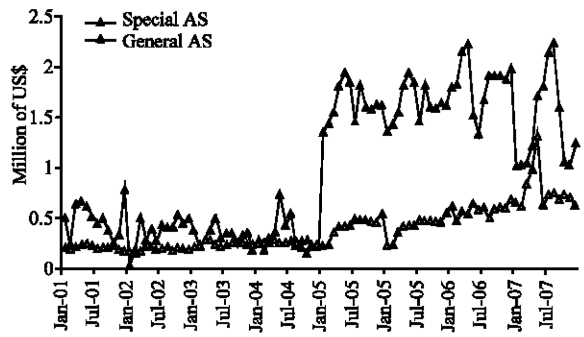

Fig. 9: Ancillary service transactions

SARLP (power in MW) is assigned by ISO to DISCOs that do not have contracted the total amount of their maximum demand of their service territory. ISO matches the received bids submitted by GENCOs and assigns them to consuming participants. GENCOs submit annually to ISO their bids for each month of the following year.

Daily system demand has been divided in four period called hour blocks. The hour blocks are calculated according to the level of the demand, along with the system load curve. The bids to supply SARLP are submitted in one or more hour blocks of power, each hour block with the wanted price. After receiving the bids, ISO ranks them in ascending order depending of the prices. The price of SARLP is corresponding to the last accepted bid, which is the most expensive. Besides, there is a cap price for SARLP which was fixed by ERSP, it is 7.38 $/kW-month. The need of SARLP is calculated weekly by ISO.

The load following AS price is closely related to the start up costs of the generating units. These costs arise as a result of the economic dispatch and the daily operation of the system. Furthermore, the start up costs of generating units are not including in the system marginal price calculation.

The economic transactions for the special AS are higher and they show more volatility than the general AS (Fig. 9). Attributable to the majority of the general AS are compulsory provision as a condition for being allowed to connect to the electric grid and the payments obtained for supplying general AS are calculated using a formula, which is proportional to the energy supply to the consumers and the spot prices (Eq. 13). Therefore, from 2005, the general AS started also to increase.

RETAIL MARKET

In Panama, DISCOs control the management of the distribution network as well as the retail activities in their

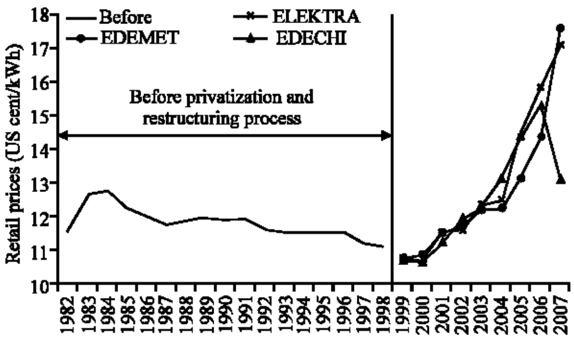

Fig. 10: Retail prices for regulated residential consumers by DISCOs

service territory as natural monopoly. Besides, the retail prices are still regulated by independent regulatory entity.

There are three distribution companies that supply energy: EDEMET, EDECHI (both of them are administrated by Unión Fenosa) and Elektra. EDEMET and EDECHI own few generating units.

EDEMET has a large share of the market, since it has a bigger service territory. Conversely, Elektra had a bigger growth in the residential consumers, 8.1% in the period under consideration. The notable growing in consumer was attributable to the incorporation of several consumers to the electricity metering who prior were illegally connected to Elektra distribution networks.

During the first 2 year of the competition in the wholesale market, the electricity prices for regulated consumers dropped. Although, the subsequent years the electricity price for the residential consumer have remarkable increased as it is shown on Fig. 10. The tariff structure also has gone through many changes, although, these changes have not been a sufficient condition to have lower prices for the residential consumers.

ELECTRICITY RESTRUCTURING AND RENEWABLE ENERGY

Now a days, the amount of renewable energy projects to be implemented in Panama has increased due to the following reasons: the restructuring process promoted renewable independent power producers entering to the electricity market, the government of Panama passed Law No. 45 of August, 2004 to supply a number of incentives for construction and development of new hydroelectric plants and other renewable energy projects. Finally, the government of Panama ratified the Kyoto Protocol in 1999 attracting the international interest to invest on greenhouse gas mitigation projects.

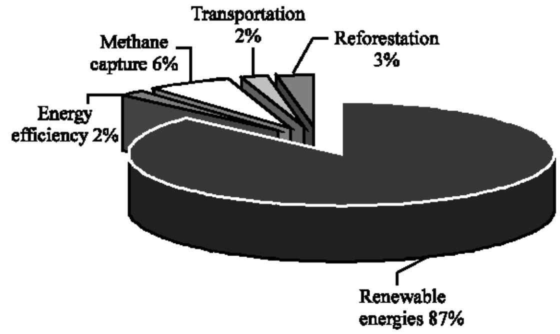

Fig. 11: Number (%) of projects by each category in CDM portfolio of Panama. Source: ANAM (2007/07/15)

Table 2: The CDM projects implemented in panama

Status	Name	Type	kt CO_2/year	MW
Registered	Los Algarrobo	Hydro	37	9.7
	Macho de Monte	Hydro	11	1.7
	Dolega	Hydro	12	0.3
	Concepcion	Hydro	36	10.0
	Paso Ancho	Hydro	22	5.0
At validation	Esti	Hydro	316	120.0
	Bayano	Hydro	32	51.0
	Santa Fe	Wind	183	81.0
	Cañazas	Hydro	17	5.9
	El Síndigo	Hydro	39	10.0
	Ojo de Agua	Hydro	21	6.4
	Los Estrechos	Hydro	30	10.0
	Changuinola I	Hydro	669	222.5
	Cerro Patacón	Landfill gas	291	6.4

The CDM projects in Panama: The carbon credits obtained from the Clean Development Mechanism (CDM) under the Kyoto Protocol provide renewable producers with an additional source of revenue that complements their income from selling electricity in wholesale markets.

The CDM portfolio of Panama contains 108 projects of which 94 projects are renewable energy projects (Fig. 11). The majority of these projects are associated to hydroelectricity. It is also, the leading form of renewable energy existing in Panama up to now. According to the UNEP/RISOE project pipeline database, Panama has five CDM projects registered by the CDM executive board and nine more projects that are in the stage of validation by the designated operational entity (Table 2). The credit buyer of 3 registered projects is Unión Fenosa (Spain), which is also the owner of the two Panamanian distribution companies.

CONCLUSION

In a cost-based dispatch environment, the system operator plays a fundamental role in the spot market. It decides, the way to trade energy in the spot market based on marginal cost of GENCOs. Consequently, GENCOs compete based on their cost of production. The clearing price in the spot market is equal to the cost of production of the last generating unit dispatched, it has been shown that the two largest generating companies Fortuna and AES usually set the market price.

During the period, when the large amount of energy was traded in the contract market, there were not incentives to increase the spot prices by GENCOs. However, from 2005 the spot prices were tended to increase due to more volatility in the spot market and exercise of market power by hydroelectric companies. Even when the prices have been set equal to the marginal costs, the generators have been able to obtain bigger profits manipulating the spot prices. These strategies have raised the average price paid by consumers.

In spite of the hydro generation is the dominant source of the electricity in Panama, the retail prices are bigger than most of the Latin America countries. As consequence of the opportunity cost of water for hydro generation, which is calculated based on the cost of supplying electricity in absent of hydro generation. Thus, the electricity generated by hydro power plants is paid as the marginal cost of all thermal generators of the system. As the fossil fuel prices have reached their maximum historical in the same way the spot prices have raised.

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