

## Original Paper

# The Effects of Electricity Sources on the Cost of Electricity in Panama

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### Abstract

*The purpose of this study is to identify which electricity production sources have a significant effect on the marginal cost of electricity in Panama. Panama, like most Central American countries, relies on hydroelectric power, thermoelectric power and electricity purchases. We only collected secondary data provided by the official entities in order to ensure that the numbers used for the study were consistent. Linear regression analysis was used to find the model that describes the behavior of the marginal cost more accurately. The findings of the study confirm the need for less oil-dependent electricity production alternatives in order to achieve lower electricity prices in Panama.*

### Keywords

*Electricity source, thermal power, hydroelectric power, Panama, Panama Canal, Marginal cost*

### 1. Introduction

The electricity market in Panama is coordinated by a national institution called Centro Nacional de Despacho [CND], a non-profit branch of the company Empresa de Transmision Electrica, S.A., [ETESA]. The Panamanian electricity market started functioning under the current regulatory framework in 1999. Based on free competition among power generators, the CND classifies market participants according to participant roles into three categories: producers, consumers and transporters. According to the CND, the Panamanian market is served by three major distributors including Empresa de Distribución Eléctrica Metro Oeste, S.A. (Edemet), Empresa de Distribución Eléctrica Chiriquí S.A. (Edechi) and Empresa de Distribución Eléctrica Elektra Noreste, S.A. (Elektra). Distributors charge the electricity fees to the end users; however, they don't have full control of the tariffs they apply. According to the Autoridad Nacional de los Servicios Públicos [ASEP] (2010), Article 3 of Law 6 of January 29<sup>th</sup>, 1996 having the function of regulating and controlling any public services, such as electricity in Panama, stipulates that new tariffs to end users must be approved by the Government. Rather than the traditional residential, industrial, government, and commercial customer segments, since 1998, Panamanian electricity end users have been divided into three segments based on the level of tension they are connected to: low tension customers are customers using 600V or less, middle tension customers are customers using more than 600V but less than 115KV, and high tension customers are customers using more than 115KV.

Due to the abovementioned considerations and to the fact that end user prices are only available on a biannual basis, marginal cost have been used, which is the average production cost of electricity for Panama reflecting the behavior of the market in a more consolidated way. Electricity in Panama is mainly produced using hydroelectric plants and thermoelectric facilities. According to the Panamanian Ministry of Commerce and Industries, the most commonly used fossil fuels for the generation of electricity are Bunker C, Light Diesel and Marine Diesel (CND, 2011). In the past few years, it was reported that the government is considering opening a coal based plant (Jordan, 2010), but the start of operations date is uncertain and there is no information about it in the CND databases. Moreover, coal is not included in the fuel price list for Panama. Panama's electricity consumption is mostly satisfied by domestically produced electricity. Electricity purchases average around 11% of the total supply of energy, of which approximately 1% comes from imports of energy into the country. Panama imports and exports are balanced. During the period March 2005 through December 2010, the total amount of electricity offset during favorable net exchange periods (measured in negative numbers, to indicate a net export of electricity) is greater than the amount of electricity offset during unfavorable periods (positive numbers) by 127.3 thousand MWh. The Panama Canal also contributes to the electricity supply with an average of 10% of the total. Even though this electricity is generated within Panamanian territory, it is considered as a purchase from outside the electric grid.

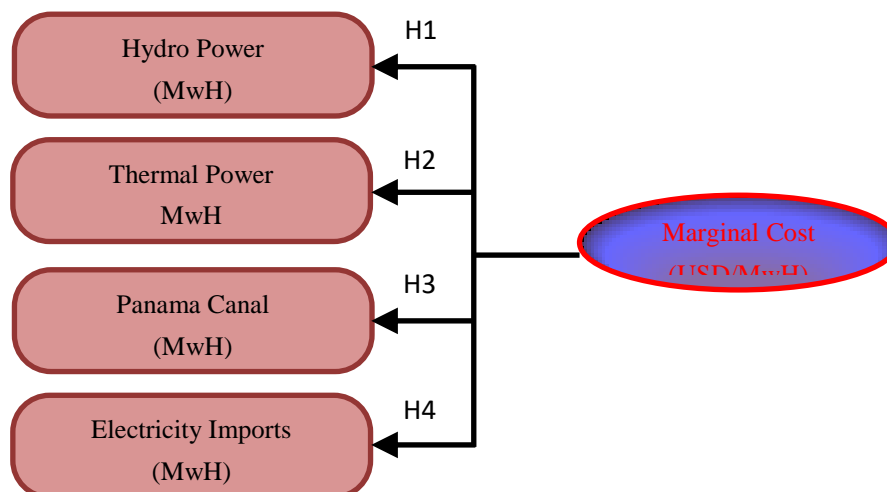
As part of the Central American Electric Market, Panama's international electricity exchange occurs primarily with the Central American countries. The market is regulated by a multilateral agreement called Tratado Marco del Mercado Electrico de America Central [TMME], which establishes a cooperative framework under which participating countries agree to function. This treaty was signed under the already existing juridical framework of the SICA (Central American Integration System), which is an initiative effective since 1991, and which was preceded by the creation of the ODECA (Organization of Central American Estates) in 1951. All signing nations have manifested their will of gradual electric integration by means of developing a competitive regional electric market through interconnection of national transmission lines and the promotion of regional generation projects. The ultimate purpose of this integrated electric market is to create an electric industry that works in favor of the population of the region (Comision Nacional de Energia Electrica de Guatemala, 1997). Electricity demand in Panama seems to remain very stable throughout the year, with peaks in December and low points in February and November. Though there are no previous studies on the topic, the lowest points coincide with a short month and a month with many holidays, potentially explaining the difference with the rest of the months. Stable demand throughout the year suggests that seasons do not have considerable impact on electricity consumption in Panama. Temperature does not vary greatly. In fact, information provided on the website of the Smithsonian Tropical Research Institute indicates that the difference in temperature between dry and rainy season is minimal. Yet, the demand displays increasing trend and greater variance. Moreover, the regression analysis reveals a low coefficient of determination of around 4% and the regression is not significant according to the F-statistic. Demand usually plays an important role in determining cost for the supply of any product. Knittel and Roberts (2005) state that electricity prices track demand movements closely. However, this statement is only true in fully deregulated markets. The Panamanian market is not 100% deregulated and therefore prices don't change dynamically. Furthermore, the variable used in this study is marginal cost, which is basically the cost in USD of producing one MWh. The linear regression analysis of marginal cost and electricity consumption in Panama shows a coefficient of determination of just 26%. However, the demand shows a very stable behavior, with a standard deviation of only 9% of its average value, while

marginal cost has a standard deviation of 43%.

Central America is now going through a stage of integration. Electricity demand in Panama is increasing and if the marginal cost continues to increase, the economic growth of the country may be hindered. A growing economy requires to have an efficient electric network to support its operations. In order to develop an efficient electric network, we need to understand the effect of the different production alternatives in the marginal cost of producing electricity. The aim of this present study is twofold:

1. Test the significance of the relationship between each production alternative and the marginal cost of electricity through linear regression analysis.
2. Make suggestions about future electric network development based on the results of the linear regression analysis.

One of the objectives of this work is to determine the significance of the relationship between each production factor and the marginal cost of electricity. Each production factor should influence the final value of the marginal cost of producing electricity. Figure 1 shows the research framework in a graphic mode.



**Figure 1. Research Framework**

The reminder of the paper is organized as follows. The next chapter examines the literature review. The third chapter analyses the research methodology. The fourth chapter discusses the data analysis. Finally, the last chapter concludes our study. Implications for practice are highlighted and limitations and future directions for inquiry are presented.

## 2. Literature Review

### 2.1 The Deregulation of Electric Markets and its Impact on the Cost of Electricity

According to Takriti, Krasenbrink, and Wu (2000) electric markets have been following a deregulation pattern in many countries. Initiatives undertaken by the United States since 1978 encouraged separation between generators and distributors. These policies have shaped the market into what it is today, and this model has also influenced many countries in Latin America, including Panama. The purpose of deregulation is to achieve cheaper prices for consumers through the increase in competition. Though, deregulation also has an impact on the electricity demand, which is said to be unpredictable due to

trading transactions. Also, because electricity is a perishable, non-storable good, prices are extremely volatile and will depend on the supply and demand of the market at any given moment in time. However, contrary to Takriti's considerations and thoughts on the purpose of deregulation, it has proven to increase the prices of electricity. Moreover, studies like "Electricity in Latin America" (Hall, 2004), show how deregulation and integration are not really working towards the benefit of the end user, but to the benefit of big corporations who try to squeeze the most profit they can from the markets they are in, in order to get the fastest possible investment recovery. In fact, the prices to the consumer in Panama have increased for almost all customer segments. Table 1 below shows the increase of the fix component of the price for each consumer segment from 1999, when the market was open, to 2010. This increase is calculated by averaging the price for each of the three mayor electricity distributors for each consumer segment.

**Table 1. Increase of the Average Price by Consumer Segment from 1999 to 2010**

Segment	Average price increase from 1999 to 2010
Low tension simple rate	22%
Low tension maximum demand rate	23%
Low tension hour block rate	-8%
Middle tension maximum demand rate	58%
Middle tension hour block rate	46%
High tension maximum demand rate	58%
Low tension simple rate	22%

## 2.2 Electricity Demand Coverage

Weather parameters such as temperature, humidity and cloud cover typically affect the demand for electricity at any given time. Though, as mentioned previously, for Panama this relationship is not significant. This might be due to the dual season weather pattern present in the Central American Region: mostly warm with only slight temperature variations throughout the year. On the other hand, supply could be affected by what happens in neighboring electric systems. For example, if a generating plant happens to suddenly stop working, demand might be unsatisfied if the network doesn't have a way to cover for that lost capacity (Takriti et al., 2000). In extreme situations, electricity shortages may occur. Electricity shortages are undesired situations. The social and financial costs of a blackout are high and not acceptable in most markets. Therefore, generators need to make sure their capacity exceeds the forecasted demand by a defined safety level.

## 2.3 The Effect of Oil Prices on the Cost of Producing Electricity

According to the International Monetary Fund, petroleum price shocks have a proven effect on the economies of Central American countries, impacting electricity prices as well (Artana et al., 2007; He & Li, 2009; Escoffier, Hache, Mignon, Paris, 2020). Through their studies they calculated the impact of the shock of oil prices on some Central American countries. The study also indicated that the impact of

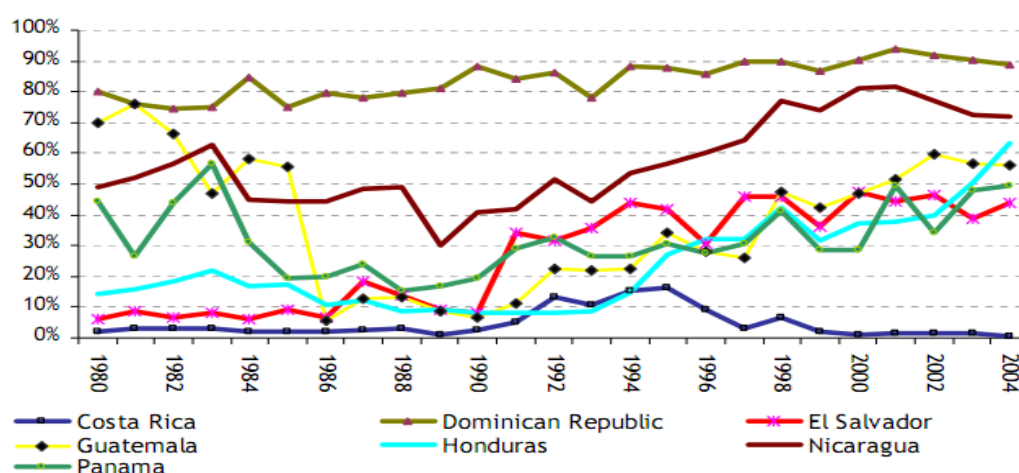
international petroleum prices on countries which electricity generation is not heavily based on thermal power is comparatively low. Central America is very vulnerable to movements in the international price of petroleum, mainly because during the 1990's Central America modified their production grid to be more dependent on thermal power. The reason for this decision according to the authors is that thermal plants require a lower initial investment than hydroelectric plants and that at the time the investment decisions made petroleum prices lower. Table 2 exhibits the price of producing energy increased as oil prices increased.

**Table 2. Increase of the Average Prices of Energy Production**

	Costa Rica	El Salvador	Guatemala	Honduras	Nicaragua	Panama	Simple Average
2003	8.2%	22.2%	21.4%	4.7%	26.3%	30.2%	18.8%
2004	16.6%	32.6%	25.0%	12.3%	32.6%	16.9%	22.7%
2005	18.7%	42.4%	32.8%	18.4%	52.3%	20.3%	30.8%
2006	19.3%	31.8%	24.5%	15.0%	27.8%	14.6%	22.1%
Accumulated 2003 to 2006	62.9%	128.9%	103.8%	50.4%	139.1%	81.9%	94.5%

Source: Artana et al. (2007), p. 12.

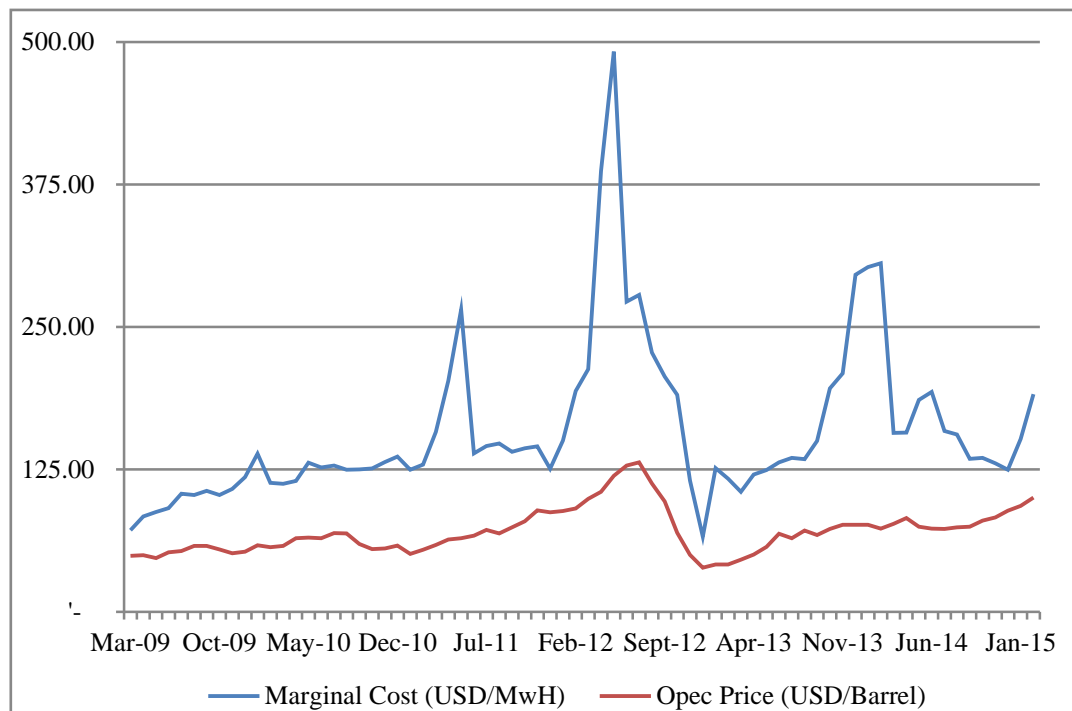
As illustrated in Figure 2, most of the countries in the study, excluding Costa Rica, followed this trend. Referring to the case of Costa Rica, the authors assert that switching to renewable types of energy can be a feasible solution to reduce the impact of the high level of petroleum prices in the electricity cost, because electricity production is no longer subject to the variations of petroleum prices. This implies that for any country to be less vulnerable to oil price shocks, investment in non-thermal plants is necessary.



**Figure 2. Thermal Generation as a Percentage of Total Electricity Generation**

Source: Elaborated by Artana et al. (2007), p. 30 with information from CEPAL.

Furthermore, the OPEC basket price in Figure 3 shows an increase of around 80% from March 2005 to December 2010. Contrasting it with the 46% increase of the marginal cost, we can preliminarily infer that thermal power might be a very important driver of the marginal cost.



**Figure 3. Marginal Cost of Electricity vs. OPEC Oil Prices**

Source: Elaborated with data from the CND (2005-2010) and OPEC basket prices available at [www.opec.com](http://www.opec.com)

#### 2.4 Additional Characteristics of the Electricity Supply

According to Takriti et al. (2000) electricity is traded between regions on a spot price basis. Moreover, market volatility can affect the input of electricity generation and the electricity trading between networks. To handle this situation, he defines his variables as stochastic variables. Takriti's (2000) concept of stochastic variables, which are values that are not known with certainty, can perfectly apply to electricity production by source, as it is a mix between domestically produced electricity and electricity purchased from outside the national electric grid. In other words, electricity produced from outside the system can be considered a stochastic variable, because the electric market has no way to precisely know or control how much electricity will be available for purchase at a certain period. Moreover, even though the national production of hydropower and thermal power can be controlled, the amount of water which will be available in the reservoirs to produce hydropower is uncertain. Even though generators base their production on forecasted demand values, demand itself is a variable that is very difficult to predict. Additionally, producer decisions of which source of production to use, and whether to produce or to purchase from outside the grid, will depend on several internal and external factors and decision criteria. Therefore, to make our model simple and workable it is assumed that such information is efficiently reflected by the values of the Mwh produced or purchased each month. In other words, we assume that the behavior of the entire market is reflected on the production volume, because the electric market is considered efficient.

Many studies on the subject targeted by Takriti et al. (2000) use deterministic models to approach electricity production allocation problems. An example of deterministic models used previously, though not mentioned in Takriti's study, is the work of *Anderson (1972)*. Even though this paper dates from the early 1970's, it is still being cited and was found cited as a reference in 363 papers regarding changes in electric network infrastructure, green energy related investments and optimization of electric systems. Its explanations and assumptions on the operating characteristics of electric networks are still valid nowadays, because electricity generation technology has not changed much throughout the years. Interestingly, *Anderson (1972)* mentioned in his work that hydropower usually has lower operation costs than fossil fuel-based power. Hydroelectric power is considered to be cheaper than fossil fuel alternatives because the water that moves the turbines used to produce electricity taken directly from the water sources available in the region of the plant at no cost other than the operation cost of taking the water from the source. However, hydroelectric power is not as reliable as fuel-based alternatives, and, therefore, needs to be combined with it in order for the system to be able to cover demand peaks and to ensure a stable supply of electricity that complies with the security levels required by the market.

Other studies found on the topic have a more social/political orientation providing good explanation of the ideologies and reasons behind Central American decision criteria for investment decisions pertaining to which kinds of electricity generation facilities to invest in. Nonetheless, these studies do not contribute to the development of our model. If the reader is interested in the topic, a good starting point is the 2004 policy research report of the World Bank (*Kessides, 2004*).

### 3. Research Methodology

#### 3.1 Data Collection

In order to establish a realistic model, data collected must be reliable and consistent. Accordingly, all information used in the study has been collected from official sources. Thanks to the regulations of the TMME, government entities and market regulatory organizations in Panama provide the required information freely to the public in order to comply with the transparency mandates. In Panama, the CND is the entity that coordinates all transactions and operations of the electric market and therefore, most of the information about the market can be found through their databases. Information such as electricity produced by source, demand and marginal cost, has been obtained from them. Also, most of the descriptions of the electric market have been extracted from information provided on the CND website. Information available on this website dates from March 2005 up to the present. Thus, we can be confident that the data series are broad enough for the analysis. Weather information, such as temperature used in the first section to verify the significance of the effect of temperature in electricity demand was obtained from the Department of Hydrometeorology at ETESA, which manages all national meteorological data in Panama and oil prices were obtained directly from the OPEC official website. No surveys are necessary for this work. Statistical analysis will be the tool used to determine the validity of the relationships between variables.

#### 3.2 Hypotheses Testing

Figure 3 shows four different electricity production alternatives that can be separated in two groups: electricity produced inside the electric grid and electricity produced outside the grid. The average electricity production mix has been explained in the first section. Depending on how much MWh of each production alternative is input into the system, it is expected that the marginal cost will increase or decrease. Based on the literature review and the behavior of the marginal cost schematized in Figure 1,

our first assumption is that the electricity cost will decrease as the concentration of hydroelectric power in the mix increases, given that it is significant to the marginal cost. Since hydroelectric plants usually have a lower average operating cost, the average cost of producing electricity should decrease. Therefore, we state our first hypothesis as follows:

*H1: There is a negative relationship between hydroelectric power and marginal cost.*

Additionally, as mentioned in the literature review, thermal power is normally used to cover demand peaks, because hydro power is said not to be as reliable as thermal power. This assertion is logical in that hydroelectric plants take their input (water) from the adjacent sources and the amount of water on those reservoirs depends on the weather. Weather, being an unpredictable and uncontrollable variable, gives water levels the same characteristics. Even though techniques such as constructing dams have been developed to minimize the variability of water levels and to provide the plants with more accessible water, it is impossible to control how much water is going to be available at any moment in time. Following the fact that thermoelectric plants, in theory, are more reliable than hydroelectric plants because we can control the input and because the utilized input (fossil fuel) is a limited resource with high price volatility, and following the findings summarized in the literature review and in the first section, we would expect that thermoelectric plants contribute to increase the marginal cost, given that the relationship is significant. Thus, we can state our second hypothesis as follows:

*H2: There is a positive relationship between thermoelectric power and marginal cost.*

Even though hydroelectric and thermoelectric power accounts for 89% of the electricity generated in the country, the remaining requirement is supplied by energy purchased from the Panama Canal and from outside the borders of the country. Such sources are “out of the grid” and therefore there is no control over their production costs. Therefore, stochastic variables are now introduced into the model, as the government and the distributors have no control over how that energy is produced out of the grid. Therefore, even if the quantity is small, compared to the sum of the other two alternatives, we would expect some extra variability in the marginal cost to be caused by those factors. Electricity purchases could present either a buffering effect on the marginal cost or contribute to its increase. The amount of available power for purchase will depend upon the capacity of the seller and the current demand of the electric systems where it is generated. However, despite such considerations, we can still track the effect of electricity purchases on marginal cost by studying the historical data provided by the time series obtained from the CND. It will be assumed that electricity purchased from outside the grid is more expensive than in-house produced electricity. Therefore, the third and fourth hypotheses are stated as follows:

*H3: There is a positive relationship between electricity purchased from the Panama Canal and marginal cost.*

*H4: There is a positive relationship between electricity purchased from outside the country and marginal cost.*

### 3.3 Variables

#### 3.3.1 Independent Variables

Our model has four independent variables. Each one of them accounts for a different source of producing or purchasing energy. We consider two groups: national produced electricity and out-of-system purchases, which also includes the electricity purchased from the Panama Canal. All the independent variables are measured in volume of production, measured in MWh, because of the lack of information about actual average production cost for each electricity generation alternative.

*National produced electricity: Hydroelectric Power and Thermoelectric Power*



Hydroelectric Power includes all energy produced by means of using water as an input to the production process. Thermoelectric power, on the other hand, is all energy produced by means of using fossil fuel as the input to the process of producing electricity. Total hydroelectric and thermoelectric power produced in Panama have already been grouped and added by the CND into a data series that is updated on a monthly basis.

#### *Electricity purchased from outside the network: Panama Canal Purchases and Electricity Imports*

As mentioned before, all the electricity used to satisfy the demand is not produced within the national electric network. A small portion of it is supplied from outside the system. On the one hand, the Panama Canal, which is an auto-generator, according to the CND classification of market participants, sells its excess electricity to the national electric network. On the other hand, electricity is also purchased from outside the country, mainly from TMME members. Information about purchases of electricity from outside the electric network has also been grouped and added by the CND to a data series that is updated on a monthly basis.

#### 3.3.2 Dependent Variables

Our model counts with only one dependent variable or response: marginal cost. The marginal cost is defined as the average cost in US Dollars of producing or in its defect purchasing one MWh. Information from all registered parties in the market is included and can also be considered as the average price paid by distributors for each MWh they sell.

## 4. Data Analysis

### 4.1 Data Analysis and Procedures

In this study, we used different types of software to process the data. Most of the data is processed in Excel, though some tests needed to be performed by using SPSS, Minitab and QM for windows 3. The data analysis procedure is further described in this section.

#### 4.1.1 Descriptive Statistics

Descriptive statistics include information such as average values, standard deviations and maximum and minimum values for each variable studied. This information will be calculated utilizing 60 data points, from January 2006 to December 2010.

#### 4.1.2 Deseasonalization

The data used in this study is influenced by seasonality and shows a trend. According to Render, Stair and Hanna (Pearson, 2009), when data series follow a trend and are influenced by seasonality, the month-to-month variations can be due to either factor, or to random error. In order to solve the problem, the authors suggest the use of the decomposition method. Deseasonalized data series usually show the relations between variables more clearly. Thus, the data obtained from the deseasonalized series describes more accurately the significance of the effect of each independent variable on the marginal cost.

#### 4.1.3 Regression Analysis

Regression analysis was performed in order to determine the relationship between variables. Because we are evaluating the effect of several factors in the marginal cost, multiple regressions were used. The Durbin-Watson test is performed in the first instance to verify that there is no presence of autocorrelation in the data. In order to be acceptable, the calculated D-W value should be between 1.7 and 2.3. If the results are satisfactory, the regression is acceptable. However, a D-W value within the accepted limits test does not indicate that the model is accurate. Thus, the accuracy of the model will be evaluated by the mean absolute percentage error [MAPE]. If the data series perform well in both tests,

then the resultant equation can be used to explain the relations between independent and dependent variables. A graphic representation of the complete data analysis procedure, including data collection is presented in Figure 4.

#### 4.2 Descriptive Statistics

The average, standard deviation, maximum and minimum of the data were calculated and summarized in Table 3, where H is hydropower, TH is thermal power, ACP stands for Panama Canal purchases, EI stands for electricity imports and MC represents the marginal cost. The factor with the greatest variability is electricity imports, with a standard deviation that represents 110% of its average value. The rest of the production factors show a lower standard deviation with values ranging from 18% to 29% of their average value. However, the marginal cost itself displays substantial variability as well, with a standard deviation of 43% of its average value.

**Table 3. Descriptive Statistics for the Variables in the Model**

Parameter	H (MwH)	TH (MwH)	ACP (MwH)	EI (MwH)	MC (MwH)
Minimum	166,664	76,579	30,542	0	66
Maximum	408,434	296,520	80,534	19,783	492
Average	295,255	174,177	53,700	4,703	169
Standard Deviation	54,597	50,251	12,365	5,196	73

#### 4.3 Deseasonalization and Regression Analysis

As suggested by Render (Pearson, 2009) all data series were deseasonalized by applying the decomposition method before doing the regression analysis. QM for Windows 3, version 3.1 (Build 45) from Pearson Education, Inc. was used to make the corresponding calculations. To ensure that the seasonal coefficients are as accurate as possible only complete years were included in the analysis. Therefore, we have excluded year 2005, because the information obtained from the CND reports for year 2005 is only available from March through December. Therefore, the data points used for the analysis are only 60 in total or five years of data from 2006 to 2010.

Tropical weather follows a more erratic pattern than other kinds of weather, because the seasons do not have the same duration. The proportion of rainy to dry season is approximately  $\frac{1}{4}$  to  $\frac{3}{4}$ . Because the decomposition method does not allow for dissimilar seasons, different approaches of seasonality need to be tested to find the one with the best fit to the data. We have tested quarters, 2-month seasons and 1-month seasons.

Quarters are tested as a seasonal approach, because dry and rainy season are distributed as  $\frac{1}{4}$  dry and  $\frac{3}{4}$  rainy in average. The 1-month season approach was tested, because tropical weather patterns usually show month-to-month variability. However, according to the Smithsonian Tropical Research Institute, weather changes can be delayed or advanced by one or two weeks. This means we should leave some space to account for that variability. Thus, the 2-month season approach was tested to account for that slack. The parameters set to perform the deseasonalization procedure are shown below:

- Method: Multiplicative decomposition (seasonal)
- Number of seasons: 4, 6, 12

- Basis of smoothing: Centered Moving Average
- Seasonal Factor Scaling: No

For each level of deseasonalization, multiple regression was performed, and it was found that deseasonalizing to quarters smoothed too much the data, to the point that the coefficient of determination was almost 100% and the F-statistic of the model was in the order of  $10^{-76}$ . On the other hand, the 2-month season approach and the 1-month season approach show better results. Both models appear to be significant, according to the F-Statistic, though the significant factors present in each model are not the same. For the 1-month approach, only thermal power is a significant factor affecting the marginal cost, while the 2-month approach also includes Panama Canal purchases and electricity imports. In both cases hydropower did not show a significant relation.

The Durbin-Watson test was performed for the two models by using SPSS to test if there were autocorrelation in the time series. The results of the test were 2.2 for the 1-month seasons model and 1.7 for the 2-month seasons model. Both models are within the acceptable limits. However, it is important that we select the model with the best fit to the data. We have used 60 data points, from January 2006 to December 2010, to do the regression analysis and we have obtained the corresponding equations for both models. In order to do the MAPE the first 6 periods of 2011 are forecasted and compared to their actual values. The results of the forecast and MAPE calculations are shown in Table 5 and Table 6 and the correspondent equations are the following:

1-month season model:  $MC = 39.81 + 7.4 \times 10^{-4} TH$

2-month season model:  $MC = 313.2 + 6.7 \times 10^{-4} TH - 4.5 \times 10^{-3} ACP - 3.6 \times 10^{-3} EI$

**Table 4. Forecast Results for 1-Month Seasons Model**

Period	Actual Marginal Cost	Seasonal Factor	Forecasted Marginal Cost	Absolute Error	% Error
January 2011	151.62	0.97	151.00	0	0.00
February 2011	191.05	1.02	212.00	21	0.11
March 2011	221.26	0.88	234.00	12	0.06
April 2011	240.94	1.17	318.00	77	0.32
May 2011	277.94	1.42	441.00	163	0.59
June 2011	266.96	1.00	293.00	26	0.10
				MAPE	0.20

**Table 5. Forecast Results for 2-Month Seasons Model**

Period	Actual Marginal Cost	Seasonal Factor	Forecasted Marginal Cost	Absolute Error	% Error
January 2011	151.62	0.98	182.00	31	0.20
February 2011	191.05	0.98	271.00	80	0.42
March 2011	221.26	0.90	226.00	4	0.02
April 2011	240.94	1.03	304.00	63	0.26
May 2011	277.94	1.10	385.00	108	0.39
June 2011	266.96	0.94	229.00	38	0.14
				MAPE	0.24

Comparing Tables 5 and 6, it can be inferred that the 1-month seasons model have a better fit to the data than the 2-month seasons model. The regression analysis, after removing the non-significant terms for the 1-month season model is shown in Table 6.

**Table 6. Regression Results 1-Month Seasons Deseasonalization**

Regression Statistics					
Multiple R	0.830326				
R Square	0.689442				
Adjusted R Square	0.684087				
Standard Error	16.46435				
Observations	60				
ANOVA					
	df	SS	MS	F	Significance F
Regression	1	34903.75	34903.75	128.7605	2.33E-16
Residual	58	15722.35	271.0749		

Total	59	50626.09						
	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	39.8104	11.58732	3.435685	0.001099	16.61585	63.00495	16.61585	63.00495
Thermal	0.000742	6.54E-05	11.34727	2.33E-16	0.000611	0.000873	0.000611	0.000873

Table 6 shows the 1-month seasons model. The other production alternatives were found not to have a significant relation to the marginal cost. The model above also reveals that the coefficient of the thermal power is in the order of  $10^{-4}$ . Please note that while marginal cost (dependent variable) is measured in USD/MwH, which is in the order of tenths and hundreds, the volume of production by each alternative (independent variables), given in MwH, is usually in the order of thousands and hundreds of thousands. Rescaling couldn't be applied to the data series because there were some zero values in the time series of electricity imports, which didn't allow us to apply LOG function to the data series. However, the model is significant according to the F-Statistic value and the P-value of the variable shows that it is also significant. After conducting the multiple regression analysis, we can conclude that H1, H3, and H4 are rejected and that H2 is accepted. In other words, all production alternatives except for thermoelectric power are not significantly related to the marginal cost. Therefore, we can conclude that thermal power generation is an important driver of the marginal cost. Our findings are in line with Artana's (2007) research, which indicates that fossil fuel-based electricity production has a significant impact on the cost of producing electricity. The equation that describes the model is obtained from the regression analysis and can be written as:

$$MC = 39.81 + 7.4 \times 10^{-4} TH$$

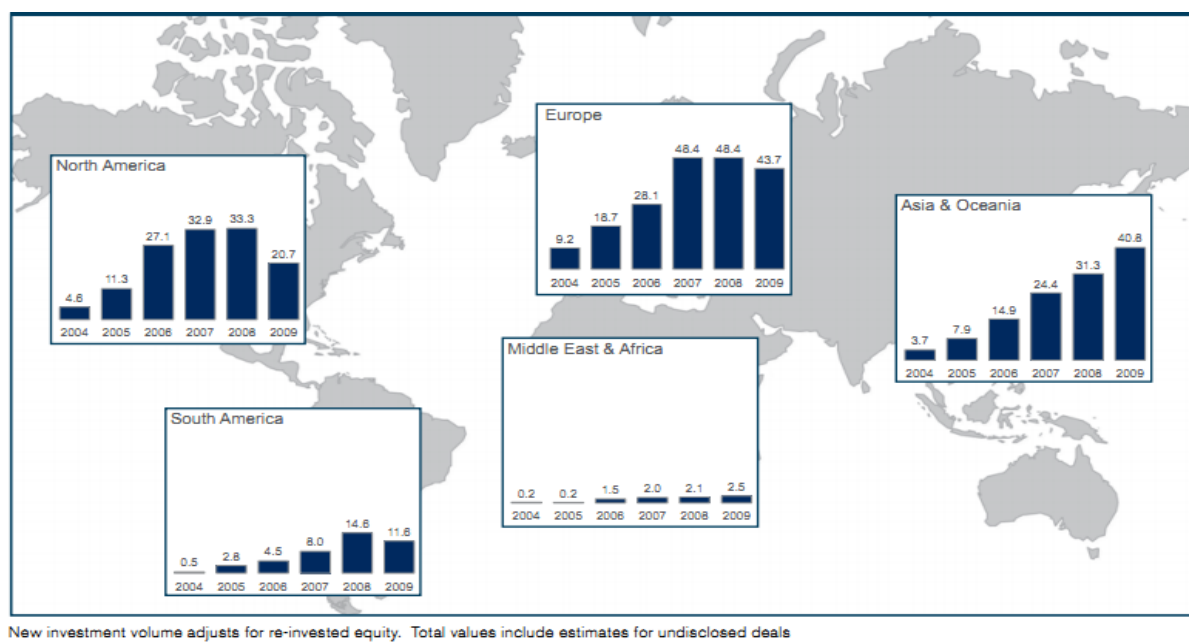
Where TH represents the thermal power and MC is the marginal cost. The equation shows that the marginal cost has a lower bound of 39.81USD/MwH if the value of TH is set to 0 and increases as thermal power utilization scales up. Our model further confirms the assumptions about thermal power based production of electricity having an adverse effect on the marginal cost, as exposed by Artana (2007). Moreover, the fact that the other production alternatives were found not to have a significant effect also means that by reducing the dependence of fossil fuel-based alternatives the marginal cost can be decreased. However, we must remember that thermal power is one of the most reliable electricity production alternatives.

#### 4.4 Implications of the Findings

It is in the interest of the market in general, to reduce the marginal cost. It can be discussed that according to the equation obtained from the regression analysis, thermal power dependence needs to be reduced. However, there are some limitations to this approach. The fact that thermal power generation is still present around the globe is an indicator that there are reasons to keep these plants running. Even though hydroelectric power, Panama Canal purchases and electricity imports were found not to be significant, producing electricity through hydroelectric plants does generate an operation cost and electricity originated from outside the electric network has a purchasing cost. The fact that the regression analysis found them not significant doesn't mean they don't add up to the cost, but that the variation of their value does not significantly impact the outcome of the marginal cost.

Moreover, the literature review and the further regression analysis of the impact of OPEC oil prices on the marginal cost of electricity in Panama also support our argumentation. The relationship between oil prices and electricity cost is already proven, therefore it makes sense that the thermal power has a significant impact on the marginal cost. The real problem is how to reduce the dependence on thermoelectric power to cover the demand peaks. If we refer to Table 4, we can see that the maximum historical electricity production of hydroelectric power is around 408,434MwH. On the other hand, the historical average demand is around 516,921MwH. This means that the historical maximum production of hydroelectric power can only cover approximately 79% of the average demand.

Electricity purchases are not enough to cover the demand, because their contribution to the total electricity production is low and are not controllable variables, because they are external to the system. That means that even if we wanted to purchase electricity from the Panama Canal or import it from outside the country to supply what hydro power is not able to supply, it makes no sense to establish goals for the purchases if there is no security that the demanded power will be provided. As explained before by Takriti (2000), hydro plants are used to cover average demand, leaving the peaks to be covered by thermal power. This means that, if we can increase the level of coverage of non-fossil fuel-based production alternatives, we could make the peaks that need to be covered by thermal power smaller in magnitude. In that way, the marginal cost could be reduced. It is not by chance that green technology shows an increasing trend all over the world as mentioned in the *Renewables Global Status Report* (2010).



**Figure 4. Financial New Investment by Region, 2004-2009 (USD Billions)**

Source: Global trends in sustainable energy investment (UNEP, 2010).

Even though, hydroelectric plants can bring benefits to the system by reducing the average production cost, in the medium to long-term, water sources are limited and therefore the hydroelectric network can't be expanded infinitely. Other production alternatives can also be used to cover average demand, such as solar power, and wind power, especially in countries like Panama with high solar radiation levels between 4.5 and 5.0, according to the PV education website. Green technology is becoming

more efficient and is being more widely supported.

## 5. Conclusion

This study demonstrates that the electric system in Panama is vulnerable to petrol price shocks. The resultant regression model clearly supports the studies of Artana (2007). The high dependability of the electric system on thermal power is the main cause of the increase of the marginal cost during the studied period. To test whether our hypotheses were supported, we used linear regression. Hypothesis 1 (H1): The relationship between hydroelectric power and marginal cost is significant, and hypothesis 3 (H3): The relationship between Panama Canal purchases and marginal cost is significant, and hypothesis 4 (H4): The relationship between electricity purchased from outside the country and marginal cost is significant were all not supported in our study. Hypothesis 2 (H2): The relationship between thermoelectric power and marginal cost is significant was supported in our research. Following the objectives stated in the introduction we can state that after analyzing the different production factors we found out that only one of them was significant. The regression analysis of the independent variables (thermoelectric power, hydroelectric power, purchases from Panama Canal and Electricity imports) shows that the only significant factor is the thermoelectric power.

The main contribution of this paper, if not achieving any major leap on numerical methods or offering any new solution to solve the electricity problem, is to provide the end users in Panama with a realistic point of view, different from the one provided by the multinational companies. Those companies in most Latin American countries (Hall, 2004), and whose main objective is to profit from our markets as much as they can with the least investment. This study also aims at opening the eyes of the end users to the reality of our markets in order to motivate changes towards more green electricity production alternatives. The UNEP reports clearly show a global trend of implementing green energies and emphasize the benefits to implement non-fuel-based alternatives. Being green is not only about protecting the environment (Liu et al., 2020), but it is also part of achieving the Paris Climate Agreement and United Nations Sustainable Development Goals (UNDGs) (Baniya, Giurco, & Kelly, 2021; Akram, Chen, Khalid, Huang, Irfan, 2021). There are also economic reasons to switch to cleaner energies. This paper supports a scarce collection of publications that criticize how electric networks have been developed and the badly managed deregulation and privatization of Latin American markets in general. The Central American countries need to start pushing for a new network development approach if they truly want the TMME initiative to fulfill its objectives and if they really want to improve the quality of life of their population. Otherwise, the TMME is just a bigger market for multinational companies to profit from in a more cost-effective way. Moreover, renewable energies present a clear benefit for each individual country and therefore we want to encourage Panamanian citizens to promote renewable energies. An electric system that is less vulnerable to petroleum price shocks needs to be developed. Fossil fuel-based alternatives not only bear a higher production cost, but also have high social and environmental costs. The use of thermal plants to produce electricity also fosters the need for oil transportation, which can lead to natural disasters such as the one which occurred in the Gulf of Mexico in 2010. Also, according to Baumert et al. (2005), power generating plants running on fossil fuels are the largest source of CO<sub>2</sub> emissions worldwide. This is contributing to global warming, which according to the Intergovernmental Panel on Climate Change 4<sup>th</sup> Assessment Report 2007, is undeniable and can be observed in the increase of air and ocean temperatures, average surface temperature, snow melting all around the world and the increase of global average sea levels (Pachauri & Reisinger, 2007).

Our model, as any study, is bound by some limitations. The most critical one is that the financial cost of each MwH produced by the different alternatives was not available. Therefore, we had to base our regression model on volume of electricity produced. Performing a similar analysis with actual prices for each MwH produced or purchased by each different alternative could probably allow a more accurate model. Time limitations and privacy policies from the involved entities did not allow us to obtain these data in a timely manner and therefore future researchers should focus on developing these models. We think that it is important to research more in-depth how clean production alternatives affect the marginal cost of producing electricity in order to motivate the population to push the government to support clean energy production for sustainable development. Moreover, as stated by Artana et al. (2007), investing in non-thermal electric production has beneficial effects on the cost of electricity in the long run. Integrating more green sources of electricity makes the network less vulnerable to petroleum prices shocks. We hope that this study, being first in its class for Panama and probably Central America, can be referenced for future research on the performance of the Central American Electric Market and of each country in particular, thus contributing to the development of an efficient regional electric market that will really create tremendous benefits for end-users.

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