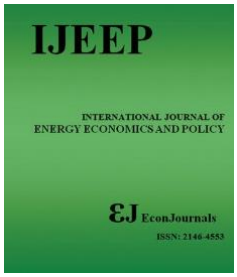

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Analysis of a Log-Linear Model for Forecasting Electricity Demand Based on Economic Growth in Colombia

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ABSTRACT

This study analyses the relationship between the Gross Domestic Product and Electricity Demand in Colombia. The development of these forecasting models supports long-term electricity sector planning. The study used annual data from 2006 to 2023 to construct two regression models—one linear correlation and the other log-linear. Actual data for 2024 were used to validate the predictive capacity of both models. Indicators such as R2, MAE, RMSD, and MAPE were used to evaluate the fitting period. The results show that the log-linear model achieved greater accuracy, with an MAPE of 1,30% in the fit and an error of 0,58% in the validation of the 2024 data. This approach demonstrates the usefulness of incorporating logarithmic transformations in energy models to obtain a more robust fit between economic and energy variables.

Keywords: Econometric Model, Energy Planning, Annual Forecast
JEL Classifications: Q41, Q43, Q47

1. INTRODUCTION

The Electricity Demand (ED) has increased significantly in recent decades due to economic growth, urbanization, and technological advancements (Mezghani and Ben Haddad 2017; Scheffran et al., 2020). The ability to accurately forecast future electricity needs has become a critical strategic tool and an important pillar for the sustainability and stability of modern energy systems (Shakouri et al., 2023).

Reliable demand forecasting enables system operators and government agencies to make informed decisions that optimize electricity generation, transmission, and distribution, reducing the risks of shortages or oversupply (Fose et al., 2024; Khan et al., 2023). Moreover, the increasing integration of renewable energy sources (Prado-Bonilla et al., 2021) and the transition toward low-carbon economies have added complexity and volatility to electricity demand (Shah et al., 2022; Velasquez et al., 2022), underscoring the need for robust and adaptive forecasting models (Ahmad et al., 2022). Without accurate forecasts, the reliability of power supply may be compromised, leading to higher operating costs and adverse impacts on both economic productivity and quality of life (Ahmad et al., 2022; Mohammed and Al-Bazi 2022; Nti et al., 2020).

Electricity Demand (ED) forecasts are vital for planning infrastructure expansion, assessing the feasibility of investments in new generation plants, and enhancing the resilience of power systems against unexpected disruptions (Gebremeskel et al., 2021; Silva-Ortega et al., 2023; 2025). Among the various forecasting approaches, linear models that incorporate macroeconomic variables (Gebremeskel et al., 2021; Grimaldo-Guerrero et al., 2021; Li et al., 2021), such as Gross Domestic Product (GDP) (Grimaldo Guerrero et al., 2017), have been widely used. Due

to their simplicity and strong correlation with ED, these models provide a valid and reliable basis for decision-making in energy planning.

This study extends previous analyses of the relationship between GDP and annual ED in Colombia, highlighting the strong connection between economic activity and electricity consumption. It examines the linear relationship between GDP and ED using data from 2006 to 2023, compares it with a log-log linear model, and evaluates the forecasting performance of both approaches for the year 2024. The findings provide valuable insights for energy planning, supporting the management of generation capacity and the design of growth strategies aligned with projected demand.

2. METHODOLOGY

The methodology of this study was structured in three phases to analyse and model the relationship between Gross Domestic Product (GDP), provided by the Bank of the Republic of Colombia (Banrep, 2025), and the Electricity Demand (ED), reported by the Colombian electricity system operator (XM, 2025a; 2025b).

In the first phase, a linear correlation analysis was conducted using data from 2006 to 2023, and descriptive statistics along with a linear regression model (ASCN 2025b) were developed to explore the direct relationship between the variables. In the second phase, a log-linear regression model (ASCN, 2025a) was constructed by applying a natural logarithmic transformation to both variables to reduce skewness and stabilize variance. The model parameters and associated statistical measures were determined to evaluate their performance relative to the simple linear model.

Finally, the third phase involved a forecasting analysis to validate the predictive capacity of the proposed models. For this purpose, error metrics such as mean absolute error (MAE), root mean square error (RMSE) and mean absolute percentage error (MAPE) were computed for the training period (2006–2023) (Ahmad et al., 2022; Fraga-Hurtado et al., 2025). Additionally, the actual GDP for 2024 was used as an input to assess the accuracy of the projections generated by both models.

3. RESULTS

The evolution of Electricity Demand (ED) and its relationship with Gross Domestic Product (GDP) are key to understanding the dynamics between energy consumption and a country's economic performance. This study analyses data from 2006 to 2023, with 2024 serving as a validation year to assess forecasting capabilities. Figure 1 illustrates electricity demand in GWh alongside the annual percentage growth rates of both ED and GDP, highlighting interannual variability.

The figure illustrates a clear relationship between GDP and ED, with a notable disruption in 2020 due to the effects of the COVID-19 pandemic, which led to a decline in productive activity and a sharp rebound in the following year.

3.1. Correlation between GDP and Electricity Demand

To examine the relationship between GDP and ED in Colombia over the period 2006–2023, a linear regression analysis was conducted, incorporating the Pearson correlation coefficient to assess the strength and direction of the association. This analysis quantifies the extent to which economic growth influences energy consumption, highlighting GDP as a key determinant of electricity demand. Table 1 summarizes the regression statistics for this model.

The results revealed a correlation coefficient of R = 0,9793, indicating an extremely strong positive linear relationship between GDP and ED. This value suggests that as the Colombian economy grows, there is a proportional increase in electricity demand. Furthermore, the analysis of for the regression model yielded an F statistic of 374,54 with a critical F value of $1{,}5877\times10^{-12}$, confirming the model's extremely high statistical significance. Table 2 summarizes the regression results.

The linear regression model between GDP and DEE yielded highly significant results. The slope of GDP was 0,025 and the intercept was 43.092,15. The t-statistics obtained for both coefficients (37,161 and 19,353) provide strong evidence that these parameters are statistically different from zero. The results confirm the existence of a strong linear relationship between GDP and ED. Figure 2 presents a graphical representation of the regression results.

Figure 1: Behaviour of ED and GDP

Source: Banrep, 2025; XM 2025a, 2025b

Table 1: Statistics of the regression between GDP and DEE for the years 2006–2023

Indicator	Value
Multiple correlation coefficient	0,9793
Coefficient of determination R^2	0,9590
Adjusted R^2	0,9565
Standard error	1820,7253
Observations	18

Table 2: Linear regression model between GDP and ED for the years 2006–2023

Model 01	Coefficient	Standard error	Statistic t	P-value
Interception	43092,149	1159,614	37,161	5,847E-17
GDP	0,025	0,001	19,353	1,588E-12

The graphical representation exhibits an ascending pattern with a linear trend. The regression line highlights the positive slope of the relationship and confirms the absence of significant outliers that could influence the analysis.

3.2. Log-Linear Model between GDP and Electricity Demand

To capture the proportional, rather than purely additive, relationship between GDP and ED, a log-linear regression model was developed. This approach enables the estimation of energy elasticity, defined as the percentage change in electricity demand in response to a percentage change in GDP. The model is expressed as:

$$\ln(ED) = \beta_0 + \beta_1 \ln(GDP) + \varepsilon \quad (1)$$

Where ln(GDP) and ln(ED) represent the natural logarithmic transformations of the original variables, the values of β represent the model coefficients, and ε represents the error term. Table 3 summarizes the regression statistics for the log-transformed variables.

The results yielded a correlation coefficient of R = 0,9931, indicating an extremely strong positive linear relationship between ln(GDP) and ln(ED). This suggests that as the Colombian economy grows, there is a proportional increase in electricity demand. Compared to the previous model, the correlation values are closer to 1, reflecting an improved fit. Furthermore, the analysis of variance for the regression model produced an F statistic of 1.155,83 with a critical F value of $2{,}3866\times10^{-16}$, confirming the model's extremely high statistical significance. Table 4 summarizes the regression results for the log-linear model.

The linear regression model between ln(GDP) and ln(DE) produced highly significant results. The estimated slope for GDP was 0,332 and the intercept was 6,558. The t-statistics for both coefficients (49,536 and 33,998) provide evidence that these values are statistically different from zero. These findings confirm the existence of a strong linear relationship between ln(GDP) and ln(DE). Figure 3 illustrates a graphical representation of the regression results.

The graphical representation exhibits an upward pattern with a clear linear trend. The regression line highlights the positive slope of the relationship and confirms the absence of significant outliers that could influence the analysis. These results also demonstrate improved statistical indicators compared to the previous model.

3.3. Electricity Demand Forecast Analysis

To evaluate the performance of the developed models, a fit analysis was conducted for the period 2006–2023, followed by a validation exercise using actual electricity demand (ED) data for 2024. The models considered were a linear regression (Model 01) and a log-linear regression (Model 02), whose results were presented in the previous sections. Table 5 summarizes the actual data, the estimates from both models, the differences, and the corresponding percentage errors.

Figure 2: Correlation between GDP and ED

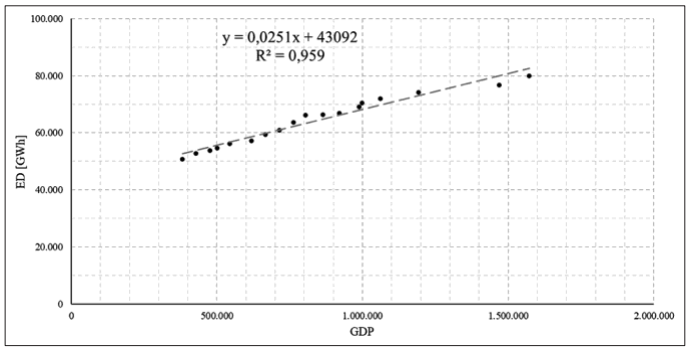

Figure 3: Log-Linear Model between GDP and ED

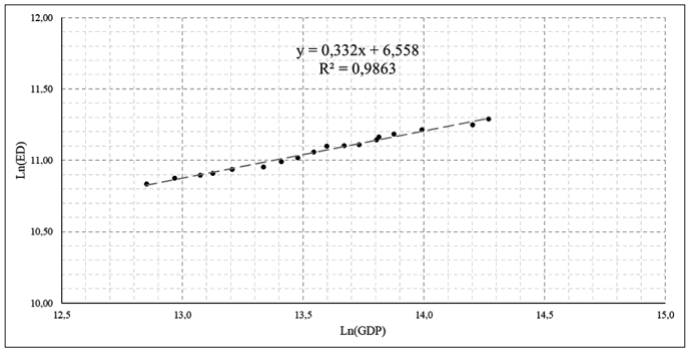

Table 3: Regression statistics between ln (GDP) and ln (ED) for the years 2006–2023

Indicator	Value
Multiple correlation coefficient	0,9931
Coefficient of determination R^2	0,9863
Adjusted R^2	0,9855
Standard error	0,0165
Observations	18

Table 4: Linear regression model between ln (GDP) and ln (ED) for the years 2006–2023

Model 02	Coefficient	Standard error	Statistic t	P-value
Interception	6,558	0,132	49,536	6,110E-19
GDP	0,332	0,010	33,998	2,387E-16

The analysis indicates that Model 02, based on the logarithmic transformation, consistently achieved lower percentage errors than Model 01 during the adjustment period. Model 01 had MAE (Mean Absolute Error) of 1.494 GWh, RMSD (Root Mean Square Deviation) of 1.717 GWh, and MAPE (Mean Absolute Percentage Error) of 2.29%. Model 02 had MAE of 838 GWh, RMSD of 1.014 GWh, and MAPE of 1.30%, demonstrating greater accuracy.

For the validation exercise using 2024 data, the actual electricity demand was 82.085 GWh. Model 01 forecasts a demand of 85.854 GWh, with an absolute difference of −3.769 GWh and a percentage error of −4.59%, indicating an overestimation. Model 02 projected 82.564 GWh, with an absolute error of −479 GWh and a percentage error of −0.58%, reflecting a closer alignment with the observed value.

Table 5: Comparison of actual data and estimates from Models 01 and 02

Real			Model 01			Model 02			
Year	GDP	ED	Forecast	Diff	%	Ln (ED)	Forecast	Diff	%
2006	381.604	50.815	52.661	−1.846	−3.63	10,8243	50.229	586	1.15
2007	428.506	52.853	53.837	−984	−1.86	10,8628	52.199	654	1.24
2008	476.554	53.870	55.042	−1.172	−2.18	10,8981	54.074	−204	−0.38
2009	501.574	54.664	55.669	−1.005	−1.84	10,9151	55.000	−336	−0.61
2010	544.060	56.137	56.735	−598	−1.06	10,9421	56.505	−368	−0.66
2011	619.023	57.148	58.614	−1.466	−2.57	10,9849	58.979	−1.831	−3.20
2012	666.507	59.370	59.805	−435	−0.73	11,0095	60.444	−1.074	−1.81
2013	714.093	60.890	60.998	−108	−0.18	11,0324	61.843	−953	−1.57
2014	762.903	63.571	62.222	1.349	2.12	11,0543	63.216	355	0.56
2015	804.692	66.175	63.270	2.905	4.39	11,0720	64.345	1.830	2.77
2016	863.782	66.319	64.752	1.568	2.36	11,0955	65.876	443	0.67
2017	920.471	66.893	66.173	720	1.08	11,1166	67.281	−388	−0.58
2018	987.791	69.127	67.861	1.265	1.83	11,1401	68.876	250	0.36
2019	1.061.119	71.925	69.700	2.225	3.09	11,1638	70.533	1.392	1.94
2020	998.471	70.422	68.129	2.293	3.26	11,1436	69.123	1.299	1.85
2021	1.192.634	74.117	72.998	1.119	1.51	11,2026	73.323	794	1.07
2022	1.469.791	76.657	79.948	−3.290	−4.29	11,2720	78.589	−1.932	−2.52
2023	1.572.458	79.982	82.522	−2.540	−3.18	11,2944	80.371	−389	−0.49
2024*	1.705.322	82.085	85.854	−3.769	−4.59	11,3213	82.564	−479	−0.58

The results indicate a greater effectiveness of Model 02 (log-linear), which more accurately captures the relationship between economic growth and electricity demand. This provides an additional tool that can provide greater reliability for energy planning. Its ability to generate more accurate forecasts is key to strategic decision-making aimed at ensuring an efficient and sustainable electricity supply in Colombia.

4. CONCLUSION

This research analysed the relationship between Gross Domestic Product (GDP) and electricity demand (ED) in Colombia during the period 2006–2024, using two statistical models to forecast electricity demand. The results confirm the existence of a positive and significant correlation between both variables, which validates the use of GDP as the main predictor of the evolution of ED trends. This relationship is reflected in the high values of the coefficient of determination (R2) obtained in the applied models, with an R^2 of 0,959 for the linear model and 0,987 for the log-linear model.

The models showed differences in predictive performance; the log-linear model presented a better fit and lower error dispersion, with MAE of 838 GWh and MAPE of 1.30% for the training period (2006–2023). In the validation using the 2024 data, this model showed greater accuracy, with an absolute percentage error of 0.58%, compared to 4,59% observed in the linear model. The results show that the logarithmic transformation positively impacts the model's ability to capture the relationship between GDP and ED.

The enhanced predictive capability of the log-linear model makes it a valuable tool for national electricity sector planning. It supports the estimation of future infrastructure requirements, the development of energy efficiency strategies, and the assurance of supply security. The proposed methodology can be extended to other models, such as multivariate models, and adapted to higher-resolution time series, enabling more detailed and timely forecasting for strategic energy planning.

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