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Short-Run dynamics and forecasting of per capita electricity consumption in Ecuador: Empirical evidence using ARIMAX model

Dinámica de corto plazo y pronóstico del consumo eléctrico per cápita en Ecuador: Evidencia empírica mediante un modelo ARIMAX

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Abstract

This study analyzes the dynamics of per capita electricity consumption in Ecuador and its relationship with per capita GDP and CO_2 emissions during the period 1990–2022. Augmented Dickey-Fuller (ADF) tests indicate that the variables are integrated of order one I (1), while the Engle-Granger procedure confirms the existence of a long-term equilibrium relationship between the series. Since the main objective is medium-term energy forecasting, rather than strictly causal inference, an ARIMAX (1,0,2) model is estimated in levels to preserve long-term information and capture the temporal dynamics of electricity consumption. Model selection was performed using AIC, AICc, and BIC criteria, complemented by out-of-sample validation for 2019–2022. The results show high temporal persistence of electricity consumption and a positive income elasticity, allowing for the generation of dynamic projections up to 2026 with adequate predictive performance.

Keywords: energy, arimax, forecast, elasticity, electricity, forecasting

Resumen

Este estudio analiza la dinámica del consumo eléctrico per cápita en Ecuador y su relación con el PIB per cápita y las emisiones de CO_2 durante el período 1990-2022. Las pruebas Dickey-Fuller aumentadas (ADF), indican que las variables son integradas de orden uno I(1), mientras que el procedimiento de Engle-Granger confirma la existencia de una relación de equilibrio de largo plazo entre las series. Dado que el objetivo principal es la previsión energética a mediano plazo, más que la inferencia estrictamente causal, se estima un modelo ARIMAX (1,0,2) en niveles para preservar la información a largo plazo y capturar la dinámica temporal del consumo de electricidad. La selección del modelo se realizó mediante criterios AIC, AICc y BIC, complementados con una validación fuera de muestra para 2019-2022. Los resultados evidencian elevada persistencia temporal del consumo eléctrico y una elasticidad ingreso positiva, permitiendo generar proyecciones dinámicas hasta 2026 con adecuado desempeño predictivo.

Palabras Clave: energía, arimax, pronóstico, elasticidad, electricidad, forecasting

Introduction

Electricity consumption plays a central role in economic development, as it is a cross-cutting input for production, services, and households. The economic literature has extensively documented the close relationship between energy use and economic growth, industrialization, and improvements in welfare levels (Stern, 2004; Apergis & Payne, 2010). In developing countries such as Ecuador, this relationship takes on particular significance due to the coexistence of energy infrastructure constraints, macroeconomic volatility, and institutional limitations on long-term planning (Ouedraogo, 2017).

The electricity sector has undergone significant transformations in recent decades, driven by investments in generation, changes in the energy mix, and sustainability-oriented policies (Ministry of Energy and Mines, 2023). However, planning for the electricity system continues to face challenges related to the timely availability of statistical information. In particular, official data on per capita electricity consumption are often published with a lag of one or more years, making it difficult to use them for short-term decision-making and the timely evaluation of public policies.

In this context, *forecasting* is a relevant empirical tool for projecting the future evolution of electricity consumption using historical dynamics of macroeconomic and energy variables, enabling the generation of forward-looking scenarios useful for demand planning and public policy formulation (Hyndman & Athanasopoulos, 2021; Box et al., 2015).

In the energy sector, various studies have applied time-series models to forecast electricity demand, with the ARIMA and ARIMAX approaches standing out for their flexibility and econometric robustness (Box & Jenkins, 1976; Liu & Lin, 1991). The inclusion of exogenous variables allows for the capture of the influence of macroeconomic and environmental factors, thereby improving the explanatory and predictive power of time-series models (Box et al., 2015; Hyndman & Athanasopoulos, 2021). In particular, gross domestic product (GDP) per capita has established itself as a key determinant of energy consumption (Kraft & Kraft, 1978; Ozturk, 2010), while per capita CO_2 emissions partially reflect energy intensity, the structure of production, and the economy's degree of dependence on fossil fuels (Warr et al., 2010).

This study contributes to the applied literature on energy demand in Ecuador by estimating an ARIMAX model of per capita electricity consumption that incorporates relevant macroeconomic and environmental variables. Unlike approaches focused exclusively on long-term causal relationships, this research prioritizes medium-term energy *forecasting* and out-of-sample validation, generating dynamic projections useful for energy planning and assessing electricity demand through the year 2026.

The empirical strategy combines estimating electricity consumption with projecting exogenous variables using univariate ARIMA models, thereby extending the *forecasting* horizon in the absence of observed data (Hyndman & Athanasopoulos, 2021).

Unlike previous studies that focused primarily on causal relationships or long-term aggregate projections, this research emphasizes medium-term energy *forecasting* and the model's econometric consistency, incorporating tests for stationarity, cointegration, out-of-sample validation, and dynamic specification diagnostics (Engle & Granger, 1987; Hyndman & Athanasopoulos, 2021).

Additionally, out-of-sample predictive evaluation allows us to examine the model's robustness to macroeconomic shocks and sample size limitations, an aspect that is particularly relevant in economic forecasting applications (Pesaran & Timmermann, 2005).

In this context, the study not only provides empirical evidence on the dynamics of per capita electricity consumption in Ecuador, but also proposes a replicable methodological strategy for emerging economies with information constraints and limited availability of high-frequency data.

Literature Review

The relationship between economic growth and energy consumption has become one of the central themes in energy economics over the past four decades. From an extended neoclassical perspective, Stern (1993) proposed incorporating energy as an additional factor of production into the aggregate production function, arguing that traditional formulations systematically underestimate its contribution to output. Within this conceptual framework, electricity consumption not only serves as an indicator of the level of economic activity but also directly influences total factor productivity through mechanization, automation, and technological efficiency.

Since the pioneering work of Kraft and Kraft (1978), empirical evidence has documented different patterns of causality between energy consumption and economic growth, depending on the productive structure and level of development of each economy.

In developing economies, electricity typically functions as a key intermediate input for productive expansion, generating procyclical relationships between economic activity and energy demand (Apergis & Payne, 2009). This evidence supports the hypothesis that energy is energy-dependent on growth, according to which an increase in per capita income systematically drives electricity consumption.

However, the empirical literature has focused on analyzing long-term relationships using cointegration and vector error correction models (Johansen, 1991; Engle & Granger, 1987). Although these approaches are useful for identifying structural equilibria between macroeconomic and energy variables, they have limitations when the primary objective is energy forecasting and short- and medium-term predictive assessment.

In this context, recent research has emphasized the importance of dynamic, forecast-oriented models to support energy planning and public policy design (Hyndman & Athanasopoulos, 2021).

ARIMA models are among the most well-established methodologies in time series analysis, due to their ability to model persistence, autoregressive components, and short-term dynamics.

When the variable of interest also depends on observable macroeconomic factors, the natural extension is an ARIMAX model, which incorporates exogenous regressors into the dynamic structure of the process. Various studies have shown that ARIMAX models significantly improve predictive power compared to purely univariate specifications in energy demand applications (Contreras et al., 2003; Mohamed & Bodger, 2005).

Recent studies have emphasized the importance of econometric and time-series models for estimating energy consumption and other related indicators, highlighting their usefulness in both the short and medium term. In this context, Mustafa and Al-Yozbaky (2025) conduct a comparative analysis of more than 145 studies focused on time-series models applied to forecasting energy demand, consumption, and production; The authors compare methodologies such as Moving Average (MA), Exponential Smoothing (ES), ARMA, ARIMA, Fuzzy Time Series (FTS), Prophet, and Gray Prediction models, evaluating their performance using accuracy metrics such as RSME, MAE, MAPE, and R2, highlighting that ARIMA models and their extensions remain reliable forecasting techniques when historical time series data are available.

Moslemi et al. (2024) emphasize that California's high energy demand—as one of the largest economies and energy consumers in the United States—requires robust forecasting tools to support energy planning and the design of public policies. By applying ARIMA and ARIMAX models, the authors analyze energy consumption patterns by source and economic sector, incorporating exogenous variables and accounting for distortions due to the COVID-19 pandemic and limited recent data availability. The results show that, although fossil fuels continue to dominate California's energy mix, renewable sources—especially solar energy and biomass—are expanding steadily.

In the Ecuadorian context, electricity consumption has steadily increased over the past few decades, reflecting both the expansion of economic activity and shifts in consumption patterns among households and productive sectors. National studies have explored the relationship between energy and growth from various theoretical and empirical perspectives. Renteria et al. (2016) conducted a study of the relationship between pollutant emissions, economic growth, and energy consumption for the period 1971 to 2010, finding a monotonically increasing linear relationship, which indicates that GDP is associated with rising levels of CO_2 emissions in the long term; and, about energy consumption, an inverse relationship was found in the long term—that is, as energy consumption increases, GDP decreases. The methodology used in this study involved autoregressive vectors and Johansen cointegration; the results led to the conclusion that the Environmental Kuznets Curve (EKC) does not hold.

Chong and Aguilar (2016) conduct time-series projections of residential electricity consumption in Ecuador; the authors apply ARIMA and ARIMAX models to forecast consumption, accounting for economic variables such as income, electricity prices, and oil prices. The results show high levels of fit and predictive accuracy, further demonstrating that income is positively associated with electricity demand. In contrast, electricity prices hurt consumption, supporting the usefulness of time-series models for planning and evaluating energy policies in Ecuador.

Another relevant study is that conducted by Mendez-Santos et al. (2025), which uses ARIMAX techniques to analyze monthly data and model the average cost of energy supply by integrating operational and economic variables. Although this study focuses on prices, it achieves high predictive accuracy and complements the local literature that employs time-series methods to understand national energy dynamics.

Hidalgo and Chuquin (2024) conducted a study modeling residential electricity consumption in the Latacunga canton, assessing the potential impact of lockdown scenarios on household energy demand. The results show that extraordinary events, such as lockdowns, can significantly alter the dynamics of residential electricity consumption, increasing pressure on energy distribution systems. The study also highlights the importance of incorporating forecasting and simulation tools into energy planning and contingency management, providing useful evidence for decision-making—both by businesses and governments—in situations of high uncertainty.

Korablyov et al. (2024) analyze the main forecasting models, such as statistical models (autoregressive model, moving average, exponential smoothing, moving average with autoregression and integration) and deep learning models (artificial neural network, recurrent neural network, short- and long-term memory, transformer), outlining their advantages and disadvantages and selecting the best one. The study presents experimental results from a comparative analysis of electricity consumption forecasting models, showing that the Transformer model was 1.5%-2% more effective at forecasting electricity consumption across various metrics.

This research suggests that while traditional models remain competitive, the use of complementary techniques can enhance accuracy in complex scenarios or those involving nonlinear relationships.

Although there is relevant literature on energy and growth in Ecuador and Latin America, significant gaps remain in energy forecasting approaches with rigorous out-of-sample validation, limiting the practical usefulness of projections for energy planning and public policy design.

Along the same lines, few studies model per capita electricity consumption by incorporating macroeconomic determinants into dynamic short- and medium-term time-series frameworks. Similarly, there is little empirical evidence for consistent projections of per capita GDP and CO_2 emissions that are integrated into a unified framework for forecasting electricity demand. In this context, the present study justifies the application of an ARIMAX model with out-of-sample validation, dynamic projection of exogenous variables, and predictive evaluation, providing useful empirical evidence to strengthen energy planning and electricity demand forecasting processes in Ecuador.

Materials and Methods

The empirical analysis uses annual data for Ecuador covering the period 1990–2022 from the World Bank's World Development Indicators[1] . The variables considered are:

- E_t: per capita electricity consumption (kWh per capita);
- Y_t: Gross Domestic Product (GDP) per capita in terms of purchasing power parity (PPP), expressed in constant 2017 international dollars;
- C_t: per capita carbon dioxide (CO_2) emissions, excluding the land use, land-use change, and forestry (LULUCF) sector, measured in metric tons per inhabitant.

Per capita GDP serves as an indirect indicator of income and aggregate economic activity, reflecting demand pressures on electricity consumption. Per capita CO_2 emissions capture the structural characteristics of the energy-economy nexus, including dependence on fossil fuels and energy intensity.

The time series used ensure methodological consistency and international comparability; furthermore, the use of per capita indicators mitigates scale effects and allows the analysis to focus on the structural dynamics of electricity consumption.

To stabilize variance, reduce potential heteroscedasticity issues, and allow for the direct interpretation of coefficients as elasticities, all variables are transformed using natural logarithms. The logarithmic transformation is particularly suitable for long-term macroeconomic studies, as it linearizes potentially multiplicative relationships, reduces distribution asymmetries, and allows the estimated coefficients to be interpreted as elasticities.

Prior to the econometric estimation, the stochastic properties of the time series are evaluated using the Augmented Dickey-Fuller (ADF) test, incorporating optimal deterministic components and lag selection. The general specification considered is:

$$\Delta X_t = \alpha + \beta t + \gamma X_{t-1} + \sum_{i=1}^{p} \delta_i \Delta X_{t-i} + \varepsilon_t \quad (1)$$

1 https://datos.bancomundial.org/pais/ecuador

Where $X_t \in\{\ln E_t, \ln Y_t, \ln C_t\}$, Δ represents the first-difference operator, and corresponds to the optimal number of lags included to eliminate serial autocorrelation in the residuals.

The null hypothesis assumes the presence of a unit root (H_0: $\gamma = 0$), while the alternative hypothesis implies stationarity (H_1: $\gamma < 0$).

The classical literature on time series has extensively documented that macroeconomic aggregates such as GDP, energy consumption, and emissions tend to behave as first-order integrated processes, I(1) (Hamilton, 1994; Enders, 2004).

In this context, the presence of a stochastic trend implies that the first difference of the series is stationary, which conditions the dynamic specification of the model and avoids spurious regression problems originally identified by Granger and Newbold (1974).

Given that the variables may share common stochastic trends, the existence of long-run equilibrium relationships is further evaluated using the Engle and Granger (1987) procedure. In the first stage, the cointegration equation is estimated:

$$\ln(E_t) = \alpha + \beta_1 \ln(Y_t) + \beta_2 \ln(C_t) + u_t \tag{2}$$

In the second stage, an Augmented Dickey-Fuller test is applied to the estimated residuals:

$$\Delta\hat{u}_t = \rho\hat{u}_{t-1} + \sum_{i=1}^{k} \phi_i \Delta\hat{u}_{t-i} + \varepsilon_t \tag{3}$$

The estimated main model corresponds to an ARIMA process with exogenous regressors (ARIMAX), whose general form can be expressed as:

$$\Phi(L)(1-L)^d \ln(E_t) = \alpha + \beta_1 \ln(Y_t) + \beta_2 \ln(C_t) + \Theta(L)\varepsilon_t \tag{4}$$

where L represents the lag operator, $\Phi(L)$ and $\Theta(L)$ correspond to the autoregressive and moving average polynomials, respectively, d is the order of differentiation, and ε_t is an error term with a zero mean and constant variance.

In expanded form:

$$\ln(E_t) = \alpha + \sum_{i=1}^{p} \phi_i \ln(E_{t-i}) + \sum_{j=1}^{q} \Theta_j \varepsilon_{t-j} + \beta_1 \ln(Y_t) + \beta_2 \ln(C_t) + \varepsilon_t \tag{5}$$

The optimal order is selected (p,d,q) using the Akaike Information Criterion (AIC):

$$AIC = -2\ln(\hat{L}) + 2k \tag{6}$$

where $\hat{L}$ is the maximum value of the likelihood function and is k the number of estimated parameters. The estimation is performed using maximum likelihood.

Given the small sample size (*n = 33*), the corrected AICc criterion is also reported:

$$AICc = AIC + \frac{2k(k+1)}{n-k-1} \tag{7}$$

Burnham and Anderson (2002) recommend using the AICc when the ratio $n/_k < 40$, a condition that is met in this study.

This specification allows us to capture the autoregressive dynamics of electricity consumption, model the serial correlation structure of the errors, and estimate contemporaneous elasticities with respect to income and emissions.

The ARIMAX specification is selected using a two-stage sequential procedure. In the first stage, different candidate models are estimated using the training sample corresponding to the period 1990–2018. The specifications were compared using the Akaike Information Criterion (AIC), the Akaike-corrected Information Criterion (AICc), and the Bayes on Criterion (BIC), with the aim of identifying the model that best balances fit quality and parsimony.

Subsequently, the predictive capacity of the selected specification is evaluated through out-of-sample validation, reserving the observations from the 2019–2022 period as the validation sample. Predictive performance is quantified using the Root Mean Square Error (RMSE), defined as:

$$RMSE = \sqrt{\frac{1}{T}\sum_{t=1}^{T}\left[\ln(E_t) - \widehat{\ln(E_t)}\right]^2} \tag{8}$$

Where E_t represents the expected electricity consumption, E_t the forecasted value, T and the number of observations in the evaluation sample. Lower RMSE values indicate greater predictive accuracy.

Finally, once the specification with the best predictive performance was selected, the model was re-estimated using the full sample (1990–2022). This final estimate serves as the basis for the econometric analysis, the interpretation of the parameters, and the generation of forecasts for per capita electricity consumption.

This procedure allows us to examine the model's robustness to data not used in the estimation and to evaluate its performance in the presence of recent macroeconomic shocks.

To verify the model's appropriate dynamic specification, the Ljung-Box test is applied to assess the absence of serial autocorrelation in the residuals:

$$Q = n(n+2)\sum_{k=1}^{m}\frac{\hat{\rho}_k^2}{n-k} \tag{9}$$

where $\hat{\rho}_k$ represents the sample autocorrelation of order k. Under the null hypothesis of no serial correlation, the statistic approximately follows a distribution χ^2 with m-p-q degrees of freedom.

Additionally, a graphical inspection of residuals, histograms, and autocorrelation functions (ACF) is performed to verify white noise-like behavior and the absence of systematic patterns.

Since the ARIMAX model requires future values of the explanatory variables to generate forecasts, univariate ARIMA models are estimated for $\ln(Y_t)$ and $\ln(C_t)$. The projections obtained allow us to construct the matrix of future predictors and generate dynamic forecasts of per capita electricity consumption through 2026.

Dynamic *forecasting* is obtained using:

$$\ln(\widehat{E_{t+h}}) = \hat{\alpha} + \sum_{i=1}^{p} \hat{\phi}_i \ln(E_{t+h-i}) + \hat{\beta}_1 \ln(\widehat{Y_{t+h}}) + \hat{\beta}_2 \ln(\widehat{C_{t+h}}) \quad (10)$$

The 95% confidence intervals are calculated using the forecast error variance:

$$\ln(\widehat{E_{t+h}}) \pm 1.96 \cdot \hat{\sigma}_{forecast} \quad (11)$$

Finally, the projected values are transformed to levels using the exponential function:

$$\widehat{E_{t+h}} = \exp\left(\ln(\widehat{E_{t+h}})\right) \quad (12)$$

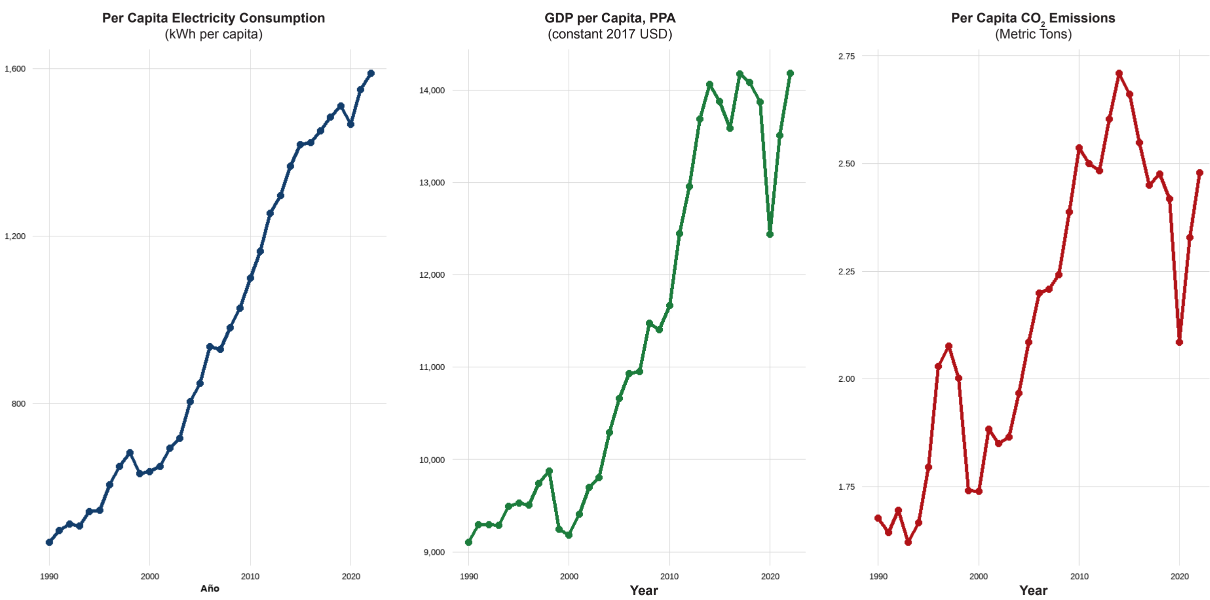
This approach yields coherent, dynamically consistent, and statistically sound projections of per capita electricity consumption for Ecuador through 2026.

Results and Discussion

The time series for per capita electricity consumption, per capita GDP (PPP), and per capita CO_2 emissions in Ecuador for the period 1990–2022 are presented below in Figure 1.

Figure 1

Trends in Macroeconomic and Energy Variables in Ecuador, 1990–2022



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In general terms, all three variables show a long-term upward trend, consistent with the process of economic expansion and increased energy demand observed in Ecuador.

Table 1 presents the descriptive statistics for the variables.

Table 1

Descriptive statistics for the variables by level

Variable	Mean	Std. Dev.	Min	Max
Per capita electricity consumption (kWh)	968.34	381.30	469.56	1,589.27
GDP per capita (2017 PPP USD)	11,457.38	1,968.95	9,104.82	14,343.02
CO_2per capita (t CO_2e)	2.17	0.35	1.62	2.71

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Per capita electricity consumption averages 968.34 kWh per person, with a maximum of 1,589.27 kWh, reflecting a sustained increase in energy demand associated with economic growth, urbanization, and the expansion of electricity coverage in Ecuador. The standard deviation of 381.30 reflects considerable variability in the temporal behavior of consumption.

GDP per capita in terms of purchasing power parity averages USD 11,457.38 (constant 2017 prices), showing a relatively stable growth trend, although influenced by fluctuations in the economic cycle, structural changes, and external shocks.

Meanwhile, per capita CO_2 emissions averaged 2.17 metric tons per inhabitant, with relatively less variation compared to the other variables, suggesting a more stable trajectory in the carbon intensity of the Ecuadorian economy.

Preliminary to the econometric estimation, the presence of unit roots was assessed using Augmented Dickey-Fuller (ADF) tests incorporating an intercept, a deterministic trend, and optimal lag selection based on the AIC criterion

Table 2

Augmented Dickey-Fuller (ADF) Tests

Variable	Tau statistic	Critical value (1%)	Critical value (5%)	Critical value (10%)	Lags (AIC)	Decision
Ln_energy	-1.7087	-4.15	-3.50	-3.18	1	Non-stationary
Ln_gdp	-2.2173	-4.15	-3.50	-3.18	1	Non-stationary
Ln_co2	-2.5433	-4.15	-3.50	-3.18	1	Non-stationary

Author (2026)

The estimated statistics are greater in absolute value than the 5% critical values; therefore, the null hypothesis of a unit root is not rejected for any of the analyzed variables. Consequently, the series exhibit nonstationarity in levels and display characteristics consistent with first-order integrated I(1) processes.

The empirical literature on energy consumption and economic growth has consistently documented the presence of nonstationarity in aggregate macroeconomic variables (Stern, 2000; Payne, 2010; Ozturk, 2010). From an economic perspective, this result implies that shocks to electricity consumption, income, or emissions have persistent effects over time, permanently affecting the trajectory of the variables.

Given that the variables are nonstationary, we proceed to assess the existence of long-run equilibrium relationships using the Engle and Granger (1987) procedure. The results are summarized in Table 3.

Table 3

Engle-Granger Cointegration Test (residuals)

Tau Statistic	Critical value 1%	Critical Value 5%	Critical value at 10%	Lags	Decision
-2.5984	-2.62	-1.95	-1.61	1	There is cointegration

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The Engle-Granger cointegration test shows that the residuals of the long-run relationship are stationary, confirming the existence of cointegration among electricity consumption, GDP per capita, and CO_2 emissions. This result indicates that the variables share a long-run equilibrium relationship, maintaining a common dynamic. Based on this evidence and consistent with the proposed econometric strategy, we proceed to compare different specifications of the ARIMAX model, with the aim of identifying the optimal balance between fit quality, parsimony, and predictive power. Table 4 presents a comparison of candidate ARIMAX models.

Table 4

Comparison of Candidate ARIMAX Models

Model	AIC	AICc	BIC
ARIMAX (1,0,0)	-100.32	-97.71	-93.48
ARIMAX (1,0,1)	-98.72	-94.90	-90.51
ARIMAX (1,0,2)	-104.19	-98.85	-94.61
ARIMAX (2,0,2)	-100.26	-93.06	-89.32

Author (2026)

The ARIMAX (1,0,2) specification was selected through a comparative analysis of alternative specifications, using the Akaike Information Criterion (AIC), Corrected Akaike Information Criterion (AICc), and Bayesian Information Criterion (BIC). This model presented the best balance between fit quality and parsimony.

The final selected model incorporates a first-order autoregressive component, two moving average terms, and exogenous regressors associated with GDP per capita and CO_2 emissions, allowing for the simultaneous representation of the temporal dependence of electricity consumption and the contemporary influence of its main macroeconomic determinants.

To evaluate the predictive power of the selected model, an out-of-sample validation was conducted using the 2019–2022 period, while the estimation was performed using data from 1990–2018. The results are presented in Table 5.

Table 5

Out-of-sample validation

Period	RMSE
2019–2022	0.10827

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The RMSE value of 0.10827 indicates that the average prediction error, measured in natural logarithms, is relatively small for the evaluation period. This result shows that the model maintains adequate predictive power for observations not used during estimation, which is strong evidence of its generalization ability and suggests the absence of significant overfitting issues. Taken together, these results support the use of the ARIMAX(1,0,2) model as a tool for *forecasting* per capita electricity consumption in Ecuador.

From an economic perspective, the predictive stability observed during 2019–2022 is particularly relevant because this period includes episodes of high macroeconomic volatility and structural changes associated with the aftermath of the pandemic, fluctuations in economic activity, and shifts in energy demand. Despite this adverse environment, the model maintains reasonable forecast accuracy, supporting its usefulness as a tool for energy forecasting and electricity demand planning in Ecuador.

This finding is consistent with previous empirical evidence in the country, such as that presented by Chong and Aguilar (2016), who conclude that time-series approaches allow for high levels of fit and predictive accuracy for medium-term horizons; similarly, Suntaxi et al. (2019), who conducted research applied to the Quito electricity system using the Box-Jenkins methodology, demonstrating that autoregressive models provide better predictive capabilities than traditional deterministic approaches; they therefore suggest that these models are relevant tools for infrastructure planning and electricity capacity expansion.

Table 6 shows the results of the ARIMAX model estimation; we can observe high temporal persistence in electricity consumption, as indicated by the autoregressive coefficient close to unity (0.9905). This behavior confirms that Ecuador's energy dynamics exhibit a strong dependence on their historical trajectory.

Table 6
ARIMAX Model Estimation

Parameter	Coefficient	Standard Error
AR(1)	0.9905	0.0130
MA(1)	0.2948	0.1471
MA(2)	0.6119	0.1541
intercept	2.2858	1.4485
ln_gdp	0.4616	0.1535
ln_co2	0.1980	0.1008

Author (2026)

Consequently, we can express the estimated equation as follows:

$$\ln(E_t) = 2.2858 + 0.9905\ \ln(E_{t-1}) + 0.4616\ \ln(Y_{t-1}) + 0.1980\ \ln(C_t) + 0.2948_{\varepsilon_{t-1}} + 0.6119_{\varepsilon_{t-2}} + \varepsilon_t$$

On the other hand, the coefficient for GDP per capita indicates that a 1% increase in income is associated, on average, with an approximate 0.46% increase in per capita electricity consumption, holding all other variables constant.

Likewise, CO_2 emissions exhibit a positive elasticity of 0.198, suggesting that increases in the economy's carbon intensity are associated with higher levels of energy consumption.

The estimated income elasticity is consistent with the international literature, which documents positive elasticities in developing economies, albeit with values less than one, reflecting gradual improvements in energy efficiency (Stern, 2011; Apergis and Payne, 2012).

The high time persistence observed in the autoregressive parameter confirms that electricity consumption exhibits structural inertia, a characteristic typical of aggregate energy demand due to technological rigidities, existing infrastructure, and established consumption patterns. From an economic perspective, this result confirms the close relationship between economic growth and the expansion of energy demand in Ecuador. Rising income levels typically translate into greater electricity requirements stemming from increased consumption of durable goods, industrial expansion, urbanization, and the expansion of energy-intensive productive activities. However, the fact that the elasticity is less than one suggests an inelastic relationship, indicating that economic growth generates proportionally smaller increases in electricity consumption, possibly associated with gradual improvements in energy efficiency and technological changes.

Table 7

Key statistical performance measures of the estimated model

Measure	Value
Log-Likelihood	64.1392
AIC	-114.2784
AICc	-109.7984
BIC	-103.8029
RMSE	0.0315
MAE	0.0266
MAPE (%)	0.3943
$Sigma^2$	0.0012
ACF1 residuals	-0.2297

Author (2026)

The information criteria reported in this section differ from those presented in Table 4 because they correspond to the re-estimation of the ARIMAX (1,0,2) model using the complete sample (1990–2022), once the out-of-sample selection and validation process was completed. In contrast, Table 4 presents the criteria used solely during the specification comparison stage on the training sample (1990–2018).

The obtained indicators show a high level of fit and adequate predictive power. In particular, the low MAPE confirms that the model satisfactorily reproduces the observed dynamics of per capita electricity consumption. Furthermore, to validate the correct dynamic specification of the ARIMAX model, the Ljung-Box test was performed, which evaluates the null hypothesis of no serial autocorrelation in the residuals. Two versions of the test were applied: the version adjusted for effective degrees of freedom, and the standard version without manual adjustment.

Table 8

Autocorrelation Diagnosis (Ljung-Box)

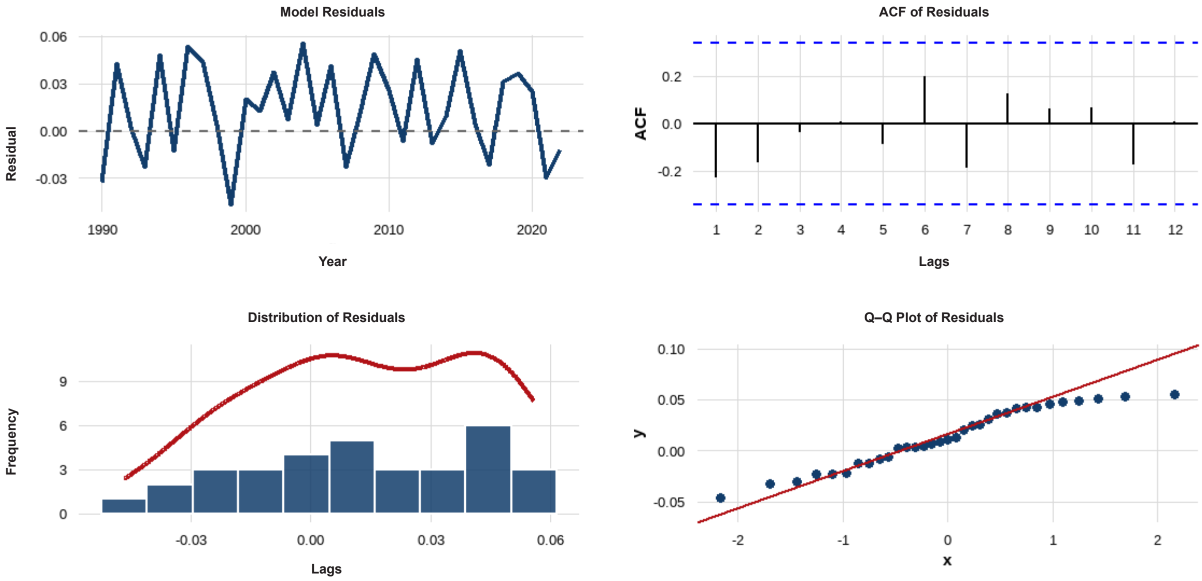
Specification	Lags	Q-Statistic	gl	p-value	Conclusion
Standard	4	2.9610	4	0.5644	Does not reject H_0
Fitted	4	2.9610	1	0.0853	Does not reject H_0
Standard	6	4.9671	6	0.5480	Does not reject H_0
Fitted	6	4.9671	3	0.1742	Does not reject H_0
Standard	8	7.2712	8	0.5077	Does not reject H_0
Fitted	8	7.2712	5	0.2012	Does not reject H_0
Standard	10	7.6793	10	0.6601	Does not reject H_0
Fitted	10	7.6793	7	0.3617	Does not reject H_0

Author (2026)

Table 8 presents the results of the Ljung-Box test for residual autocorrelation. The results indicate the absence of significant serial autocorrelation in the residuals, confirming the model's appropriate dynamic specification.

Figure 2

Comprehensive Diagnosis of Residuals from the ARIMAX (1,0,2) *Model*



Author (2026)

Figure 2 presents the residual diagnostics for the ARIMAX (1,0,2) model, suggesting that the selected specification exhibits statistically appropriate behavior consistent with the classical assumptions of a well-fitted time series model.

First, the residual series fluctuates around zero without showing systematic trends or visible persistent patterns, indicating that the model adequately captures the temporal dynamics of per capita electricity consumption. Furthermore, the autocorrelation function (ACF) of the residuals shows no significant serial correlations at the various lags evaluated, reinforcing the hypothesis of white-noise-like behavior.

The distribution of the residuals is approximately symmetric and close to normal, while the Q-Q plot shows that most observations align reasonably well with the theoretical normal distribution, with no severe deviations in the tails. Additionally, the Jarque-Bera test reports a statistic of 1.8918 and a p-value of 0.4082, which is above the conventional significance level of 5%; consequently, the null hypothesis of normality of the residuals is not rejected, suggesting the absence of significant problems of asymmetry or excessive kurtosis.

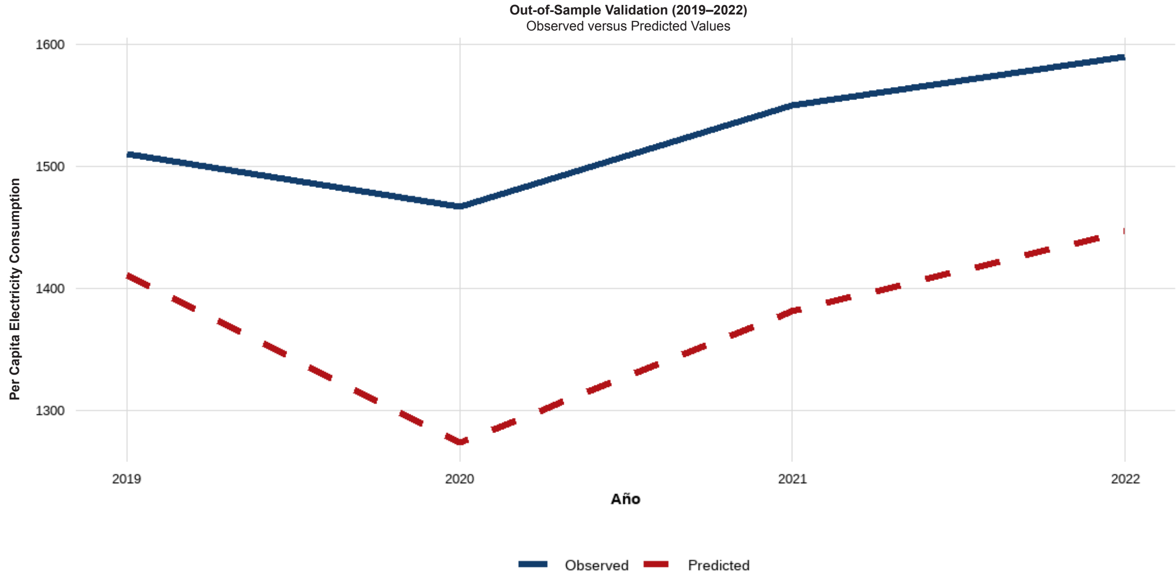
Figure 3 shows the out-of-sample validation of the ARIMAX(1,0,2) model for the 2019–2022 period, comparing the observed and forecasted values of per capita electricity consumption in Ecuador. In general terms, the model adequately reproduces the trajectory and temporal trend of the time series, correctly capturing the decline observed in 2020 and the subsequent recovery in electricity consumption in the following years.

However, there is evidence of a systematic underestimation of observed levels, particularly during 2021 and 2022, when the differences between actual and forecast values widen moderately. This behavior may be associated with extraordinary shocks and structural changes following the pandemic, which increased macroeconomic and energy volatility during the analyzed period.

Despite this, the model maintains dynamic consistency and predictive stability, demonstrating its ability to capture the general behavior of electricity demand. In this regard, the out-of-sample forecasting results support the usefulness of the ARIMAX model as a tool for medium-term energy projections for Ecuador.

Figure 3

Graphical comparison between observed and predicted out-of-sample values (2019–2022)



Author (2026)

Table 9

Forecast of Per Capita Electricity Consumption

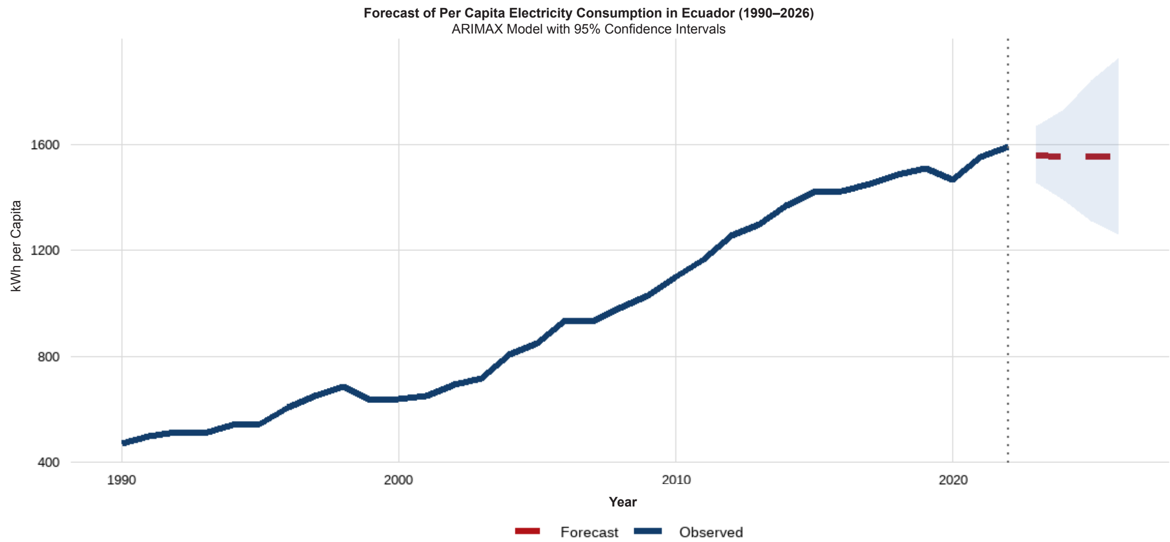
Year	Forecast	95% Lower Bound	95% Upper Limit
2023	1,557,739	1,454,860	1,667,894
2024	1,549,610	1,386,435	1,731,990
2025	1,552,830	1,309,807	1,840,942
2026	1,556,120	1,257,966	1,924,939

Author (2026)

Table 9 shows projections with a relative stabilization of per capita electricity consumption by 2026, although accompanied by a progressive application of confidence intervals, reflecting the natural increase in predictive uncertainty as the time horizon extends. Figure 4 shows the forecast for per capita electricity consumption

Figure 4

Forecast of per capita electricity consumption in Ecuador (1990–2026)



Author (2026)

From an economic perspective, the results suggest that Ecuador's electricity demand remains highly influenced by the dynamics of economic growth and by the structural evolution of the energy and environmental intensity of the national production system.

Future research could expand the analysis by using data with higher temporal frequency—such as monthly or quarterly data—as well as by incorporating territorial, climatic, and institutional variables that capture short-term dynamics, the effects of spatial heterogeneity, and transmission mechanisms associated with macroeconomic and energy shocks. Likewise, the application of spatial econometric approaches, climate models, and data science techniques would help strengthen the model's explanatory and predictive power, especially in the context of economic monitoring, energy planning, and economic resilience assessment.

Conclusions

This study analyzed the dynamics of per capita electricity consumption in Ecuador during 1990–2022 using an ARIMAX model with exogenous variables for per capita GDP and CO_2 emissions. The econometric results show that the time series are nonstationary in levels and consistent with first-order integrated (I(1)) processes. However, the Engle-Granger cointegration test confirms the existence of a long-run equilibrium relationship among the variables analyzed, justifying estimation of the model in levels and preserving the long-run structural information of Ecuador's energy system.

The ARIMAX(1,0,2) specification was selected as the optimal model because it had the lowest AIC, AICc, and BIC among the evaluated specifications, in addition to demonstrating adequate out-of-sample predictive power. The results indicate that per capita electricity consumption exhibits high temporal persistence, reflecting a strong dependence on its historical trajectory. Similarly, per capita GDP exhibits a positive and statistically significant elasticity, confirming the close relationship between economic growth and energy demand. Furthermore, CO_2 emissions also show a positive association with electricity consumption, suggesting that energy expansion remains linked to carbon-intensive production processes.

Out-of-sample validation for the 2019–2022 period demonstrates satisfactory predictive performance, even amid high post-pandemic macroeconomic volatility.

Furthermore, residual diagnostic tests—including the Ljung-Box test, residual ACF, and the Jarque-Bera test—confirm an adequate dynamic specification of the model and the absence of significant problems with autocorrelation or non-normality in the residuals.

The projections obtained through 2026 suggest a relative stabilization of per capita electricity consumption in Ecuador. However, this is accompanied by a gradual widening of the confidence intervals as the time horizon increases. From an economic and public policy perspective, the results indicate that the future evolution of electricity demand will continue to be strongly influenced by economic growth dynamics and the country's energy and environmental structure.

In practical terms, the findings support the usefulness of ARIMAX models as energy forecasting tools for electricity planning, infrastructure expansion, and the evaluation of energy policies in emerging economies. However, the annual frequency of the data limits the ability to capture short-term dynamics and transitory shocks. Future research could incorporate quarterly or monthly data, as well as multivariate error-correction models and hybrid approaches that leverage data science techniques, with the aim of strengthening predictive accuracy and structural analysis of energy consumption in Ecuador.

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Additional Information

JEL codes: C22, Q41, Q43, C53, C51