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Article

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International Journal of Energy Economics and Policy

Provided in Cooperation with:
International Journal of Energy Economics and Policy (IJEEP)

Reference: Suárez Santa Cruz, Liliana del Carmen/Rodriguez, Victor Hugo Puican et. al. (2024). Electricity industry strategies in Ecuador and Peru : their impacts on energy efficiency and prices. In: International Journal of Energy Economics and Policy 14 (5), S. 464 - 478.
https://www.econjournals.com/index.php/ijeep/article/download/16713/8195/39308.
doi:10.32479/ijeep.16713.

International Journal of Energy Economics and Policy

ISSN: 2146-4553

available at http: www.econjournals.com

International Journal of Energy Economics and Policy, 2024, 14(5), 464-478.

Electricity Industry Strategies in Ecuador and Peru: Their Impacts on Energy Efficiency and Prices

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Received: 05 May 2024 **Accepted:** 12 August 2024 **DOI:** https://doi.org/10.32479/ijeep.16713

ABSTRACT

Through an empirical analysis of the impact of determinants on energy efficiency and electricity prices using monthly data, we compare the outcomes of energy strategies in Ecuador and Peru from 2014 to 2023. OLS regression models with Newey-West matrices are applied in two contexts: Energy efficiency and energy prices. Energy efficiency is explained through variables such as the proportion of renewable energies, national income, and the international oil price. The results indicate that in Ecuador, the proportion of renewable energies is positively related to energy efficiency, whereas in Peru, energy efficiency mainly depends on the trend component capturing changes in productivity and the decline in fuel prices. Furthermore, electricity prices are sensitive to fluctuations in oil prices, especially in Peru, due to its dependence on thermoelectric generation. The energy strategies of both countries, including the integration of renewables and the management of fossil fuel costs, play crucial roles in determining energy efficiency and prices. This study provides a comprehensive view of how various economic and structural factors influence the performance of the energy sector in both nations, highlighting the differences in their approaches and outcomes.

Keywords: Energy Industry, Renewable Energies, Ecuador, Peru
JEL Classifications: Q42, Q43, N76

1. INTRODUCTION

Latin America's electricity sector is characterized by a high diversity in terms of its energy sources, market structures, and challenges. Understanding the results of energy strategies and what factors affect the performance of the electricity sector are crucial aspects for the sustainable development of any developing country. This article compares energy strategies and their impact on the electricity sectors of Ecuador and Peru, two countries with different approaches to electricity generation and use. While Ecuador has invested significantly in renewable energy over the past decade (Cabeza-Villón and Nevárez-Toledo, 2023; Souza et al., 2024), Peru has focused its efforts on improving energy efficiency, while maintaining a high reliance on thermoelectric power (Groh, 2014). This comparison is made through a detailed analysis of the situation between 2014 and 2023, and through the use of regression models to identify the factors influencing energy efficiency and energy price in both countries.

Since 2015, Ecuador has demonstrated a growing commitment to sustainability by increasing its investments in renewable energy, particularly hydroelectric and solar energy. These investments not only seek to diversify the country's energy matrix, but also to reduce dependence on fossil fuels and greenhouse gas emissions. The results of these policies are evident in the improvement of the efficiency of the electricity sector and in the stabilization of the price of energy, despite the volatility in international oil prices. In this context, it is analyzed how factors such as oil prices and energy policy have influenced Ecuador's energy efficiency during the study period.

On the other hand, Peru has adopted a different strategy, focusing on improving energy efficiency through the modernization of its infrastructure and the implementation of more efficient technologies. Although thermoelectric energy remains the main source of electricity generation, Peruvian policies have sought to optimize the use of energy resources and reduce losses in transmission and distribution. This approach has allowed Peru to maintain the competitiveness of its electricity sector and moderate the impacts of fluctuations in the price of oil on the cost of energy. Through regression models, this study examines the key determinants that have affected energy efficiency and prices in Peru, providing a comparative view with Ecuador.[1]

The Ecuadorian and Peruvian economies, strongly linked to energy production, have experienced a deep and complex relationship with the performance of the energy sector. In the current context in which the transition to more sustainable and renewable energy sources has been at the Centre of political and economic agendas globally, understanding the impact of taxation on this sector is of vital importance. In this article, we aim to analyse how the energy strategies of these two developing economies shaped the relationship between fundamental variables such as the price of oil or the share of renewable energy with energy efficiency and domestic energy prices. To that end, we used monthly time series data between 2014 and 2023 from public institutions in Peru and Ecuador and estimated ordinary least squares models with Newey-West matrices.

The detailed comparison between the energy strategies of Ecuador and Peru offers important lessons for public policymaking and international cooperation in the Latin American region. Collaboration on electricity interconnection projects and harmonisation of energy regulations could promote energy efficiency and security at the regional level, reducing dependence on fossil fuels and strengthening resilience to external shocks. In addition, the promotion of financing and technology transfer mechanisms could facilitate the accelerated adoption of innovative solutions in renewable energy and energy efficiency, thus contributing to sustainable development and climate change mitigation. It is important to note that in a general context, the countries analyzed have structural challenges for the implementation of energy strategies. Whether these challenges are of an economic or political nature: weak tax culture, informality of business, deficit in governmental institutions (Neira Cruz et al., 2022; Perez Jimenez and Puican Rodriguez, 2022; Olano et al., 2023).

The importance of conducting this research lies in its ability to provide a rigorous and detailed comparative assessment of the energy strategies implemented in Ecuador and Peru, countries with distinct approaches to electricity generation and use. This analysis not only contributes to the understanding of how specific policies affect energy efficiency and energy prices in diverse contexts, but also provides crucial insights for policymakers, academics, and private sector actors interested in promoting sustainable development and energy resilience in developing economies. In addition, by integrating econometric models and empirical time-series data, the research not only provides a better understanding of the key determinants shaping the electricity sector, but also suggests concrete recommendations to improve energy efficiency and competitiveness at the national and international levels.

The implementation of energy policies in Ecuador and Peru has been the subject of exhaustive analysis in the academic literature, especially in the context of Latin America. Numerous studies have explored how energy strategies and regulatory decisions impact the transition to more sustainable energy sources and the efficiency of the electricity sector in both countries. Previous research, such as that by Camioto et al. (2018) and Montalbano and Nenci (2019) for South American countries, suggests that investments in renewable energy can not only diversify the energy matrix, but also strengthen energy security and reduce greenhouse gas emissions. In turn, recent studies such as that of Ibrahim et al. (2023), when comparing energy policies in Latin American countries, highlight the importance of tax incentives and stable regulatory frameworks to promote innovation and investment in modern energy infrastructure. These analyses underscore the critical relevance of coherent and long-term policies to facilitate the transition to a more efficient and sustainable energy system in the region.

The structure of the article is organized into four essential sections: The introduction, which presents the problem addressed and highlights the relevance of the study in the economic context of Ecuador and Peru; a historical context that examines the development in the last decade of the energy industry in both countries; methodology, which details the data and methods used in inferential and statistical analysis; the results, which present and explain the empirical evidence obtained by the implemented models, discussing the main findings and reflecting on their scope and implications; and finally, the conclusions, where the contribution of the study is summarized and possible directions for future research in this field are proposed.

2. RECENT DEVELOPMENT OF THE ENERGY INDUSTRY OF ECUADOR AND PERU

From 2010 to 2016, the energy industries of Ecuador and Peru underwent significant evolutions, each following different trajectories, but with certain parallels in terms of diversification of the energy matrix and infrastructure expansion. In both countries, efforts were focused on improving generation capacity and modernizing energy infrastructure to respond to growing environmental demands and challenges.

In Ecuador, these goals were closely linked to the strategy of reducing dependence on fossil fuels. The cited period began with a strong focus on the expansion of hydroelectric capacity. In

1 The implementation of energy strategies in Ecuador and Peru has had significant repercussions not only in environmental terms, but also in economic and social aspects. In Ecuador, for example, the expansion of renewables has contributed to job creation in emerging sectors such as solar and wind power, as well as strengthening the country's energy security. In contrast, in Peru, policies focused on energy efficiency have underpinned industrial competitiveness by reducing production costs linked to electricity consumption.

2010, the country's energy matrix was dominated by hydroelectric generation, which constituted about 50% of installed capacity. Reliance on oil and gas for thermal generation was significant, prompting the government to promote greater integration of renewable sources. The administration of President Rafael Correa implemented an ambitious plan to develop hydroelectric infrastructure, highlighting the construction of large-scale projects such as the Coca Codo Sinclair Hydroelectric Power Plant, which began construction in 2010 and was inaugurated in 2016 with a capacity of 1500 MW. This project, largely financed by China, represented a fundamental pillar in Ecuador's strategy to increase its renewable generation capacity and reduce dependence on energy imports.

During this same period, Ecuador also undertook efforts to improve energy efficiency and diversify its matrix with non-conventional renewable energy sources, albeit to a lesser extent. Investment in energy infrastructure, facilitated by international cooperation agreements and external financing, allowed not only the construction of new hydroelectric plants, but also the improvement of the distribution network and the modernization of existing plants. By 2016, hydropower's share had risen to approximately 60-70% of installed capacity, reflecting remarkable success in implementing the country's hydropower expansion plans.

In contrast, Peru's energy industry developed through a combination of expansion of thermal generation and the initiation of diversification into renewable sources. In 2010, Peru's energy matrix was dominated by thermal generation, mainly from natural gas, which accounted for about 50% of installed capacity. Dependence on natural gas intensified with the expansion of pipeline infrastructure and the construction of thermoelectric plants that took advantage of natural gas resources from the Camisea fields.[2] However, the variability of fossil fuel prices and the need to improve energy security prompted the Peruvian government to look for alternatives.

Peru adopted a more diversified strategy to expand its generation capacity, promoting both renewable and thermal energy. In 2011, renewable energy auctions were introduced that attracted investment in solar, wind, and biomass energy projects. Between 2010 and 2016, the installed capacity of non-conventional renewables in Peru grew significantly, although it still constituted a small fraction of the energy matrix compared to thermal generation. In addition, the implementation of renewable energy auctions allowed the entry of private capital and the reduction of costs in emerging technologies, which positioned Peru as a regional leader in the promotion of clean energy.

The development of energy infrastructure in Peru also included improvements in the transmission and distribution network, as well as the integration of new technologies for efficient energy management. Energy regulation was adapted to facilitate the entry of new technologies and improve the competitiveness of the energy market. Unlike Ecuador, which focused on hydroelectric expansion, Peru maintained a balance between thermal generation and the incorporation of renewables, reflecting a diversified strategy that considered both the abundance of natural resources and the volatility of fossil fuel markets.

Both countries faced common challenges in the development of their energy industries. Environmental concerns, the need to attract foreign investment, and infrastructure modernization were recurring themes. Ecuador and Peru implemented policies to improve energy efficiency, promote sustainability, and diversify their energy matrices, albeit with approaches tailored to their specific contexts. In Ecuador, the construction of large hydroelectric projects significantly transformed generation capacity, while in Peru, the promotion of renewable energy and the expansion of thermal generation reflected a more diversified strategy.

In Ecuador, as of 2017, the strategy of diversification of the energy matrix was consolidated with a continuous focus on the expansion of hydroelectric generation. The entry into operation of important hydroelectric projects, such as the Coca Codo Sinclair plant in 2016 and the Sopladora plant in 2017, consolidated the dominance of hydroelectric energy in the Ecuadorian energy matrix. This hydroelectric expansion, with an installed capacity of more than 1,500 MW, has allowed Ecuador not only to meet its domestic energy demand, but also to export electricity to neighboring countries, such as Peru and Colombia. This strengthened Ecuador's position as a net exporter of energy in the Andean region.[3]

Ecuador's energy policy has focused on increasing the sustainability and resilience of the electricity system by diversifying sources and promoting non-conventional renewable energy. In 2018, pilot projects were launched for solar and wind energy, which, although smaller in scale compared to hydropower, represented an important step towards greater diversification of the energy matrix. In 2021, Ecuador inaugurated the Villonaco II and III Wind Farm, which together with the El Aromo photovoltaic plant, represent the most significant advances in non-conventional renewable energies. These projects reflect a strategic approach to reducing dependence on fossil fuels and improving long-term energy security.

In 2017 and 2018, Ecuador has also implemented regulatory reforms to attract investment in the energy sector. The introduction of auctions for the purchase of renewable energy in the long term and the modernization of the regulatory framework have facilitated the entry of private capital and the adoption of new technologies. In 2020, the Organic Law on Energy Efficiency was approved, promoting energy efficiency and the reduction of the carbon footprint in the sector. These reforms have been crucial in meeting the challenges of fluctuating demand and changing energy consumption patterns.

Peru, in parallel, has continued to expand and diversify its generation capacity, with a strong emphasis on the integration of

2 Camisea's natural gas is an inexhaustible energy resource extracted from the San Martín and Cashiriari fields, in Block 88, in the jungle of Cusco, Peru. This site is the most important in the country and one of the most representative in Latin America.

3 For more information, see: https://www.celec.gob.ec/cocacodo/informacion-tecnica/central-hidroelectrica-coca-codo-sinclair/

non-conventional renewables and the modernization of its thermal generation infrastructure. Since 2017, Peru has made significant progress in incorporating solar and wind energy into its energy matrix. Landmark projects such as the Wayra I Wind Farm and the Rubí Solar Plant, both inaugurated in 2018, have increased the country's renewable generation capacity, allowing Peru to reach an installed capacity of operational non-conventional renewables of approximately 1,129 MW by 2023.

The regulatory framework in Peru has facilitated the entry of investments in renewable energy through competitive auctions and long-term contracts, similar to the reforms implemented in Ecuador. In 2018, additional auctions were held for renewable energy projects, which attracted significant investment in wind, solar, and biomass energy. These auctions, together with tax incentives and the implementation of preferential tariffs, have been instrumental in increasing the share of renewable energy in the Peruvian energy matrix. In terms of thermal generation, Peru has continued to develop its natural gas infrastructure, with the expansion of the Southern Peruvian Gas Pipeline and the modernization of combined cycle plants that have improved the efficiency and responsiveness of the electricity system. Investment in natural gas infrastructure has been crucial in ensuring energy security and mitigating the volatility of international fossil fuel prices. By 2021, natural gas-fired generation accounted for approximately 45% of installed capacity, reflecting a balanced strategy between the promotion of renewables and the expansion of efficient thermal generation.

Both countries have faced similar challenges in terms of integrating new technologies and adapting to changes in energy demand. Regulatory reforms and infrastructure investments have been key to improving the efficiency and resilience of energy systems. In Ecuador, reliance on hydropower has provided stability in generation costs, while in Peru, diversification into renewables and modernization of thermal generation have improved the country's ability to adapt to fluctuations in demand and fuel prices.

The COVID-19 pandemic, which began in 2020, affected both countries, although their energy systems demonstrated remarkable resilience. The temporary reductions in electricity demand were managed through adjustments in production and the adoption of policies to maintain the stability of the electricity supply. In both countries, the pandemic accelerated digitalization and the implementation of smart technologies in the management of the electricity grid, improving operational efficiency and facilitating the integration of renewable sources.[4]

Between 2021 and 2023, Peru and Ecuador's energy strategies have diverged in their approach, although both countries share the goal of diversifying their energy matrix. Ecuador has prioritized the consolidation of its hydroelectric capacity as a fundamental pillar of its energy strategy, which is reflected in the completion of large hydroelectric projects such as Coca Codo Sinclair and Sopladora. This strategy has allowed Ecuador to reduce its dependence on fossil fuels and stabilize electricity generation costs. However, the country has also begun to explore other renewable sources, such as solar and wind power, with projects such as the Villonaco II and III Wind Farm and the El Aromo solar plant, although their contribution to the energy matrix remains limited compared to hydropower.

In contrast, Peru has adopted a more balanced strategy between the expansion of thermal generation and the incorporation of non-conventional renewable energies. The modernization of its thermal generation infrastructure, especially in natural gas plants, has been crucial to improve the efficiency and responsiveness of the electricity system. In parallel, Peru has significantly boosted solar and wind energy through competitive auctions and the implementation of projects such as the Wayra I Wind Farm and the Rubí solar plant. This duality in Peruvian strategy has allowed the country not only to diversify its energy matrix but also to mitigate dependence on fossil fuel imports, although thermal generation continues to represent a substantial portion of installed capacity.

At the regulatory level, both countries have implemented reforms to attract investment and encourage the integration of new technologies in the energy sector. In Ecuador, reforms have focused on the creation of auctions for the purchase of renewable energy and the enactment of the Organic Law on Energy Efficiency, which promotes the reduction of the carbon footprint. Peru, for its part, has used competitive auctions to increase the share of renewables in its matrix and has incentivized investment in natural gas infrastructure to ensure supply stability. While both approaches have been successful in attracting investment and improving the sustainability of the sector, Ecuador's reliance on hydropower and Peru's dual strategy reflect specific adaptations to its national contexts and available natural resources.

3. DATA AND ESTIMATION TECHNIQUES

3.1. Data

To estimate the results of the strategies of the electricity industry of Peru and Ecuador on energy efficiency and energy prices, economic indicators directly related to the generation, distribution and consumption of electricity were selected. This analysis covers the period from January 2014 to December 2023. The analysis period was chosen based on the availability of data and in order to capture the significant changes in the energy strategies of both countries over the last decade. The frequency of the data is monthly, and a time series approach has been used to perform the analyses.

The focus of this study is on two distinct regression models. The first model examines how the price of oil and other factors affect energy efficiency in Peru and Ecuador. For this analysis, data from sources such as Peru's Ministry of Energy and Mines (MINEM) and Ecuador's Ministry of Energy and Non-Renewable Natural Resources have been used, which provide detailed information

4 The need to maintain work activities from home resulted in a notable increase in electricity consumption in the residential sector. Equipment such as computers, printers, and communication devices were in continuous use, raising the daily demand for energy. The implementation of online classes and remote educational activities increased the use of electronic devices, such as computers and tablets, and energy consumption related to lighting and heating/cooling.

on energy production, peak demand, fuel price index, and other relevant variables. The second regression model analyzes the factors that influence the price of energy, incorporating variables such as the production of renewable energy, the proportion of renewable energy in the energy matrix, the effective power of energy, and other indicators of efficiency in the electricity sector.

The methodology used includes the collection and processing of data from various official sources, such as the Agency for the Regulation and Control of Electricity of Ecuador (ARCONEL) and the National Superintendence of Customs and Tax Administration of Peru (SUNAT), to obtain accurate and up-to-date data. This data allows for a detailed analysis of tax refunds, taxation and their specific impact on the energy sectors of each country. In addition, advanced econometric techniques, such as the Newey-West matrix ordinary linear regression (OLS) model, have been used to identify and quantify the causal relationships between the selected variables and the efficiency of the electricity sector.[5]

The main dependent variable in this work, the energy efficiency index, was estimated from data from the Ministry of Energy and Mines of Peru and the Ministry of Energy and Non-Renewable Natural Resources of Ecuador. This index is a key measure that allows evaluating the relationship between the amount of energy produced and the efficiency with which this energy is used in the economy. To estimate the energy efficiency index, detailed data on energy production and consumption were considered, as well as the integration of renewable and non-renewable sources in the energy matrix of each country. The methodology used to calculate the index involved several steps: First, information was collected on total energy production, broken down by source type, and total energy consumption, both at the residential and industrial levels. These data were adjusted to account for factors such as losses in power transmission and distribution, as well as the power plants' own consumption. The data were then normalized to obtain a comparative index that reflects energy efficiency over time, allowing technological improvements and changes in energy policy to be captured.[6]

The energy efficiency index was calculated to reflect both the reduction in energy losses and the increase in the share of energy generated from renewable sources. This approach allows for a comprehensive assessment of how improvements in energy infrastructure, investments in more efficient technologies, and clean energy integration policies have impacted the overall efficiency of the sector. The results obtained from these calculations are essential to understand the efficiency dynamics in the energy sectors of Peru and Ecuador, providing a solid basis for analyzing the effectiveness of the energy policies implemented and the areas where further intervention or adjustment is required.

Figure 1 shows the behavior of one of the main variables of interest. Some interesting details can be gleaned from this graph. First, there is a clear gap between the energy efficiency of Ecuador and Peru. In addition, we observe that Ecuadorian energy efficiency reduces its growth rate from 2019, which could be explained by the maturation of renewable energies in the country, while the growth of Peruvian energy efficiency has been relatively constant throughout the period, which can be explained by the fundamentally incremental innovation component that this industry has experienced since 2010.

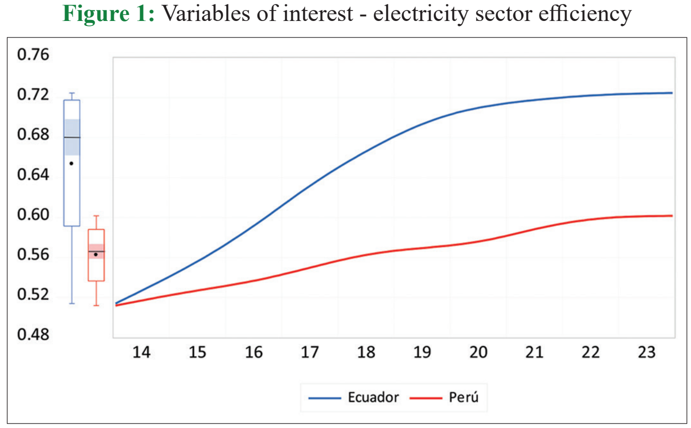
To evaluate the impacts of the energy strategies of Ecuador and Peru, a set of variables representative of the state of the energy industry of both countries were selected. Among them, the proportion of renewable energies as a proportion of the total energy produced, which allows changes in the country's energy structure to be captured, deserve to be highlighted; electricity prices, which allow us to observe the evolution of energy costs for companies and families; the energy load factor, which measures the relationship between the energy actually used and the installed capacity of the system, provides a perspective on the utilization and efficiency of the generation system; energy consumption per capita, an indicator of the average level of energy consumption per individual, providing information on consumption patterns in relation to the country's economic and social development; the effective power of the electricity sector, which captures the installed capacity available to meet electricity demand, reflecting the level of development of the energy infrastructure and the capacity to respond to peak demand; and energy intensity, defined as the amount of energy consumed per unit of GDP, is used to assess energy efficiency in the context of economic growth.

Table 1 shows information on the sources used and the descriptive statistics of the variables used in the study, which allow a better interpretation of the results and magnitudes of the effects found in the models that will be presented in the next section.

3.2. Model Specification

The empirical strategy of this work was divided into three parts. Initially, the evolution of indicators of the electricity

Figure 1: Variables of interest - electricity sector efficiency



Source: Authors' own elaboration with data from the Ministerio de Energía y Minas of Peru and the Ministerio de Energía y Recursos Naturales No Renovables of Ecuador. The data were processed by the Hodrick-Prescott filter

5 For more information on these databases, see: ARCONEL: https://www.controlrecursosyenergia.gob.ec/estadistica-del-sector-electrico/SUNAT: https://www.sunat.gob.pe/

6 This methodological approach facilitates international comparison, as the standardized index allows for differences and similarities in energy efficiency between the two countries, despite their diverse economic and infrastructure contexts. The robustness of the energy efficiency index, derived from reliable data and consistent methodologies, provides a valuable tool for policy evaluation and planning of future strategies in the field of energy management.

Table 1: Descriptive statistics and source of variables

Country	Name	Description	Source	Mean	Median	Maximum	Minimum	SD
Ecuador	EF	Electricity sector efficiency	ARCER	0.668	0.681	0.871	0.492	0.075
	RE	Renewable energies (percentage of total)	ARCER	0.718	0.748	0.799	0.519	0.084
	EC	Per capita energy consumption	ARCER	753	759	916	578	66
	ELF	Energy load factor	ARCER	0.810	0.809	0.907	0.698	0.038
	EI	Energy intensity	ARCER	0.068	0.068	0.083	0.056	0.006
	EP	Electric energy prices	INEC	113	114	116	107	2
	GDP	GDP	INEC	161	160	194	102	15
	EPES	Effective power of the electrical sector	ARCER	3928	3848	4813	3424	370
Peru	EF	Electricity sector efficiency	COES	0.568	0.563	0.710	0.492	0.046
	RE	Renewable energies (percentage of total)	COES	0.419	0.433	0.614	0.038	0.116
	EC	Per capita energy consumption	COES	637	635	788	534	48
	ELF	Energy load factor	COES	0.619	0.615	0.736	0.419	0.047
	EP	Electric energy prices	COES	133	132	155	107	10
	EI	Energy intensity	BCRP	0.051	0.051	0.063	0.045	0.003
	GDP	GDP	BCRP	165.120	165.257	197.559	102.931	14.798
	EPES	Effective power of the electrical sector	COES	11948	12463	13885	8798	1208
International	IOP	International oil price (WTI)	USEIA	60.493	57.206	114.630	16.836	18.417

ARCER: Energy and resources regulation and control agency, INEC: National institute of statistics and censuses, BCRP: Central Reserve Bank of Peru, COES: System economic operation committee, USEIA: U.S. Energy Information Administration

sector in Ecuador and Peru between 2014 and 2023 is evaluated. With this, we seek to understand what hypotheses can be established about the results of the energy strategies of both countries. Next, we estimate the effects of different key variables for the performance of the energy industry on energy efficiency. In this model, it is expected to reach results compatible with the literature that deals with the determinants of energy efficiency in countries. Our second model, on the other hand, seeks to determine which factors influence energy prices for Ecuador and Peru. With this, the model seeks to answer whether there is a significant association between the price of oil and the cost of energy for households and businesses and how the energy structure influences this relationship. It is considered that the volatility of oil prices can have significant effects on electricity generation costs, especially in systems that rely heavily on thermoelectric generation (Leal et al., 2017; Tohidi et al., 2022).

In summary, our models are as follows:

$$EF_t = \alpha_0 + \alpha_1\, TREND_t + \alpha_2\, RE_t + \alpha_3\, GDP_t + \alpha_4\, IOP_t + \varepsilon_t \quad (1)$$

$$EP_t = \beta_0 + \beta_1\, AR(1)_{t-1} + \beta_2\, EC_t + \beta_3\, RE_t + \beta_4\, IOP_t + \beta_5\, Month\_Dummy_{t,i} + \mu_t \quad (2)$$

Where ε_t and μ_t~N $(0, \sigma^2)$.

The control variables were selected for their explanatory power of the observed phenomena and based on the literature review. Specifically, they are:

RE- The production of energy from renewable sources (as a proportion of a country's total production) can significantly affect energy efficiency due to the more efficient and sustainable nature of renewable energy technologies compared to conventional sources of energy. Renewables, such as wind, solar, and hydropower, generally have lower energy losses in conversion and transmission compared to fossil fuels, which not only have less efficient extraction and combustion processes, but also generate higher carbon emissions and pollutants. For example, solar photovoltaic and wind power plants can convert solar and wind power into electricity with efficiency rates that are less susceptible to losses during the generation process, in contrast to thermal power plants that suffer from inherent inefficiencies in burning fossil fuels and in managing thermal waste (Ellabban et al., 2014). In addition, the integration of renewable sources can reduce the need for secondary and backup generation infrastructure, optimizing resource utilization and reducing the costs associated with maintaining surplus capacity based on non-renewable energy sources (Gielen et al., 2019).

On the other hand, the share of renewables in a country's production matrix can influence electricity prices by reducing dependence on fossil fuels, the costs of which are more volatile and sensitive to global market fluctuations. Renewables have lower marginal production costs once the infrastructure is installed, since they do not require fuel for power generation. This can lead to a reduction in electricity prices in the long term by decreasing exposure to the variability of fossil fuel prices and the costs associated with conventional electricity generation. In addition, subsidies and policies to support renewables can incentivize their adoption, influencing a more stable and predictable energy price structure compared to traditional energy sources, which are subject to rising costs and supply risks (Oosthuizen et al., 2022).

IOP- An increase in the international price of oil can negatively affect energy efficiency, especially in countries with high dependence on oil, since it increases the operating costs of the energy industry and energy-intensive sectors, limiting the resources available for investments in more efficient technologies. In addition, these additional costs are often passed on to consumers, reducing the incentive to adopt more energy-efficient practices. The high volatility of oil prices may also discourage long-term investments in energy efficiency due to economic uncertainty and associated risk.[7]

In addition, the price of oil directly affects electricity prices for families and businesses because oil is a crucial component in electricity generation, especially in countries with a high dependence on thermoelectric generation. When oil prices rise, electricity production costs also increase, resulting in higher electricity rates for end consumers. In addition, this effect is amplified by the transfer of costs along the energy supply chain, from generation to distribution, which is particularly pronounced in markets where infrastructure and the energy mix do not allow for a rapid transition to cheaper and more sustainable alternative sources.

GDP- GDP can affect energy efficiency through various mechanisms related to economic development and the structure of energy consumption (Sorrell et al., 2009). Higher GDP is often associated with a greater ability to invest in more efficient technologies and advanced energy infrastructure, which can reduce energy intensity and improve energy efficiency. In addition, economies with high GDP tend to have better energy management practices and greater resources to implement energy efficiency policies (Filippini & Hunt, 2011). However, it can also be the case that economic growth leads to an increase in energy demand that does not necessarily translate into efficiency improvements if consumption growth outpaces technological improvements in energy efficiency. Therefore, the impact of GDP on energy efficiency may depend on the balance between investment in efficient technologies and growth in energy demand (Stern, 2011).

EC- Per capita energy consumption can affect electricity prices in a variety of ways. First, an increase in per capita consumption leads to increased demand for electricity, which can put pressure on power generation and distribution capacity. This can lead to additional investments in expensive infrastructure and more resource-intensive use to meet demand, which increases production costs. In addition, higher per capita consumption is associated with increased use of energy-intensive technologies, such as heating and cooling systems, which can increase seasonal and daily demand for electricity (Borenstein, 2012). However, the increase in per capita consumption could potentially also lead to a reduction in the cost of electricity under certain specific conditions. For example, if the increase in per capita consumption is accompanied by significant improvements in energy efficiency at the level of infrastructure and consumption technologies, this could mitigate the impact on total electricity demand. Greater energy efficiency can lead to more efficient utilization of generation and distribution resources, which in turn could reduce operating and production costs (Jardot et al., 2010).

In model (1), we also include a trend component that may reflect long-term changes in energy behavior and policies that are not adequately captured with static variables. For example, technological advances, changes in environmental regulations, or changes in consumption patterns over time can significantly influence energy efficiency.

In model (2), in turn, we include a first-order autoregressive component and dummy variables for each month of the year. The first-order autoregressive component allows us to capture the temporal dependence of electricity prices, reflecting how prices in a period are influenced by the prices observed in the previous period. This dynamic structure helps to effectively model seasonal and cyclical fluctuations in prices, improving the predictive power of the model and allowing the identification of patterns of behavior over time. On the other hand, dummy variables for each month of the year are critical to capture specific seasonal effects that can affect electricity prices, such as seasonal demand for heating in winter or increased cooling demand in summer. These variables allow differentiating the seasonal impact from other influences on the price, facilitating more accurate analyses adjusted to changing temporal conditions in the energy market.

Equations (1) and (2) are estimated using ordinary least squares (OLS) using the Newey-West matrix (HAC) to avoid problems arising from autocorrelation or heteroskedasticity.[8] Initially, all the variables are used in their level form, but estimates are also made with the variables in their logarithmic form in order to obtain the elasticities and effects with direct interpretations. To check if the series has a unit root, we performed the Philips-Perron (PP) and Fisher (ADF) unit root tests that can be found in Table 2. The results indicate that the most important series of our model exhibit a zero-order I(0) integration behavior, that is, they are not cointegrated. We also found some I(1) series, however, estimating them in the first order could result in the loss of relevant information about the long-term relationship between the variables. This is because the results of the Johansen test reveal that the series are co-integrated, as can be seen in Table 3, and since we have a limited number of observations, it is crucial to consider this long-term relationship. To avoid this problem, the recommendation of Hamilton (2020) is followed and the models with series are estimated at the level.

4. EMPIRICAL RESULTS

To evaluate the impact of the energy strategies adopted by Ecuador and Peru, a comparative analysis of the main indicators of the energy sector in both countries for the years 2014 and 2023 was carried out. Table 3 presents a detailed view of this comparison, allowing to identify significant trends and changes in key variables

7 Recent research indicates that, in developed economies, when oil prices are high and the costs of energy produced from fossil fuels increase, consumers and industries may be motivated to adopt more efficient technologies and practices to reduce energy consumption and, therefore, operating costs. This phenomenon is supported by the theory of the "industrial effect," which suggests that high energy prices lead to greater investment in energy-efficient technologies. Conversely, low oil prices may reduce the economic incentive to improve energy efficiency, as energy costs fall, and economies may become less motivated to implement advanced energy efficiency technologies.

8 The Newey-West matrix is essential in series COD regression analysis because it ensures consistency and efficiency of estimates and allows reliable hypothesis testing even in the presence of autocorrelation and heteroskedasticity. Its use is essential to obtain valid and robust results when working with time series data in statistical inference.

Table 2: Unit root test

Variable	Phillips-perron		Augmented dickey-fuller		
	P	Bandwidth	Lag	P	Maximum Lag
Ecuador					
EC	0.000	8	1	0.01	12
EF	0.000	7	1	0.000	12
RE	0.002	5	0	0.004	13
ELF	0.000	6	1	0.000	13
EI	0.000	7	1	0.001	12
EP	0.000	1	1	0.238	12
GDP	0.000	5	0	0.000	12
EPES	0.000	4	0	0.000	13
Peru					
EF	0.000	4	12	0.484	12
RE	0.001	1	7	0.190	13
EF	0.000	6	0	0.000	12
EC	0.000	8	12	0.869	12
ELF	0.039	1	13	0.923	13
EP	0.048	0	0	0.148	13
EI	0.000	6	12	0.064	12
GDP	0.000	4	13	0.035	13
EPES	0.031	2	0	0.0341	13
International					
IOP	0.547	2	1	0.360	13

Akaike and Schwarz information criteria were used to determine the exogenous terms of the test equation (intercept only - I or trend and intercept - I+T), when tied, the Hannan-Quinn criterion was used as the deciding vote

such as the efficiency of the electricity sector, the proportion of renewable energy, the load factor, energy intensity, the electricity price index, the effective power of the electricity sector, per capita energy consumption and the contribution of the electricity sector to primary intensity.

The results show that Ecuador has made remarkable progress in several aspects of the energy sector. The efficiency of the electricity sector in Ecuador increased by 37%, from 0.527 in 2014 to 0.724 in 2023. This increase can be attributed to the growing investment in renewable energies, whose share in the energy matrix went from 50.5% to 73.0%, an increase of 45%. In addition, Ecuador experienced improvements in other indicators, such as the 42% increase in the effective power of the electricity sector and the 50% increase in the contribution of the electricity sector to primary intensity. These developments underscore the positive impact of policies focused on renewable energy and the modernization of the electricity sector.

On the other hand, Peru also showed progress, although with a different dynamic. The efficiency of the electricity sector increased by 16%, from 0.517 in 2014 to 0.601 in 2023. However, the share of renewables in the Peruvian energy matrix remained virtually stagnant, with only a 1% increase. This reflects Peru's continued reliance on thermoelectric power. Despite this, Peru achieved a significant increase of 59% in the effective power of the electricity sector and 31% in the electricity price index. These changes suggest a strategy focused more on improving infrastructure and energy efficiency than on diversifying energy sources. The analysis of the data in Table 4 suggests several interesting hypotheses that can be explored based on the academic literature. First, the notable improvement in the efficiency of the electricity sector in Ecuador (37%) compared to Peru (16%) may be related to investment in renewable energy. Previous studies have shown that the adoption of renewable technologies not only reduces carbon emissions, but also improves the operational efficiency of the electricity sector.

The share of renewable energy in Ecuador increased by 45%, which contrasts with the almost total stagnation in Peru (1%). This increase in Ecuador is in line with energy transition theories that suggest that countries that invest in renewables tend to experience improvements in the efficiency of the electricity sector due to the integration of more modern and cleaner technologies. In addition, the increased stability and predictability of costs associated with renewables can contribute to better planning and management of the electricity system, which in turn improves the overall efficiency of the sector.

On the other hand, the decrease in the load factor in Peru (−12%) suggests possible problems in demand management and generation capacity. The literature suggests that a lower load factor may indicate inefficient utilization of installed capacity, which may be related to an overreliance on underperforming thermoelectric plants. This trend could partly explain the significant increase in the electricity price index in Peru (31%), as higher production costs and inefficiency are passed on to consumers.

Energy intensity, which measures the amount of energy used per unit of GDP, increased in Ecuador (22%) but remained constant in Peru (1%). This increase may be a reflection of the growth in energy demand due to economic development and industrial expansion in Ecuador, driven by a more sustainable and diversified energy matrix. However, an increase in energy intensity may also indicate a need to improve energy efficiency policies to ensure that economic growth does not lead to a disproportionate increase in energy consumption.

This scenario allows us to ask the following three questions. Is the increase in energy efficiency in Ecuador related to the growth of energy production from renewable sources? Does Peru's energy development strategy make its electricity industry and energy efficiency susceptible to variations in the price of oil? What is the degree of exposure to the international price of oil that the price of energy has in these two countries? To answer these questions we will be analyzing the results of the regressions of equations (1) and (2).

Table 5 shows the results of the regressions based on equation (1). These models allow us to examine the relationship between the efficiency of the electricity sector and several key explanatory factors, including the share of renewables, GDP and the international price of oil. The model fit indices (adjusted R^2) reveal that although the in-level models offer a reasonable fit, the logarithmic models offer a better fit to explain the efficiency of the electricity sector, with values of 0.751 for Ecuador and 0.966 for Peru. These results indicate that the percentage changes in the explanatory variables correspond more precisely to the variations in the efficiency of the electricity sector. The F statistic and its p-values indicate a high significance of the models as a whole, suggesting that the selected variables significantly explain the efficiency of the electricity sector in both countries.

Table 3: Cointegration test

Test type, data trend	No interceptno trend, none	Interceptno trend, none	Interceptno trend, linear	Intercepttrend, linear	Intercepttrend, quadratic
Number of cointegrating relations by model - equation (1) - ecuador					
Trace	1	2	2	2	2
Max-Eig	1	2	2	2	2
RCE					
0	7.988326	7.988326	8.135158	8.135158	8.269985
1	8.004957	7.987918*	8.094051	8.080326	8.179289
2	8.221042	8.157264	8.222814	8.217742	8.276826
3	8.46512	8.427133	8.460035	8.483913	8.513951
Number of cointegrating relations by model - equation (1) - peru					
Trace	2	2	2	2	2
Max-Eig	2	2	2	2	2
RCE					
0	−8.463903	−8.4639	−8.32779	−8.32779	−8.24529
1	−8.491380*	−8.47306	−8.37632	−8.48644	−8.42061
2	−8.345506	−8.39998	−8.34381	−8.47362	−8.4477
3	−8.095354	−8.11244	−8.09521	−8.192	−8.19242
Number of cointegrating relations by model - equation (2) - ecuador					
Trace	1	1	1	1	1
Max-Eig	1	1	1	1	1
RCE					
0	14.88446	14.88446	15.03492	15.03492	15.19784
1	14.89382*	14.91707*	15.02536	15.0115	15.1305
2	15.14518	15.13281	15.19717	15.22363	15.30493
3	15.45008	15.46494	15.4889	15.55	15.58776
Number of cointegrating relations by model - equation (2) - peru					
Trace	1	2	2	1	2
Max-Eig	1	1	1	1	1
RCE					
0	19.34245	19.34245	19.4866	19.4866	19.61482
1	19.38188*	19.39716*	19.50332	19.543	19.63184
2	19.60784	19.59327	19.66138	19.72216	19.7764
3	19.88421	19.86008	19.8924	19.98152	20.02047

Selection (level 0.05) - critical values based on MacKinnon-Haug-Michelis (1999); Schwarz's informational criterion by Rank (rows) and Model (columns). RCE: Rank of Cointegration Equation

Table 4: Comparison of the main indicators of the energy industry of ecuador and peru

Variable	Country	2014 (%)	2023 (%)	Var (%)
Efficiency in the electrical sector	Ecuador	0.527	0.724	37
	Peru	0.517	0.601	16
Renovable energy	Ecuador	50.5	73.0	45
	Peru	48.0	48.3	1
Energy load factor	Ecuador	79.0	81.0	2
	Peru	72.4	63.8	−12
Energy intensity	Ecuador	0.064	0.078	22
	Peru	0.051	0.051	1
Electric energy prices index	Ecuador	109.883	115.162	5
	Peru	107.561	141.272	31
Effective power of the electrical sector	Ecuador	3298.767	4671.619	42
	Peru	8262.775	13106.247	59
Per capita energy consumption	Ecuador	770.801	825.897	7
	Peru	606.224	651.334	7
Contribution of the electricity sector to primary intensity	Ecuador	1.1	1.6	50
	Peru	1.1	1.3	16

Additional statistical tests, such as the Lagrange Multiplier Test (LM) and the ARCH test, provide valuable information about model quality. In Ecuador, the LM test indicates the presence of serial autocorrelation in the residuals (P = 0.031 and 0.043), suggesting the need to consider more robust correction structures. In contrast, in Peru, the high P-values of the LM test (0.149 in levels and 0.924 in logarithms) suggest the absence of serial autocorrelation, which reinforces the reliability of the model results. Likewise, the ARCH test does not reveal significant problems of conditional heteroskedasticity in the residuals in both

Table 5: Ordinary linear regression (Newey-West) estimates for the determination of the efficiency of the electricity sector in Ecuador and Peru

Equation 1, regressors	Dependent variable: Electricity sector efficiency			
	Ec	Ec (log)	Pe	Pe (log)
C	0.573*** (0.052)	−0.479* (0.286)	0.613*** (0.071)	1.124*** (0.280)
Trend	0.002*** (0.000)	0.297*** (0.026)	0.001*** (0.000)	0.885*** (0.027)
RE	0.132*** (0.045)	0.084* (0.046)	−0.056 (0.106)	−0.096 (0.033)
GDP	−0.001*** (0.000)	−0.255*** (0.058)	−0.001*** (0.000)	−0.140* (0.006)
IOP	0.000 (0.001)	−0.008 (0.065)	−0.004*** (0.001)	0.017** (0.007)
Adjust R^2	0.734	0.751	0.386	0.966
F-statistic	79.443	90.929	19.681	304.953
P (F-stat)	0.000	0.000	0.000	174.183
LM test	3.589	3.238	1.935	0.080
P (LM)	0.031	0.043	0.149	0.924
ARCH test	0.559	0.628	0.001	0.839
P (ARCH)	0.456	0.430	0.970	0.362

Levels of significance: ***0.01, **0.05 and *0.1. SE in parentheses. OLS equation based on Newey and West (1987) estimators. SE: Standard error, OLS: Ordinary least squares

countries, as reflected in the high P-values. These results reinforce our decision to use Newey-West matrices in both models to ensure the robustness of the results.

In Ecuador, the efficiency of the electricity sector shows a positive and significant relationship with the temporal trend and with the proportion of renewable energies produced in relation to the total (coefficient of 0.132 at the level), which suggests that the increase in energy generation from renewable sources has contributed significantly to the efficiency of the sector. Logarithmic regression indicates that for every 1% increase in the share of renewables in Ecuador, energy efficiency tends to increase by 0.08%. This aligns with previous studies indicating that the integration of renewable energies can improve operational efficiency by diversifying the energy matrix and reducing long-term marginal costs and lower losses in energy transmission and distribution (Brown et al., 2018; Bagherian and Mehranzamir, 2020). The positive effect of the trend, in turn, suggests that external or internal factors, such as technological improvements and energy policies, consistently contribute to the efficiency of the electricity sector in Ecuador. This is in line with the literature highlighting the importance of continued investments in infrastructure and technology to improve energy efficiency (Lin and Zhu, 2020).[9]

In addition, GDP shows a negative relationship with efficiency, both in levels (−0.001) and logarithms (−0.255), which could indicate that economic growth does not necessarily translate into efficiency improvements in the electricity sector, possibly due to an increase in energy consumption faster than technological improvements.

On the other hand, in Peru, the proportion of renewable energies presents a non-significant relationship in the logarithmic model, which suggests that, unlike Ecuador, the integration of renewable energies has not contributed to efficiency to the same extent. This discrepancy may be due to differences in energy infrastructure and in the implementation of renewable policies between the two countries. The temporal trend, again, has a significant positive effect on both the tiered model and the logarithmic model, indicating that the efficiency of the electricity sector improves over time, possibly due to factors similar to those observed in Ecuador, such as investments in infrastructure and improvements in system management. In addition, the effect of the trend is even more pronounced in the logarithmic model, suggesting an exponential growth in the efficiency of the electricity sector, which may be consistent with energy policies that seek to improve efficiency through system modernization.

GDP also shows a negative relationship with efficiency (−0.001 in levels and −0.140 in the logarithmic model), similar to Ecuador, which highlights a pattern in which economic growth does not automatically lead to greater energy efficiency (Marques et al., 2019). This finding could be related to an increase in demand that exceeds efficient generation capacity, or to insufficient investments in modernizing the electricity system in response to economic growth.

The analysis of the effects of the international price of oil on the efficiency of the electricity sector reveals a significant divergence between Ecuador and Peru. In Ecuador, the relationship is not statistically significant, indicating that fluctuations in the price of oil do not significantly affect the efficiency of the electricity sector. This may be due to the high penetration of renewable sources in Ecuador's energy matrix, which has increased from 50.5% in 2014 to 73% in 2023 (Table 4). This high share of renewable energy makes the country less vulnerable to variations in the price of fossil fuels. Diversification into sources such as hydroelectricity and wind power provides relative stability in power generation costs, thus cushioning the impact of volatile oil prices.

In contrast, in Peru, the international price of oil shows a significant negative relationship with the efficiency of the electricity sector, especially in the logarithmic model (−0.004 in levels and 0.017 in logarithms). This finding suggests that fluctuations in oil prices affect the efficiency of the Peruvian electricity sector, which can be attributed to a greater dependence on thermoelectric power. Despite a modest increase in the share of renewables from 48% in 2014 to 48.3% in 2023, Peru's electricity sector is still significantly influenced by thermal sources.

9 The logarithmic results suggest that the elasticities of these factors follow patterns similar to those found in the analysis at levels, although with different magnitudes, underlining the robustness of these effects.

Table 6: OLS (Newey-West) estimates for electric energy price determination in Ecuador and Peru

Equation 2	Dependent variable: Electric energy prices			
Regressors	**Ec**	**Ec (log)**	**Pe**	**Pe (log)**
C	16.731***	0.716***	29.578***	1.124***
	(4.158)	(0.179)	(6.436)	(0.280)
AR (1)	0.848***	0.851***	0.888***	0.885***
	(0.040)	(0.038)	(0.028)	(0.027)
EC	−0.001	−0.003	−0.019***	−0.096***
	(0.001)	(0.005)	(0.007)	(0.033)
RE	0.854	0.005	−4.056	−0.009
	(0.578)	(0.003)	(3.003)	(0.006)
IOP	0.007**	0.003**	0.034**	0.017**
	(0.003)	(0.001)	(0.015)	(0.007)
Month=1	−0.023	0.000	−0.857	−0.006
	(0.191)	(0.002)	(1.388)	(0.010)
Month=2	0.161	0.002	−2.766***	−0.019**
	(0.176)	(0.002)	(1.008)	(0.007)
Month=3	−0.294*	−0.002*	−2.697**	−0.018**
	(0.180)	(0.002)	(1.092)	(0.008)
Month=4	−0.079	0.000	−4.779***	−0.035***
	(0.186)	(0.002)	(1.044)	(0.008)
Month=5	−0.128	−0.001	−3.665***	−0.027***
	(0.187)	(0.002)	(1.010)	(0.008)
Month=6	−0.123	−0.001	−3.775***	−0.027***
	(0.181)	(0.002)	(1.020)	(0.007)
Month=7	−0.188	−0.002	−2.628**	−0.02**
	(0.183)	(0.002)	(1.065)	(0.008)
Month=8	−0.189	−0.002	−1.752	−0.013
	(0.178)	(0.002)	(1.091)	(0.008)
Month=9	−0.161	−0.001	−2.42**	−0.019**
	(0.176)	(0.002)	(1.079)	(0.008)
Month=10	−0.126	−0.001	−2.052*	−0.015*
	(0.175)	(0.002)	(1.055)	(0.008)
Month=11	−0.092	−0.001	−1.315	−0.010
	(0.173)	(0.002)	(1.021)	(0.008)
Adj. R2	0.954	0.953	0.965	0.966
F-stat	−35.541	468.520	−223.942	304.953
P-value (F-stat)	126.563	123.162	168.785	174.183
LM test	3.151	3.030	0.037	0.080
Prob (LM)	0.048	0.053	0.964	0.924
ARCH test	3.619	3.644	0.634	0.839
Prob (ARCH)	0.060	0.059	0.428	0.362

Levels of significance: *** denotes 0.01, ** denotes 0.05 and * denotes 0.1. Standard errors in parentheses. OLS equation based on Newey & West (1987) estimators.

Thermoelectric energy, which in Peru is predominantly generated from fossil fuels, is highly sensitive to fuel costs, which has a direct impact on the economic and operational efficiency of the sector (Wikipedia). The volatility in oil prices translates into fluctuations in generation costs, thus affecting the efficiency of thermoelectric plants. In addition, the energy infrastructure in Peru, which includes a large installed thermoelectric generation capacity and lower penetration of renewables, exacerbates this vulnerability (CEIC Data). Reliance on fossil fuels for electricity generation means that any increase in oil prices can lead to higher operating costs, reducing the overall efficiency of the system.

The difference in oil price response between Ecuador and Peru may also be influenced by national energy policies. Ecuador has implemented active policies to increase the share of renewables in its energy matrix, thereby mitigating dependence on fossil fuels. On the other hand, Peru has followed a strategy more oriented towards energy efficiency and maintaining a significant share of thermal sources, which makes it more susceptible to variations in international oil prices. This distinction in electricity sector policies and structure between the two countries partly explains why the price of oil has differentiated impacts on the efficiency of the electricity sector.

The positive and significant relationship between the share of renewable energy and energy efficiency in Ecuador is a fundamental result of this work, indicating that increased investment in renewable energy has contributed to improving the efficiency of the electricity sector. On the other hand, the negative and significant relationship between oil price and energy efficiency in Peru highlights the country's vulnerability to fossil fuel price volatility. These results suggest that, while Ecuador benefits from a more diversified and sustainable energy matrix, Peru faces significant challenges due to its dependence on thermoelectric power. Previous research, such as that by Razmjoo et al. (2021) and He et al. (2021) has suggested that investments in renewable energy can improve energy efficiency and reduce carbon emissions, supporting the idea that a sustainable energy strategy can have significant positive impacts on the efficiency of the electricity sector. However, it is also true that an eventual spiral of cheaper oil prices can have very positive impacts on Peru's energy efficiency.

The results presented in Table 4 show the estimates obtained through OLS regressions in order to analyze the factors that determine the electricity price index in Ecuador and Peru. Like the previous ones, these models were adjusted in both levels and logarithms for all variables and include several explanatory factors such as per capita energy consumption, the share of renewable energies and the international price of oil.

In general, the models fit the data well, with adjusted coefficients of determination (R^2) indicating a high explanatory capacity: 0.954 and 0.953 for Ecuador in levels and logarithms, respectively, and 0.965 and 0.966 for Peru in the same transformations. The statistical significance of the models, as indicated by the values of the F statistic and its corresponding P-values, underscores the robustness of the results in both countries, suggesting that the factors included in the model significantly explain the variations in electricity prices.[10]

The coefficient of the first-order autoregressive term AR(1) is positive and significant in both countries, with values of approximately 0.85 in Ecuador and 0.88 in Peru, which indicates a strong inertia in electricity prices. This inertia suggests that prices tend to follow historical patterns with high persistence in their evolution. The presence of a high autoregressive term in the models can be interpreted as an indication that current energy prices are strongly influenced by the prices observed in previous periods. One of the reasons behind this persistence could be the existence of long-term power supply contracts. These contracts, which are typically designed to provide stability and predictability for both producers and consumers, tend to set prices based on long-term projections of production costs and demand expectations. [11]

10 As the slope variable is a price index, the interpretation of the constant of the regressions does not generate much explanatory value for us.

11 In many cases, tariff adjustments are made on a regular basis and are subject

Table 7: Outline of suggestions for complementary research

No.	Method	Dependent variables	Independent variables	Research proposal
1	Autoregressive vector models (VAR)	Greenhouse gas emissions	Carbon pricing, climate policies, investment in renewable energy, economic development	Analysis of the impact of climate and economic policies on greenhouse gas emissions
2	OLS, GMM	Investment in energy infrastructure	Energy prices, regulatory policies, political risk, international financing	Assessing how regulatory policies and political risk affect energy infrastructure investment
3	Difference-in-difference analysis	Energy efficiency of major industries	Government policies, economic incentives, technological innovation in the energy sector	Assessing the Effects of Government Policies on Energy Efficiency in Key Industries
4	Survival analysis	Duration of energy policies in Ecuador and Peru	Political stability, regulatory changes, foreign direct investment, economic conditions	Longitudinal Study on the Duration and Effectiveness of Energy Policies in Ecuador and Peru

Because prices are fixed in long-term contracts, any significant changes in market prices are dampened, resulting in a series of prices that evolve gradually and predictably, rather than reacting sharply to short-term fluctuations.

As for per capita energy consumption, the results show a discrepancy between the two countries. In Ecuador, this variable is not significant in any of the models, which indicates that per capita energy consumption does not have a clear effect on the electricity price index. This may suggest that other factors, such as the cost structure and the energy matrix, play a more crucial role in determining prices in this country. On the contrary, in Peru, per capita energy consumption shows a negative and significant relationship in both models, with coefficients of −0.019 in levels and −0.096 in logarithms. As observed in Table 6, this suggests that an increase in per capita energy consumption is associated with a decrease in the price of electricity, which could be due to economies of scale or greater efficiency in cost distribution.[12]

In the analysis of the influence of the share of renewable energy on electricity prices, the results show that the share of renewable energy does not have a significant impact on either of the models for Ecuador and Peru, as indicated by the coefficients and their corresponding non-significant P-values in both countries. This result suggests that, during the period studied, the participation of renewable energies in the energy matrix has not had a clear and direct effect on the determination of electricity prices.

There are several possible explanations for this lack of significance. First, the effects of the transition to renewable energy may be diluted or offset by other energy market factors. For example, although the adoption of renewables has the potential to reduce marginal electricity generation costs in the long term, these benefits can be neutralized by upfront investment costs, effects on the financial system, and the integration of these technologies into the electricity grid (Safarzynska and Bergh, 2017). Renewables, such as solar and wind, require specific infrastructure, such as storage and load balancing systems, which can incur additional costs and affect the cost-benefit ratio of energy produced from renewable sources.

In addition, the presence of subsidies or policies to support renewable energy generation can distort the direct relationship between the share of renewables and electricity prices. In many cases, governments implement subsidies for renewable energy to incentivize their adoption and accelerate the energy transition (Poudineh et al., 2018). These subsidies may reduce the apparent cost of renewable energy to consumers, but they do not necessarily reflect a reduction in market energy prices, as the costs may be hidden in the tax structure or absorbed by other parts of the economic system. Therefore, the influence of renewables on energy prices may be more complex and mediated by government policy and market design.

Another consideration is the volatility in fossil fuel costs. During the period of analysis, fluctuations in fossil fuel prices may have had a more pronounced impact on electricity prices than the share of renewables. Fossil fuels continue to play a crucial role in power generation in many countries, and their prices can have an immediate and significant effect on power generation costs, especially in markets where renewables do not completely dominate the energy matrix (Foster et al., 2017). This could mean that variations in fossil fuel costs have masked the impact of renewables on electricity prices.[13]

The international price of oil shows a positive and significant relationship in both Ecuador and Peru. In Ecuador, the coefficients

to regulatory mechanisms that seek to balance the interests of consumers and energy suppliers, avoiding abrupt fluctuations in tariffs. These mechanisms typically include tariff revisions based on economic indicators such as inflation, exchange rate, and energy input costs, as well as social and political considerations that may delay the transmission of costs to the final consumer (Joskow, 2008).

12 The concept of economies of scale is fundamental to understanding this relationship. In the context of electric power production and distribution, economies of scale refer to the reduction of the average cost of production as the amount of energy generated and distributed increases. When per capita energy consumption increases, generating and distributing companies can operate at higher levels of capacity, which in turn allows fixed costs to be distributed over a larger production base. This results in a decrease in the average cost per unit of energy generated, allowing a reduction in electricity prices for end consumers (Borenstein, 2012).

13 It is important to consider the infrastructure and technological capabilities available to integrate renewable energies into the energy system. The lack of adequate infrastructure for the storage and distribution of renewable energy can limit its impact on prices. Without efficient integration, renewable energy may not be available at times of high demand, forcing reliance on traditional energy sources and maintaining relatively stable prices (Leonard, Michaelides, & Michaelides, 2020). The technology and integrability of renewable energies play a crucial role in maximizing their economic benefits and reducing energy prices.

are 0.007 in levels and 0.003 in logarithms, indicating that an increase in the international price of oil is associated with an increase in the price of electricity. More specifically, a 1% increase in the international price of oil generates on average a 0.3% increase in electricity prices domestically. This suggests that, despite a high penetration of renewables, oil costs still influence energy prices, possibly through generation and transportation costs. In Peru, sensitivity to fluctuations in the price of oil is more pronounced, with coefficients of 0.034 in levels and 0.017 in logarithms. This can be attributed to a greater reliance on thermoelectric generation in Peru, which makes the price of electricity more sensitive to variations in fossil fuel costs. The impact of the price of oil on the cost structure of thermoelectric generation is directly reflected in the price of electricity. As oil prices rise, the cost of generating electricity in thermoelectric plants also rises, which in turn translates into higher prices for end consumers.

The monthly effects are largely not significant in Ecuador, suggesting that there is not a strong seasonality in electricity prices throughout the year. This can be explained by long-term supply contracts, which are common in the Ecuadorian electricity sector. These contracts often set fixed or adjusted prices in a predictable manner, which helps mitigate seasonal fluctuations in electric power prices. The presence of supply contracts with agreed prices can decouple energy prices from seasonal fluctuations in demand and supply.

In contrast, in Peru, several months show significant negative effects, especially from February to October. These effects may be related to seasonal patterns in electricity demand, climatic influences, or variations in the availability of power generation. The rainy season in Peru usually begins in September and culminates in April, with the heaviest rainfall occurring between December and March. However, electricity prices are lower between February and October for several reasons. First, the effects of heavy rainfall in the early months of the year significantly increase the flow of rivers and the capacity of reservoirs for hydroelectric generation, increasing the supply of electricity from water until well into the year. This provides a steady supply of hydropower, which is less expensive compared to thermoelectric generation, helping to keep prices lower even after the heaviest rainy period.

Additional tests, such as the Lagrange Multiplier Test (LM) and the ARCH test, indicate the presence of autocorrelation and possible heteroskedasticity problems in the residuals in Ecuador, especially in the tiered model, as suggested by P-values close to 0.05. In Peru, however, the high P-values indicate the absence of significant problems of autocorrelation and heteroskedasticity, which reinforces the stability and reliability of the models for this country. These findings justify the use of Newey-West matrices to correct possible violations of the classical regression assumptions, thus guaranteeing the robustness of the results obtained.

The results found in this section reveal substantial differences in the determination of the price of electricity between Ecuador and Peru. In Ecuador, the influence of oil prices, although significant, is moderate, while per capita energy consumption and the share of renewables do not show a clear relationship with prices. On the other hand, in Peru, per capita energy consumption significantly reduces the price of electricity, and prices are more influenced by oil price fluctuations. These results suggest the need to consider differentiated policies that address the specificities of each country to effectively manage electricity prices and improve the efficiency of the sector.

5. CONCLUDING REMARKS

This article has explored the energy strategies implemented by Ecuador and Peru, highlighting how their divergent approaches to electricity generation and use have influenced energy efficiency and energy prices. Ecuador has invested heavily in renewable energy since 2015, especially in hydroelectric and solar, managing to diversify its energy matrix and reduce its dependence on fossil fuels, which has stabilized the price of energy despite volatility in oil prices. On the other hand, Peru, although it maintains a high dependence on thermoelectric energy, has focused its efforts on improving energy efficiency by modernizing its infrastructure and optimizing its electricity system. Through a comparative analysis using econometric models based on time series data from 2014 to 2023, the determinants affecting energy efficiency and energy prices in both countries were identified. This analysis not only provides a detailed understanding of the impact of energy policies in different contexts, but also offers crucial insights for policymakers and private sector actors interested in promoting sustainable development and energy resilience in Latin America.

Our analysis indicates that Ecuador has focused its efforts on significantly expanding its hydroelectric capacity, consolidating this source as the main pillar of its energy matrix. Large-scale projects such as Coca Codo, Sinclair and Sopladora have increased hydroelectric capacity and reduced dependence on fossil fuels. Although Ecuador has also begun to diversify into other renewable sources such as solar and wind, its contribution is still limited compared to hydropower. In contrast, Peru has adopted a balanced strategy that combines the expansion of thermal generation, mainly from natural gas, with the promotion of non-conventional renewable energies. The modernization of natural gas infrastructure and the implementation of competitive auctions have facilitated the integration of solar and wind technologies, increasing renewable capacity in its energy matrix. Both countries have faced common challenges in diversifying their energy sources and modernizing their infrastructure, adapting their strategies to their specific national contexts and available natural resources. Regulatory reforms in both countries have been key to attracting investment, fostering sustainability, and adapting their energy systems to growing environmental demands and challenges.

The empirical results of the comparative analysis of the energy strategies of Ecuador and Peru reveal significant differences in their progress in electricity sector efficiency and in the proportion of renewable energy. In the period 2014-2023, Ecuador increased its efficiency by 37%, driven by a 45% increase in the share of renewable energy in its energy matrix. This progress contrasts with the more moderate growth of Peru, whose efficiency increased by 16% and the share of renewables grew by just 1%, reflecting a greater dependence on thermoelectric power. The positive relationship between energy efficiency and the share of renewable energy in Ecuador underscores the positive impact of policies focused on modernizing the electricity sector and diversifying sources. In contrast, Peru's lower response suggests a need to reevaluate its energy strategy to mitigate the negative influence of international oil prices on the efficiency of the sector. The regression models used show that the efficiency of the electricity sector in both countries is influenced by the proportion of renewable energies, GDP, and the international price of oil, with more consistent results in Ecuador. In terms of electricity prices, the analysis reveals a strong inertia in both countries, although with differences in the influence of the determining factors: In Ecuador, the share of renewables does not show a clear impact on prices, while in Peru, per capita energy consumption reduces prices significantly, highlighting the sensitivity of the system to variations in fossil fuel costs. These findings suggest the importance of differentiated policies to improve energy efficiency and manage energy prices effectively in each country.

The results of this work reveal important lessons about the energy strategy and its impact on the efficiency of the electricity sector in Ecuador and Peru between 2014 and 2023. In Ecuador, the intensive adoption of renewables has proven to be key to improving the efficiency of the electricity sector, reducing vulnerability to fluctuations in oil prices. This diversification has led to a significant increase in the efficiency and stability of the electricity system. In contrast, Peru, which has maintained a greater dependence on thermoelectric generation, has shown a pronounced sensitivity to changes in oil prices, which has negatively affected its efficiency. This underscores the need for Peru to move forward in diversifying its energy matrix and adopt policies that incentivize investment in renewable energy, not only to improve operational efficiency but also to stabilize prices and reduce dependence on fossil fuels. Therefore, it is suggested that both countries continue to strengthen their energy policies, with Ecuador consolidating its focus on renewables and Peru accelerating its transition to more sustainable sources to ensure greater energy resilience and efficiency in the long term.

Our results highlight the importance of a diversified energy matrix to mitigate exposure to variations in international oil prices, providing quantitative and qualitative evidence that reinforces the existing literature on the benefits of renewable energies on the operational efficiency of the electricity sector. This research offers valuable insights for energy policymaking in developing countries, underscoring the need to adapt national strategies to country-specific characteristics and challenges to achieve greater efficiency and sustainability in the energy sector.

Despite the progress made, both countries face persistent challenges on the road to energy sustainability. Ecuador, for example, must address integrated water resources management and the environmental impact associated with the construction of large hydroelectric dams. In the case of Peru, modernizing electricity infrastructure to optimize power distribution remains a priority, especially in remote and hard-to-reach regions. In addition, both countries must adapt to global trends such as the digitalization of the energy sector and the integration of advanced storage technologies to improve the stability of the electricity grid and facilitate a more efficient energy transition.

An important limitation of this work is the temporality of the data analyzed between 2014 and 2023, which might not capture significant changes occurring outside this period in the energy policies of Ecuador and Peru. In addition, although the efficiency of the electricity sector and the integration of renewable energies have been evaluated, there are other important variables such as long-term environmental sustainability and the socioeconomic aspects of these energy transitions that could require a more detailed analysis. Future studies could complement this work by investigating the evolution of post-2023 energy policies, examining renewable energy storage capacity and management, as well as exploring the socio-economic and environmental impact of these policies to offer a more comprehensive and robust view of the benefits and challenges of the energy transition in both countries. Table 7 below presents a detailed agenda for future research.

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