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Effects of Increased Renewable Energy Consumption on Electricity Prices: Evidence for Six South American Countries

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Abstract: This research examines the relationship between renewable energy consumption and electricity prices in six South American countries (Argentina, Bolivia, Colombia, Chile, Ecuador and Peru). The methodology used is a panel econometric model with annual data for the period 1990–2015. The results show that the consumption of renewable energies influences the price of electricity paid by households, although its influence is very moderate. On the other hand, it was observed that the consumption of renewable energies has no relationship with the energy prices of the industrial sector and the commercial and services sector. In the countries analyzed, an increase in GDP causes an increase in the price of energy in the industrial sector. With more CO₂ emissions and a rise in the international price of oil, the annual average price of the industrial sector decreases.

Keywords: electrical energy; renewable energy; South America; panel data



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1. Introduction

Growing concern about climate change in the last decade has led countries to implement policies that mitigate its impact. In this regard, it is evident that there are programs, initiatives, and efforts to change the energy matrix by increasing the use of renewable energies in order to replace the use of fossil fuel generation by hydraulic, solar, geothermal, wind and other energies. However, according to data from the Economic Commission for Latin America and the Caribbean-ECLAC [1] and the International Energy Agency [2], it is observed that although renewable energy sources were diversified and increased in Latin America and Caribbean countries, the use of fossil fuels was higher, and therefore, the percentage share of renewable energies in the total balance was lower than the consumption of fossil fuels.

Despite this decline in the share of renewable energies in the energy matrix in Latin American countries, the use of this type of energy is essential for the future, as stated by Moody [3]. His report highlights that Latin America will double its electricity consumption in the next twenty years, but a large part of that demand will be covered by renewable energies, to the point that in 2039, 70% of power generation will come from non-polluting sources. In addition, according to KPMG [4], Latin America is expected to maintain its average annual economic growth rate, estimated by the Inter-American Development Bank-IADB at 0.85% for the next 20 years, so this economic development and demographic increase will be accompanied by a proportional increase in energy consumption. “Consequently, the development of renewable energies is a great contribution to cover the growing demand for energy in the populations of Latin America and the Caribbean, taking into

account that the region is going through a period of sustained economic growth. It is in this regard that Latin American States are implementing public policies to promote and subsidize clean energy projects, which is resulting in an increasing prevalence of the region in the development of renewable energies at a global level” [5] (p. 5).

For all these reasons, renewable energies will play an important role in the development of countries, in the potential replacement of fossil fuels and in mitigating the impact of climate change. In this scientific area, research is needed to determine how their use and consumption affect electricity prices. Although there are already studies in this area, they are scarce. In general, related research deals with energy prices and their relationship with economic growth or energy consumption [6–11]. Studies that specifically address the issue of the influence of renewable energies on electricity prices include: Jensen and Skytte [12], Amundsen et al. [13], Fischer [14], De Miera et al. [15], Gelabert et al. [16], Woo et al. [17], Gerardi and Nidras [18], Labandeira and Linares [19], Würzburg et al. [20], Ketterer [21], Clò et al. [22], Dillig et al. [23], Rintamäki et al. [24], Csereklyei et al. [25], Kolb et al. [26], Abrell and Kosch [27], Timilsina and Malla [28]. The contributions of these studies will be presented in the literature review section.

In this context, this research aims to examine the relationship between electricity prices in three different sectors (industrial, residential, and commercial) and renewable energy consumption in six Latin American countries (Argentina, Bolivia, Chile, Colombia, Ecuador, and Peru). The methodology used is an econometric panel model with annual data for the period 1990–2015. The study was conducted using data from six countries, as they are in the planning or implementation stage of electricity market integration projects with each other. In the ANDEAN region, Colombia, Ecuador, Peru, Chile, and Bolivia agreed to promote the Andean Electrical Interconnection System (SINEA) and a Chile–Argentina interconnection [29] (p. 15), as well as between Peru and northern Chile, and between southern Bolivia and northern Argentina. The economic advantages are obvious: electrical interconnection lines allow for cross-border exchange and avoid costs for the construction of unnecessary generation facilities. Experts from the Latin American Energy Organization (OLADE) estimate that energy integration could save between USD 4000 and 5000 million per year [30] (p. 94).

This document is divided into six sections. The introduction contextualizes the subject under study and sets out the objective. The second section reviews the literature and presents the empirical evidence obtained from the studies carried out. The third section presents the methodology used and the fourth section presents the results. Finally, the fifth and sixth sections contain the discussion and the conclusions obtained.

2. Literature Review and Empirical Evidence

Positive and negative effects on household energy expenditure can occur when promoting renewable energies and these can occur in three ways: (1) through changes in wholesale prices, which are caused by an increase or decrease in production costs; (2) through changes in retail prices, caused by variations in supply costs, and (3) through alterations in household energy consumption resulting from changes in household behavior or because the provision of certain energy services is aligned with energy efficiency measures [31].

Following this premise, several researchers have proposed studies to determine the extent of the effect of renewable energies on energy prices. Jensen and Skytte [12] were among the first researchers to investigate the relationship between the share of renewable energy and the wholesale price of electricity. These researchers observed that a higher share of renewable energy in the total electricity generation mix can lead to a decrease in the wholesale electricity price. When applying a rational expectations simulation model of competitive storage and speculation of Green Certificates (GC), mainly based on volatile wind power, Amundsen et al. [13] show that the introduction of GC banking can reduce the volatility of energy prices considerably and lead to an increase in social surplus, i.e., it does not necessarily benefit “eco-friendly producers”.

On the other hand, Clò et al. [22] conducted a study in the Italian market in order to explore the effect of wind and solar electricity generation on the wholesale price, where they found lower prices with higher renewable energies, but higher volatility. Following this line of research, the studies by Woo et al. [17] in the North American State of Texas and that of Ketterer [21] for Germany stand out. These studies agree that the expansion of wind power generation capacity needs to go hand in hand with the implementation and use of financial instruments to control price risk, or legislative measures to ensure proper regulation of the energy market. This is the only way to control the price volatility of variable energy sources such as wind energy. Furthermore, Rintamäki et al. [24] find that in Denmark, wind energy decreases daily price volatility by equalizing the hourly price profile, but in contrast, in Germany volatility increases, as it has a stronger impact on off-peak prices. This is why the authors suggest flexibility in the access to capacity for wind power generation patterns, as they contribute to different impacts.

Another contribution is by Csereklyei et al. [25], who aimed to analyze the effect of wind and solar power generation on wholesale electricity prices in Australia during 2010–2018. To do so, they estimate autoregressive distributed lag (ARDL) models and thus manage to decompose the merit order effect of the generation of utility-scale wind, solar photovoltaic (PV) energy in all states. These authors observe that the wind merit order effect has been increasing as a function of dispatched wind capacity over time. An ex post analysis of technology use and hourly electricity prices in Spain between 2005 and 2009 by Gelabert, Labandeira and Linares [16] complements these studies. The average effects of a marginal change caused by introducing electricity from renewable sources and cogeneration on electricity market prices are observed. To do so, they use a multivariate regression model and show that an increase in energy generation from renewable sources and cogeneration does in fact reduce the price of electricity. In summary, for any given level of electricity demand, if there is an increase of 1 GWh, energy prices decrease on average by almost EUR 1.9.

Following this same line, and also in Spain, De Miera et al. [15] analyze the reduction in the wholesale price of electricity as a result of injecting more electricity from renewable energy sources (RES-E). These authors show that there is an absolute negative correlation between the promotion of wind energy and the wholesale market price. Thus, the increase in the costs of supporting RES-E implies a reduction in the short/medium term of the wholesale price and therefore, a reduction in retail electricity prices.

To understand the effect on retail prices in Australia, Gerardi and Nidras [18] apply wholesale price simulation models and calculate the net impact on retail prices. For this, they use the database of daily average energy prices and confirm the merit-order-effect for investment in renewable energy in 2013, but do not determine the impact on retail prices. However, some key features of the effect of renewables on electricity prices are not considered in the theoretical analyses of the merit-order effect at times of high electricity demand. According to authors such as Labandeira and Linares [19] or Würzburg et al. [20], this may be due to the fact that the use of fossil fuels in maximum load plants (which is another indicator of the relevance of peak demand) does affect electricity prices.

Carolyn Fischer [14], on the other hand, in her research paper reveals that primarily the relative elasticities of electricity supply from both fossil and renewable energy sources are drivers of electricity price effects, which the price elasticity of natural gas alone cannot be. Elasticity of demand is still important for estimating the magnitude of price effects, but not for their direction.

In Germany, Dillig et al. [23] studied this phenomenon for the years 2011 to 2013 and concluded that the main reason is a deficit in the installed capacities of non-renewable energy sources. This deficit has been established in recent years and is mainly due to the uncertainty of the liberalization of European electricity markets and world energy prices. However, Kolb et al. [26] updated the study and analyzed the historical supply and demand curves of the German daily market to reconstruct electricity prices without the injection of wind and PV energy from 2014 to 2018. The results show that renewable energy

sources reduced electricity prices significantly. Furthermore, the study for 18 emerging economies by Sadorsky [32], using panel data with cointegration techniques, shows that real per capita income and per capita consumption of renewable energy have a positive relationship, but they fail to show whether or not there is a bidirectional relationship between these variables.

Another contribution in this area and using panel data is the research by Apergis and Payne [33]. They conducted their research between 1985 and 2005 in 20 OECD countries and found that there is a positive relationship between renewable energy consumption and economic growth. These authors found that a 1% increase in renewable energy consumption leads to a 0.76% increase in national GDP. In the same way, they state that through capital formation there is an indirect effect on the GDP of these renewable energies, using the Granger causality test, where it is shown that in the short and long term the relationship between both variables is bidirectional. On the other hand, Abrell and Kosch [27] point out that as the electricity systems are interconnected; this stimulates a change in electricity trade flows, but this impact is ambiguous in carbon offsets and depends on the installed generation and interconnection capacities. Therefore, the cross-border order of merit effect causes opposite effects on consumers and producers: generators' profits decrease, while consumers benefit from lower electricity costs and thus an increase in consumer surplus.

Finally, Timilsina and Malla [28] analyze through an extensive review of existing empirical literature if investments in clean technologies cause an increase in productivity. Their results are mixed and inconclusive. Some studies show a positive relationship, especially in the energy-intensive manufacturing sector. However, other studies carried out in the energy sector find that the use of clean technologies does not cause an increase in productivity. They conclude that the use of field-observed data is essential at the sectorial level, particularly in the transport, energy, and construction sectors (Figure 1).

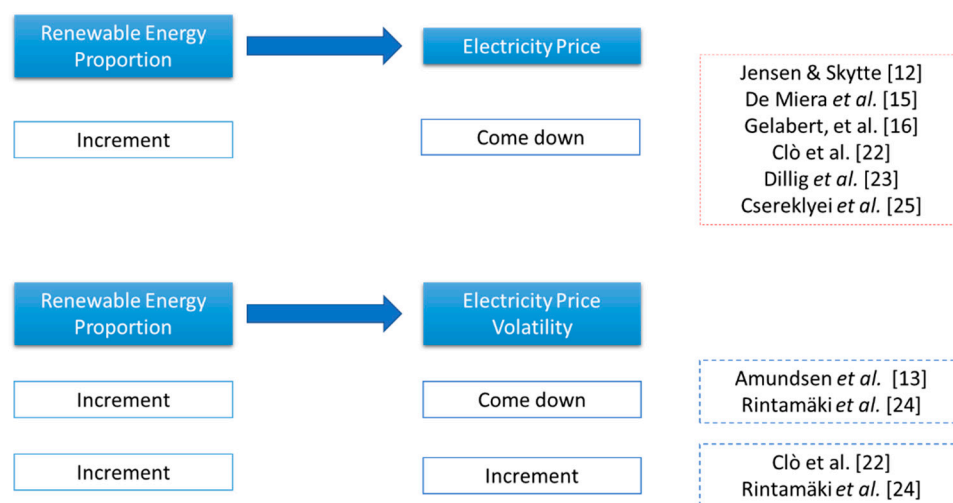


Figure 1. Summary of the studies and the cited empirical evidence.

In most of the research works, evidence is observed of the effect that the proportion of renewable energies have on volatility and the price of electrical energy. This research focuses on the correlation that exists between the price of electricity and the proportion of renewable energies. Almost all the evidence indicates that there is a negative correlation between the share of renewable energy and the price of electricity (Jensen and Skytte [12]; De Miera *et al.* [15]; Gelabert, *et al.* [16]; Clò *et al.* [22]; Dillig *et al.* [23]; Csereklyei *et al.* [25]). However, these studies were carried out in countries outside of Latin America, so this study aims to fill the research gap on this issue in this region.

In this context, the starting hypothesis is that this negative relationship has to be verified and contrasted in the six study countries. However, this degree of impact could be different for the different sectors such as households, industry, and the commercial sector, so these questions were included in the research carried out. To answer these

research questions, and based on the evidence presented, panel econometric models are considered to be the best alternative. This is consistent with what is used and verified by De Miera et al. [15], who observed a negative correlation between the mentioned variables; the effect of renewable energies on the supply and demand curves of the electricity sector [26] and the elasticities calculated by Fischer [14] and the econometric models used by Gelabert et al. [16]. In these panel models, it is necessary to use control variables related to GDP [32] and economic growth [33], the global environment, and international prices [23].

3. Methodology

3.1. General Characterization of the State of Renewable Energies in the Study Countries during the Established Period (2000–2015)

The following is a general characterization of the state of renewable energies in the study countries during the established period (2000–2015). Special specificities of each country with regard to this issue are also mentioned. The participation and growth figures for renewable energies were obtained from the database of the Energy Information System of Latin America and the Caribbean (sieLAC). In the same way, the main limitations or potentialities for the development of these energies in the region are described.

Argentina differs from the other five study countries due to its diversification in terms of renewable energies for electricity generation. While in the other countries analyzed (Bolivia, Colombia, Chile, Ecuador, and Peru) electricity generation by renewable energy source began in the middle of the period, in Argentina the generation of renewable energy is evidenced since the beginning of the period analyzed. During 2000–2015, the average share of renewable energies is 33.3% per year; the annual average growth rate of solar energy stands out at 49%, wind energy at 21%, while hydro has had a growth of 2%.

Despite this, Griffa et al. [34] (p.69) indicate that renewable energies in Argentina present a still very incipient penetration compared to what happens in other countries of the world. Renewable energy resources provide 0.8% of primary energy, while in countries such as Denmark, Finland, Germany and Sweden it represents 20% of the total. In countries of the region, such as Chile and Brazil, they contribute close to 5%. The relevance of renewable energies is also small in relation to the country's electricity demand: only 1.9% of consumption is covered with generation from renewable sources. According to Recalde et al. [35] (p. 110), despite having a high potential for generation with new and renewable sources of energy and having implemented different policies and programs in recent decades, Argentina has a very low degree of development of this type of energy. This situation is mainly due to energy policies. Governance-related factors, particularly the low level of political will and weak regulatory frameworks; and with the economic and financial aspects, they remain as the main limitations of the sector.

In Bolivia, there are two factors to highlight. On the one hand, the availability of natural gas deposits, which causes the prices of thermal generation with this fuel to be low in this country compared to other countries whose thermal generation costs depend on barrel of oil and gas costs. For this reason, in Bolivia, the development of renewable energies is more difficult. In addition, on the other hand, the significant development of the use of biomass energy, which allows, among other things, to provide electricity to rural sectors. In the period 2000–2015, on average 40% of electricity generation comes from renewable energy sources. While hydroelectric energy increased annually by 2%, renewable thermal energy (from biomass) had an annual growth rate of 14%. This is relevant since according to Oyarbide [36] bioenergy or biomass energy has two different functions in Bolivia. On the one hand, the sugar mills contributed 1.9% of the electricity that was injected into the National Interconnected System (NIS) in 2017 and produced around 80 million liters of bioethanol in 2018. On the other hand, the energy generated by the burning of biomass is the main source of energy for the isolated rural population of the NIS. The obstacles and difficulties that prevent renewable energy access to the NIS are legal (lack of incentives in regulations for project development), economic-financial

(renewable energy projects are more expensive than gas) and operational (distortions due to gas subsidies that limit competition) [37].

In Chile, during the 2000–2015 period, the average share of renewable energies was 44% per year; within these, hydroelectric energy increased by an annual average of 2% and renewable thermal energy by 10%. Wind and solar electricity generation deserves particular attention due to its exponential growth; since the first record was from 2007, in that year 2.81 GWh was generated, and for 2015 the wind energy for electric power generation was 1806 GWh; meanwhile, in 2012, generation amounts of only 0.34 GWh were registered, and for 2015 its production was 1360 GWh. This is due to the energy policy of the Chilean government. In this sense, before 2005, in the statistics of the National Energy Commission, solar photovoltaics did not even appear among the sources of electricity generation in the country. However, in 2014, it already represented 1%, and this has been progressing until today, where it is 7% of the total electricity generation in the country and represents 44% of generation with non-conventional renewable energies. In addition, the energy policy for 2050 aims to achieve 70% of generation with renewable energy; one of the goals is, in fact, that in the year 2035, Chile will become an exporter of technology and services for the solar industry. A fundamental part of this public strategy is Law 20/25 on Non-conventional Renewable Energies (ERNC), in force since 2013. This regulation also establishes the following graduation for the expansion of the energy matrix: 5% in 2013, with increases of 1% from 2014 until reaching 12% in 2020, and increases of 1.5% from 2021 until reaching 18% in 2024, and an increase of 2% in 2025 to reach 20% in 2025.

Colombia, with an average of 78% renewable energy sources for electricity generation in the period 2010–2015, is the country that stands out from the rest. It has great hydroelectric potential, and its investments in this field are very important, with an average annual growth of 2%, while thermal renewable energy grew by 11% annually. Despite this, as the BID (2019) mentions, Colombia has one of the cleanest energy matrices in the world; however, it is 69% concentrated in hydroelectricity. The high dependence on water resources makes the Colombian electricity system vulnerable to critical scenarios such as the El Niño phenomenon. Consequently, the Colombian electricity system is very sensitive to climatic changes and requires diversification of its energy matrix through the incorporation of renewable energies and other investment projects that take advantage of the diversity of natural resources in the region [38]. Wind energy sources in electricity generation did not develop significantly; from 2004 to 2015, the amount of electricity generated went from 50.17 GWh to 68.38 GWh respectively. Meanwhile, solar energy sources had no participation in electrical energy during the period.

In Ecuador, the low dependence on hydrological sources stands out. In 2000, 72% of electrical energy sources came from these sources; however, by 2015, this percentage decreased to 50%. All this was caused, on the one hand, by the increase in the use of non-renewable thermal sources and by the diversification of non-renewable sources whose use was non-existent before the middle of the period. For the latter, wind generation went from 0.96 GWh in 2007 to 98.81 GWh in 2015, the solar generation from 0.01 GWh in 2005 to 36.06 GWh in 2015, while the production of renewable thermal energy in 2004 was 3.24 GWh, while in 2015 it reached 408 GWh. Despite this, non-renewable thermal production also rose, from 28% in 2000 to 47% in 2015. This increase in energy from fossil fuels was conditioned by the situation in this country as it is a producer of oil and by its prices in the international market. The high oil prices in the period made it possible to conserve and increase subsidies for fuels and liquefied petroleum gas. These events partially limited the projects and initiatives for the use of renewable energies. In the middle of the period, between 2007 and 2015, there was a very strong state intervention through the National Development Plan, in which the expansion of the country's energy sector is proposed, qualifying it as a strategic program. This energy development will be carried out from hydroelectric generation, allowing a progressive reduction of thermoelectric generation. It also proposes the strengthening in the country of the use of non-conventional renewable energies, such as: solar, wind, geothermal, biomass, and tidal, aiming to establish the

generation of electrical energy from renewable sources as the main sustainable alternatives in the long term [39].

In Peru during the period 2000–2015, the average participation of renewable energies was 65% per year; among them, hydroelectric energy increased by 3%. As an interesting fact, it stands out that it is the only country of those studied where the presence of renewable thermal energy is non-existent. Solar electricity generation deserves special attention for its exponential growth; since the first record was in 2012, in which 59.68 GWh was generated, and for 2015, the solar sources for electricity generation were 230.26 GWh. Wind energy also exhibited significant growth; in the year 2000, 0.85 GWh was generated and in 2015 it reached 595.60 GWh. Auctions to promote the supply of renewable energy are key to this country's strategy to have a diversified and competitive energy matrix that promotes energy efficiency. According to Mitma-Ramirez [40] (p.167), although, since 2008, there has been a special regulatory framework to promote non-conventional renewable energies, the country has obtained very important results because the renewable energy auctions allowed Peru to achieve worldwide visibility in regarding the promotion of renewable energies. Peru is far from a sustainable energy transition, due to the lack of a clear direction and course on the future of renewable energy. As there is no renewable energy development plan, it is not possible to mitigate the existing uncertainty about the continuity in the development of the different renewable technologies awarded in the auctions.

3.2. Data on Energy Evolution in the Countries under Study by Sector

The average annual price of electricity in the industrial sector in the countries of interest at the beginning of the period and until 2015 (with some fluctuations) has remained below 0.12 US\$/kWh, with the exception of Chile and Colombia, which from 2004 and 2006, respectively, show a significant upward trend. In the initial period, Ecuador's tariff is the lowest compared to the rest of the countries; and, at the end of the period, Chile together with Colombia had the highest tariffs in relation to the remaining countries. The cumulative average annual growth rate of tariffs in Chile and Colombia are similar, equivalent to 3.9%, which is higher than the cumulative average annual growth rate of prices in Ecuador (3.6%), Bolivia (1.0%), Peru (0.8%) and Argentina (−3.3%) (Figure 2).

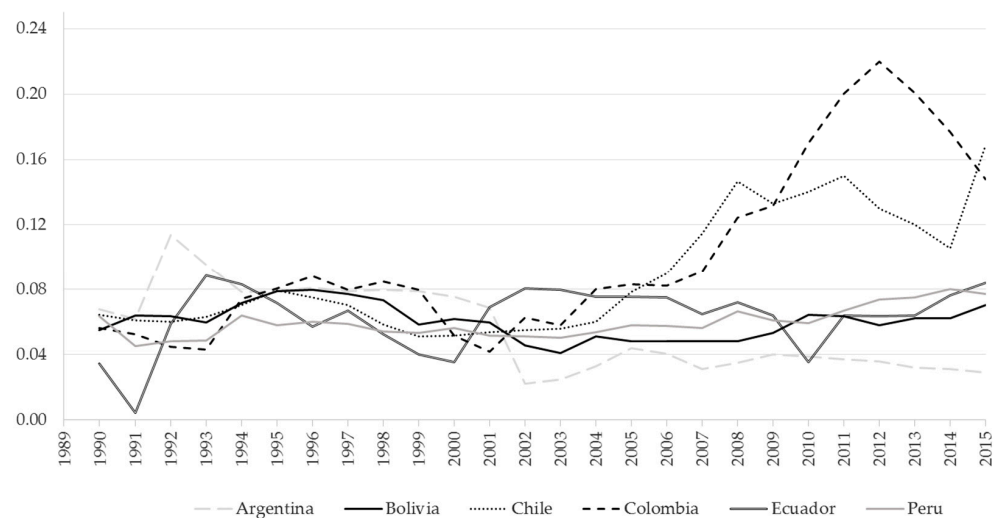


Figure 2. Annual average price of electricity in the industrial sector Source: Energy Information System of Latin America and the Caribbean (sieLAC) of the Latin American Energy Organization (OLADE) [41].

During the analysis period, the average prices in Bolivia, Chile, Colombia, Ecuador, and Peru show an increasing trend in the residential sector, whereas, in the case of Argentina, the behavior tends to be slightly decreasing with a cumulative average annual rate of −1.7%. Peru is the country that experienced the highest cumulative average annual

rate (8.8%) in the residential sector tariff during the period 1990–2015, followed by Ecuador (7.1%), Colombia (7.0%), Bolivia (2.2%), and Chile (1.1%). In particular, Chile reached its highest rate (0.23 US\$/kWh) in 2008 and 2010, and Colombia in 2012 (0.20 US\$/kWh); regarding the rest of the countries, average prices fluctuated below 0.16 US\$/kWh, throughout the period of interest (Figure 3).

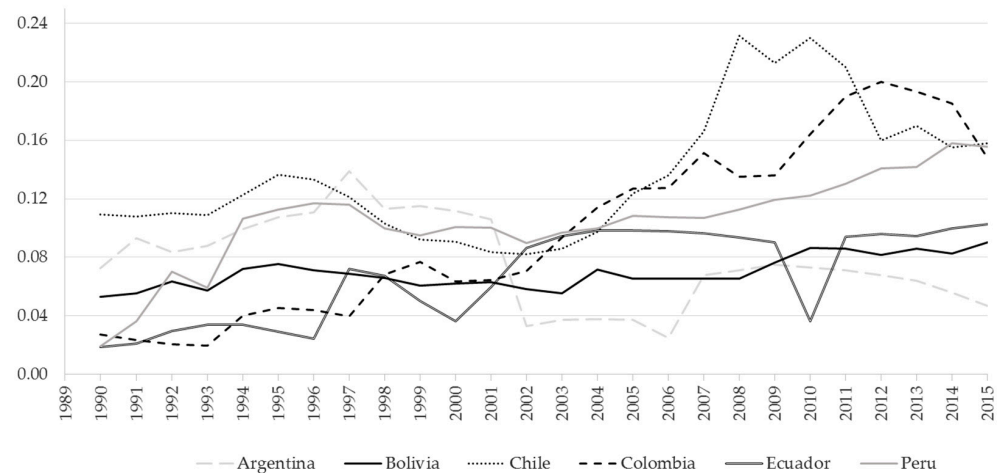


Figure 3. Average annual price of electricity in the residential sector. Source: Energy Information System of Latin America and the Caribbean (sieLAC) of the Latin American Energy Organization (OLADE) [41].

With respect to the commercial and services sector, in the long term, there is a growing trend equivalent to a cumulative average annual rate of the average electricity price of 4.3% in Ecuador, 3.5% in Colombia, 2.9% in Peru, 2.1% in Chile and 0.1% in Bolivia. On the other hand, Argentina experiences a negative cumulative average annual rate of 4.7%. At the beginning of the period, Ecuador had the lowest tariff (0.03 US\$/kWh) and Argentina the highest (0.14 US\$/kWh); however, at the end of the period, Argentina had the lowest tariff of 0.04 US\$/kWh and Peru the highest average price equivalent to 0.26 US\$/kWh (Figure 4).

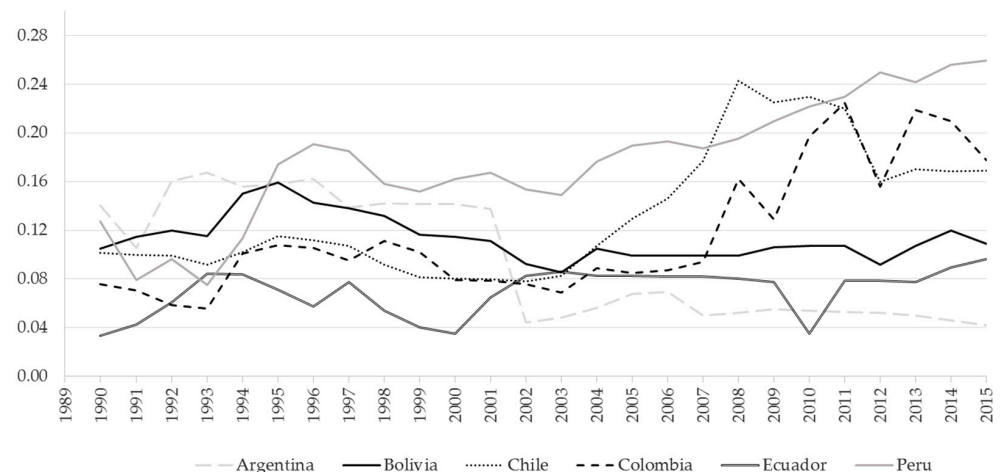


Figure 4. Average annual price of electricity in the commercial and services sector. Source: Energy Information System of Latin America and the Caribbean (sieLAC) of the Latin American Energy Organization (OLADE) [41].

According to Contreras Lisperguer [42], after the 2001 crisis, Argentina was plunged into consumer subsidy initiatives, which explains why, since 2002, the evolution of average electricity prices in the industrial, residential and commercial and services sectors, despite slight fluctuations, has been below the average prices observed in the period 1990–2001.

On the other hand, Ecuador also has several subsidy policies for electricity consumption (Dignity Tariff, Senior Adult Subsidy, Tungurahua Volcano Law and Disability Law). According to Contreras Lisperguer [42], in the Ecuadorian case, the law allows for cross-subsidies in favor of low-income consumers; in contrast, the subsidy policy in Chile is more focused, and is mostly aimed at promoting the development of renewable energies and energy efficiency. In this regard, Nasirov et al. [43] state that the Chilean economy has become one of the largest renewable energy markets in South America.

In the period of interest, a decreasing trend in renewable energy consumption (REC) is observed in almost all countries, with the exception of Argentina, which shows a slight upward trend. In the initial period, Peru, Colombia, Bolivia and Chile had the highest REC percentage compared to Ecuador and Argentina. By 2015, the REC percentage had decreased in most countries. Bolivia shows the most significant reduction, equivalent to a cumulative average annual rate of -3.0% , compared to the cumulative average annual growth rate of Chile (-1.2%), Colombia (-1.9%), Peru (-1.7%) and Ecuador (-2.2%).

In particular, during the analysis period, Argentina has a cumulative average annual rate of 0.5% ; this behavior could respond to the different efforts made in the country to promote renewable energy sources (REC). In this regard, in 1998, Law 25.019 was created, named National Regime for Wind and Solar Energy, which offered tax incentives to REC projects and a feed in tariff-type support mechanism of 10 US\$/MWh. In 2006, Law 26.190, called National Promotion Regime for the Use of Renewable Energy Sources for Electricity Production was formulated, whose goal was to reach (in 2016) 8% of national electricity consumption; the law established additional benefits to those set forth in the 1998 Law; and it also created a Trust Fund for Renewable Energies. In 2009, under Law 26.190, the Ministry of Energy implemented the GENREN program as a bidding system for 1000 MW supply contracts with REC for a period of 15 years [37,44] (Figure 5).

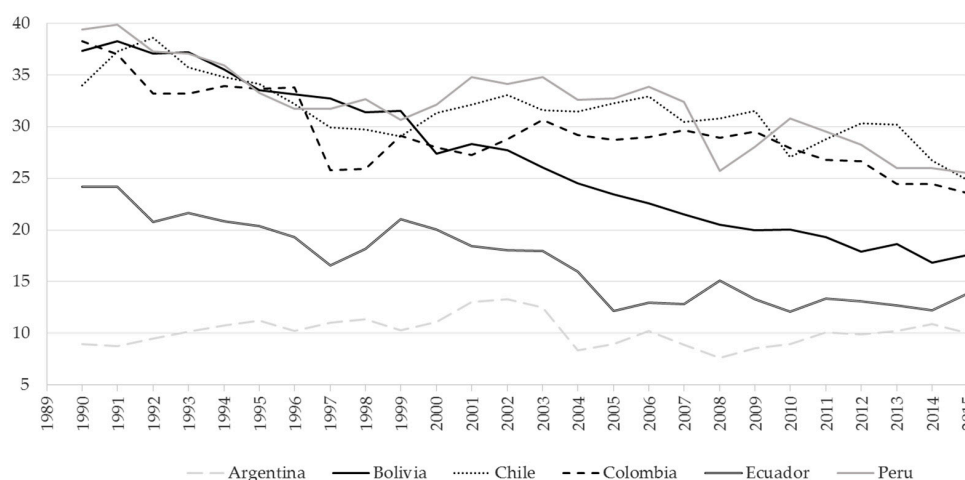


Figure 5. Percentage of renewable energy consumption over total consumption. Source: Energy Information System of Latin America and the Caribbean (sieLAC) of the Latin American Energy Organization (OLADE) [41].

3.3. Econometric Methodology: Panel Models to Estimates

Table 1 shows the dependent and independent variables of the models to be estimated, as well as the symbols to be used, units of measurement and the information sources from which the data were obtained.

Table 1. Dependent and independent variables of the models to be estimated.

Model 1				
Type	Variable	Symbol	Unit of Measure	Source
Dependent	Annual average price of electrical energy in the industrial sector	$LnPeei$	dollar per kilowatt-hour (US\$/kWh)	Energy Information System of Latin America and the Caribbean (sieLAC) of the Latin American Energy Organization (OLADE) [41]
Independent	Percentage of renewable energy over total consumption	$Pcer$	Percentage of total (%)	International Energy Agency (IEA) [2]
	Gross domestic product	$LnPIB$	Dollars current prices (USD)	World Bank [45]
	Carbon dioxide emissions	$LnCO2$	Kiloton (kt)	World Bank [45]
	Average price of a barrel of oil	$LnPet$	Dollars(USD)	Organization of Petroleum Exporting Countries [46]
Model 2				
Dependent	Average annual price of electricity in the residential sector	$LnPeer$	dollar per kilowatt-hour (US\$/kWh)	Energy Information System of Latin America and the Caribbean (sieLAC) of the Latin American Energy Organization (OLADE) [41]
Independent	Same as model 1			
Model 3				
Dependent	Annual average price of electricity in the commercial and services sector	$LnPeecs$	dollar per kilowatt-hour (US\$/kWh)	Energy Information System of Latin America and the Caribbean (sieLAC) of the Latin American Energy Organization (OLADE) [41]
Independent	Same as model 1			

With regard to the approach of the models to be estimated, in the empirical analyses in which econometric methodologies are used, a specification is generally used in which the relationship between the dependent and independent variables is specified. Therefore, it is assumed that the average annual price of electrical energy ($LnPee$) is a function or depends on Renewable energy consumption as a percentage of final energy consumption ($Pcer$) and a random disturbance term (u) in a regression model, as described in Equation (1).

$$LnPee_{it} = \beta_1 + \beta_2 Pcer_t + u_t \quad (1)$$

where t is the time and β_1, β_2 are the unknown parameters of the model.

In panel models, the specification changes slightly by including cross-sectional observations indexed with the letter i in each time period and adding a fixed unobservable individual effects term μ_i [47,48]:

$$LnPee_{it} = \mu_i + \beta_1 + \beta_2 Pcer_{it} + u_{it} \quad (2)$$

It is usually necessary to include control variables in the models to be estimated, which, although they are not the object of interest of the study, they are regressors included that allow the factors to be held constant, which, if neglected, could lead to the estimation of the

causal effect of interest being biased by the omitted variable [49]. The inclusion of these variables is shown in Equation (3).

$$\text{LnPeei}_{it} = \mu_i + \beta_1 + \beta_2 \text{Pcer}_{it} + \sum_{i=1}^p \gamma_i X_i + u_{it} \quad (3)$$

The specification of Equation (1) has been used in time series models, while Equations (2) and (3) have been used when different countries or regions are included, and the presence of control variables, so here we return to this last specification and the following models are proposed:

Model 1:

$$\text{LnPeei}_{it} = \mu_i + \beta_1 + \beta_2 \text{Pcer}_{it} + \gamma_1 \text{LnGDP}_{it} + \gamma_2 \text{LnCO2}_{it} + \gamma_3 \text{LnPet}_{it} + u_{it} \quad (4)$$

Model 2:

$$\text{LnPeer}_{it} = \mu_i + \beta_1 + \beta_2 \text{Pcer}_{it} + \gamma_1 \text{LnGDP}_{it} + \gamma_2 \text{LnCO2}_{it} + \gamma_3 \text{LnPet}_{it} + u_{it} \quad (5)$$

Model 3:

$$\text{LnPeecs}_{it} = \mu_i + \beta_1 + \beta_2 \text{Pcer}_{it} + \gamma_1 \text{LnGDP}_{it} + \gamma_2 \text{LnCO2}_{it} + \gamma_3 \text{LnPet}_{it} + u_{it} \quad (6)$$

where $i = 1, 2, \dots, 6$ and $t = 1990, 1991, \dots, 2015$, i.e., the information used in this paper corresponds to observations for the period 1990–2015, considering a group of 6 Latin American countries (Argentina, Bolivia, Chile, Colombia, Ecuador and Peru). The dependent variable in (4) is the logarithm of the average annual price of electrical energy in the industrial sector (LnPeei); in (5) the variable to be estimated is the logarithm of the average annual price of electricity in the residential sector (LnPeer); and in (6), the logarithm of the average annual price of electrical energy in the commercial and services sector (LnPeecs).

In all three models, the independent variable in each model is the Consumption of renewable energy as a percentage of the Consumption of final energy (Pcer) of each of the countries. Meanwhile, the control variables considered are related to the economic growth of each country, measured by the logarithm of the Gross Domestic Product (LnGDP); with an environmental variable, in this case, carbon dioxide emissions (LnCO2), and an international environment variable, which in this case is the average annual international price per barrel of oil (LnPet).

Table 2 shows a description of the main indicators of the variables, which will be used for the econometric models. At first, it can be observed that the data panel is balanced, which is composed of 156 observations for the six countries considered, with a time period of 26 years.

The variables can be related both in time and in space. From the results of Table 2, it can be deduced that for the case of the electricity price in the three sectors (industrial, residential, and commercial), the variation in time for a country is greater than the variation between countries. This is due to the fact that the price of electricity paid by the industry has greater variability within countries than between them because the standard deviation (SD) within them is greater than the SD between them. This is also the case for the price of electricity paid by households, as well as for the price of energy in the commercial and services sector.

Meanwhile, in the variables of the percentage of renewable energy with respect to the total, in GDP and in CO₂ emissions, it can be seen that there is greater variability between countries than within them, since for all of them, the SD decomposition between is greater than the SD within. With reference to the price of oil, the fact that it has a between equal to zero is related to the fact that this price is an international variable that is common to all six countries in all 26 years considered.

Table 2. Description of the main indicators of the variables.

Variable		Mean	Std. Dev.	Min	Max	Observations
<i>LnPeei</i>	Overall	−2.741812	0.4592363	−5.480943	−1.514507	N = 156
	Between		0.2272935	−3.003477	−2.425311	n = 6
	Within		0.409351	−5.355942	−1.831008	T = 26
<i>LnPeer</i>	Overall	−2.513096	0.5441885	−3.98939	−1.463378	N = 156
	between		0.2844461	−2.833811	−2.043433	n = 6
	within		0.4777881	−4.142023	−1.580299	T = 26
<i>LnPeecs</i>	overall	−2.246817	0.4689988	−3.396688	−1.349365	N = 156
	between		0.3203089	−2.706969	−1.781564	n = 6
	within		0.3659374	−3.054188	−1.499345	T = 26
<i>Pcer</i>	overall	24.56385	9.222533	7.609687	39.91311	N = 156
	between		8.971631	10.17846	32.20002	n = 6
	within		4.188942	14.45114	35.91472	T = 26
<i>LnPIB</i>	overall	24.97352	1.19305	22.30586	27.1114	N = 156
	between		1.129406	23.11222	26.35039	n = 6
	within		0.5945969	23.81772	26.08108	T = 26
<i>LnCO2</i>	overall	10.57603	0.8562257	8.644707	12.13399	N = 156
	between		0.8839395	9.239812	11.84287	n = 6
	within		0.278922	9.98093	11.26	T = 26
<i>LnPeer</i>	overall	3.634834	0.6538565	2.665838	4.60076	N = 156
	between		0	3.634834	3.634834	n = 6
	within		0.6538565	2.665838	4.60076	T = 26

4. Results

Before presenting the final results, some statistical diagnostic tests and specification of the proposed panel models were performed. The results of these tests are described in Table 3. In the first instance, according to the results of the Hausman test for model 1, whose dependent variable is the average annual price of the industrial sector, it is appropriate to carry out a fixed effects panel model. Meanwhile, for models 2 and 3, the null hypothesis is accepted; that is, the difference between the coefficients of random and fixed effects is not systematic, therefore, it is convenient to use the random effects method.

Table 3. Statistical diagnostic tests and specification of panel models.

Statistical Tests	Model 1	Model 2	Model 3
Hausman test H0 difference in coefficients not systematic	chi2(4) = 268.64 Prob > chi2 = 0.0000	chi2(4) = 3.97 Prob > chi2 = 0.4104	chi2(4) = 4.54 Prob > chi2 = 0.3381
Autocorrelation Wooldridge test H0: no first-order autocorrelation	F(1, 5) = 5.900 Prob > F = 0.0595	F(1, 5) = 14.13 Prob > F = 0.0132	F(1, 5) = 23.568 Prob > F = 0.0047
Heteroscedasticity Modified Wald test for groupwise heteroscedasticity in fixed effect regression model H0: $\sigma^2_i = \sigma^2$ for all i	chi2 (6) = 85.66 Prob > chi2 = 0.0000		
Panel Groupwise Heteroscedasticity Tests Ho: Panel Homoscedasticity Ha: Panel Groupwise Heteroscedasticity		-Lagrange Multiplier LM Test = 1050.3227 p-Value > Chi2(5) 0.0000 -Likelihood Ratio LR Test = 17.7221 p-Value > Chi2(5) 0.0033 -Wald Test = 5031.2 p-Value > Chi2(6) 0.0000	-Lagrange Multiplier LM Test = 738.1971 p-Value > Chi2(5) 0.0000 -Likelihood Ratio LR Test = 9.6947 p-Value > Chi2(5) 0.0844 -Wald Test = 1084.6311 p-Value > Chi2(6) 0.0000

Subsequently, models 1, 2 and 3 were tested to detect the presence of heteroscedasticity and autocorrelation. The different tests indicate that there is no evidence of autocorrelation for model 1; however, in models 2 and 3, autocorrelation is present. In the same way, the presence of heteroscedasticity is verified in the 3 models. To solve the problems presented and avoid the loss of efficiency of the coefficients obtained, regressions are carried out

using Panel Corrected Standard Errors (PCSE) as suggested by Beck [50], derived from this, models 4, 5 and 6 are obtained. Results are shown in Table 4.

Table 4. Results.

	Model 1 (4) Industrial Sector	Model 2 (5) Residential Sector	Model 3 (6) Commercial and Services Sector	Model 4 Industrial Sector	Model 5 Residential Sector	Model 6 Commercial and Services Sector
	<i>LnPeei</i> FIXED	<i>LnPeer</i> RANDOM	<i>LnPeecs</i> RANDOM	<i>LnPeei</i> PCSE	<i>LnPeer</i> PCSE	<i>LnPeecs</i> PCSE
<i>Pcer</i>	−0.006 (−0.61)	−0.021 ** (−2.82)	−0.004 (−0.55)	0.003 (0.82)	−0.004 * (−2.03)	0.006 (1.00)
<i>LnPIB</i>	1.060 *** (9.21)	1.265 *** (12.01)	0.974 *** (9.71)	0.774 *** (6.98)	1.066 *** (8.07)	0.752 *** (6.13)
<i>LnCO2</i>	−1.196 *** (−4.79)	−1.588 *** (−9.10)	−1.159 *** (−6.68)	−0.929 *** (−5.94)	−1.232 *** (−6.32)	−0.915 *** (−5.04)
<i>LnPeer</i>	−0.302 *** (−4.16)	−0.181 ** (−3.00)	−0.261 *** (−4.50)	−0.131 * (−2.00)	−0.116 (−1.55)	−0.0541 (−0.81)
<i>_cons</i>	−15.31 *** (−6.00)	−16.12 *** (−10.09)	−13.26 *** (−8.13)	−11.85 *** (−11.17)	−15.60 *** (−9.73)	−11.32 *** (−7.63)
<i>sigma_u</i>	0.283	0.222	0.260			
<i>sigma_e</i>	0.322	0.298	0.287			
<i>Rho</i>	0.434	0.359	0.452	0.319	0.675	0.568
<i>R²</i>	0.415	0.627	0.421			
<i>N</i>	156	156	156	156	156	156

Model 4 = Panel Corrected Standard Errors (PSCE); Model 5 = Heteroskedastic; Model 6 = Panel-Corrected Standard Errors (PSCE) Heteroskedastic and Correlation; t statistics in parentheses; * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$.

First, the results of each model will be described, and reference will be made to some relevant issues that lead to the deductions obtained through the proposed models, differing from those obtained by other empirical studies carried out in other latitudes.

For model 4, the results of this model allow us to deduce that renewable energies do not affect the price of energy in the industrial sector in the six countries studied, since their coefficient is not significant. It is observed that, for the price of electrical energy in the industrial sector, all the control variables are significant. The increase in GDP or the growth of the economy causes an increase in the price of energy in the industrial sector; while with a greater amount of CO₂ emissions and with a rise in the international price of oil, the annual average price of the industrial sector tends to decrease.

With the price of electrical energy in the residential sector, model 5, the result is that both the independent variable, which is the percentage of renewable energy consumption over the total consumed, as well as the control variables that reflect economic growth (GDP), and environmental issues (CO₂ emissions) are significant; not so the external environment (international oil price), which does not influence the price of household energy. The influence of economic growth on the price of electricity paid by households is direct and positive. Whereas when the consumption of renewable energy and CO₂ emissions increase, the price of this energy for families in the six countries decreases, that is, there is an inverse relationship; questions are determined by the signs of the regression coefficients.

A corrected random effects panel model makes it possible to establish that in model 6, the consumption of renewable energy does not affect the price of energy in the commercial and services sector, as this coefficient is not significant. While two of the established control variables have statistical significance, with a direct relationship between GDP and the price of this sector; and an inverse relationship (negative sign) of CO₂ emissions with the dependent variable.

5. Discussion

This research paper aims to examine the relationship between the consumption of renewable energy and the price of electricity, or in other words, to examine the influence

of renewable energy consumption on electricity tariffs. In this regard, there is already evidence to support this hypothesis in other countries, as discussed in the literature review section. However, it is important to see how this relationship behaves in South American countries by considering three different sectors (industrial, residential, commercial and services), which is the novelty of this research.

The results show that this consumption would only affect energy prices in the residential sector; in general, a 1% increase in the consumption of renewable energies over the total, would cause a 0.004% decrease in the price of this sector. The impact is relatively small, which corroborates the results obtained by other studies conducted to examine this relationship in other latitudes [51,52].

On the other hand, an increase in economic and household activities, produced as a consequence of an increase in the economy, will necessarily result in an increase in demand, and consequently an increase in its price, as confirmed by several studies that calculate the elasticity of demand in the short and long term [53–62]. Therefore, if demand increases, prices rise. In fact, for the cases studied in Latin America, the growth of the economy, measured in this study by the increase in GDP, would lead to an increase in the price of energy in the three sectors studied; however, its influence is greater in the prices of the residential and industrial sectors compared to the commercial sector. A 1% increase in the economy causes a 1.2% increase in energy prices in the residential sector, a 1% increase in the industrial sector and less than 1% in the commercial and services sector.

Furthermore, increases in CO₂ emissions cause a decrease in the price of electricity; as in the previous case, this impact is greater in the residential sector than in the other two sectors. These results do not coincide with studies from other regions, especially the European Union, due to the fact that this region has climate policy instruments that consider an increase in CO₂ rights [63]. In this regard, the price paid for polluting in Europe that companies that release carbon dioxide have to buy would affect electricity prices in the region. In the case of the Latin American countries analyzed, there is an absence of these consensual instruments and their application; this, together with other important factors such as subsidies, the purpose of climate policies and the degree of use of renewable energies would contribute to explaining this inverse relationship between electricity prices and CO₂ emissions.

In fact, as mentioned by Dong et al. [64], under the pressure of global environmental climate change, all countries in the world are developing renewable energy such as hydro-electric power, wind power and solar power. As a result, the price of electricity varies in different patterns, depending on the penetration of renewable energy. Based on the fact that Latin America emits between 9 and 10% of total Greenhouse Gas (GHG) emissions, which makes the region historically not a major emitter, it is nevertheless particularly vulnerable to climate change [65]. Therefore, policies to address this circumstance have so far been aimed at mitigating and adapting to climate change [66] rather than to reducing electricity tariffs. This inverse relationship is also related to the GDP variable, discussed above, since as indicated by ECLAC [67], there is currently a close relationship between per capita income, per capita energy consumption and per capita GHG emissions in the economies of Latin America and the Caribbean, as in all modern economies (p. 69).

The results of the models also indicate that the increase in the international oil price would cause a decrease in energy prices, with a degree of affectation in the industrial sector; but they have no effect on commercial sector energy prices and residential sector energy prices. These results do not coincide with contributions and analyses from other regions, where the relationship is positive [68–71], mainly due to specificities of the region in terms of electricity generation sources and subsidy policies.

It would be expected that with the increase in the international oil price, the prices of its derivatives used in electricity generation that uses fuels (non-renewable energy) would increase, and thus, the price of energy would rise. However, given the energy sources of electricity generation in the countries under study, the above would not have consequences on electricity costs given the significant presence of non-renewable energy sources

(including hydro, solar, wind and renewable thermal energy) in electricity generation. Data from OLADE [41] indicate that in Argentina, non-renewable sources are 61.75%, renewable sources 32.15% and nuclear sources 6.11%; in Bolivia, non-renewable 64.2% and renewable 35.8%; in Chile, non-renewable 56% and renewable 44%. Meanwhile, Colombia has 21.04% non-renewable sources and 78.96% renewable sources; Ecuador, non-renewable 21.87% and renewable 60.13%; and Peru non-renewable 39.57%, renewable 60.43%.

Bitu and Born [72] already warned that in Latin America, most countries' concessionaires are public companies, subject to political pressure to keep prices low (p. 202). Therefore, governments resort to budgetary financing of subsidies or stabilization mechanisms to reduce electricity prices in order to alleviate social tensions due to the cost of living and inequality. Correspondingly: "High levels of oil prices since 2008 have increased pressures for countries to provide energy subsidies, despite the fact that these entail fiscal costs and have non-transparent effects on distribution and efficiency. Energy subsidies are a global phenomenon, and in general terms they are as prevalent in Latin America and the Caribbean (LAC) as in other regions of the world. Depending on how they are measured, fuel and electricity subsidies ranged between 0.7 percent and 2.2 percent of the average LAC country's GDP in 2011, which is a level broadly similar to the average for Asian and Pacific countries and sub-Saharan Africa, and somewhat higher than in Europe" [73] (p. 36).

6. Conclusions

This paper aims to contribute with data and results to the scarce literature available in Latin America on the possible influence of renewable energies on the price of electricity. As a whole, for the six countries studied, for the period 1990–2015, an annual growth rate of 1.7% in energy prices in the industrial sector, an average annual increase of 4.1% in the residential sector prices and a 1.4% annual increase in the commercial and services sector prices are observed. The trend of electricity prices in Argentina differs, since they behave differently from that of the other five countries (Bolivia, Colombia, Chile, Ecuador and Peru); in Argentina the average annual was -3.3% , -1.7% and -4.7% for the industrial, residential and commercial sectors, respectively.

This behavior is reversed when analyzing the percentage of renewable energy consumption of total consumption, since only Argentina has a positive average annual growth rate of 0.5% for this period; in the other countries the annual growth rate is negative: Bolivia (-3%), Chile (-1.2%), Colombia (-1.9%), Ecuador (-2.2%) and Peru (-1.7%). On average, the six countries had an annual growth rate of -1.6% . This decrease in the percentage of renewable energy consumption occurs in the region, despite the fact that the growth in the production and use of renewable energy is important for the growing energy demand, economic growth and demographic growth. Furthermore, "the energy mix of Latin America, with a lower relative share of fossil fuels compared to the global average, places the region at an advantage in the transition to a low-carbon economy" [74].

The results of the panel model for a period of 26 years show that the consumption of renewable energies influences the price of electricity paid by households, and this level of impact is very small. On the other hand, the consumption of renewable energy has no relationship with the energy prices of the industrial sector and the commercial and services sector.

In the six countries analyzed, an increase in GDP causes an increase in the price of energy in the industrial sector; while with a greater amount of CO₂ emissions and with a rise in the international price of oil, the annual average price of the industrial sector tends to decrease. The international price of oil does not affect the price of electricity in the residential sector, while the influence of economic growth on the price of electricity paid by households is direct and positive, also while CO₂ emissions grow, the price of this Energy for families in the six countries tends to decrease. The price of energy in the commercial and services sector has a direct relationship with GDP and an inverse relationship with CO₂ emissions.

These issues do not coincide with the results of other studies in other regions, due to the specificities of the laws, subsidies, and levels of penetration of renewable energies, in addition to the fact that the energy guidelines and the goals of the renewable energy sector in the countries and regions are not consistent in several aspects.

These findings have implications for public policies in energy and economics. Although public policies that promote the production and use of renewable energies aim to reduce the consumption of fossil fuels and CO₂ emissions, they can also cause a reduction in the price of electricity in the countries of the region, depending on the sector to be considered.

It is also necessary to mention the limitations of this study, since although it aims to detect the extent to which the consumption of renewable energies affects the cost of electricity, this is a variable that depends on many factors that have not been considered in this study: prices of substitutes, regulations of each country, efficiency, climatic temporary issues. Therefore, the results of this study must be interpreted by taking into consideration other relevant issues. It is suggested that future investigations investigate the incidence of renewable energies in the volatility of electricity prices; this type of study would complement the results that this article tries to provide.

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