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**Article**

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# Impact of Renewable Electricity Consumption on the Economic Growth of Ecuador. Evidence from the Joint Cointegration Test

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**ABSTRACT**

Ecuador has become a benchmark when it comes to sustainable electricity generation in recent years. This research is based on advances in the energy sector, with the aim of knowing the impact of the consumption of renewable electrical energy on economic growth. To carry out the study, annual time series data were used for the period 1990-2021, as well as the unit root tests proposed by Dickey and Fuller in 1981 and Clemente et al. in 1998. In addition, the proposed by Bayer and Hanck which is the combined cointegration test and the autoregressive distributed lag model (ARDL) to know the impact in the short and long term. Finally, to determine causality, the VECM Granger causality framework was used. The findings demonstrated a positive impact, for every 1% increase in per capita consumption of renewable electrical energy, economic growth will increase by 5.32% in the short term. However, in the long term, for every 1% increase in per capita consumption of renewable electrical energy, economic growth will contract by 0.85%.

**Keywords:** Consumption, Economic Sciences, Ecuador, Energy, Renewable Electricity, Sustainability
**JEL Classifications:** Q4-Q42

## 1. INTRODUCTION

Electricity generation has undergone a constant metamorphosis throughout history, this is due to the new needs, objectives and perspectives that human beings manage in order to achieve sustainable economic growth and development. Electrical energy is the main input of the different sectors of the economy, thus becoming a predominant factor in driving the economic growth of a nation (Okayy et al., 2014).

When talking about natural resources, Ecuador has an infinite number of resources, however, it has gone through difficulties in terms of supply and consumption of electricity despite the use of renewable energy generation sources. This scenario raises questions about how the consumption of renewable electrical energy drives economic growth. The empirical literature, in the approach carried out, postulates standardized hypotheses for this type of research which are: Growth, conservation, feedback and neutrality, which have been tested in different studies around the planet. An example of what is indicated are the results presented by authors such as Kazar and Kazar (2014), Mutascu (2016), Asiedu et al., 2021, Azam et al. (2021), Brini (2021), Mohammadi et al. (2023), which tested the feedback hypothesis; while authors such as Payne (2009), Alper and Oguz (2016), Krkošková (2021) and El-Karimi and El- Houjjaji (2021) test the neutrality hypothesis in different nations and economic coalitions around the world.

When talking about empirical literature for Ecuador, the approach carried out is minuscule, since currently there is a study that addresses causal frameworks, it is worth highlighting the lack of previous studies that address the impact of the consumption of renewable electrical energy on the economic growth of Ecuador. This research aims to close the existing knowledge gap, by exploring the incidence and causal relationships between the consumption of renewable electrical energy and economic growth. To carry out the study, a quantitative analysis was carried out using annual time series data from the World Bank, World Labor Organization, BP plc and Our World in Data. Finally, to verify the objective, the combined cointegration test, the autoregressive model of distributed lags, and the VECM Granger causality framework were applied.

This study contributes to academic knowledge by addressing the impact of renewable electrical energy consumption on economic growth; likewise, it will serve as a source of robust statistical data for decision-making in the field of energy policy in Ecuador.

## 2. LITERATURE REVIEW AND THEORETICAL ASPECTS

The literature that addresses the topic of renewable energy consumption, economic growth, has a wide range of results that depend on the region where the studies were applied**.** In that sense, Yoo and Kwak (2010)**,** Tugcu et al. (2012), Kahia and Charfeddine (2016) indicate that the link between the consumption of renewable, non-renewable, renewable and non-renewable energy with economic growth is characterized by using four hypotheses, which included growth, neutrality, feedback and conservation, the same which is characterized by testing causal frameworks.

The growth hypothesis indicates the presence of unidirectional causality, which starts from energy consumption to economic growth. On the other hand, the neutrality hypothesis indicates the absence of causality. While, the feedback hypothesis indicates the existence of bidirectional causality. Finally, the conservation hypothesis indicates the presence of a unidirectional causal relationship, which starts from economic growth towards energy consumption. Pinzón (2018) addressed the causality between economic growth and energy consumption in Ecuador for the period 1970-2015, using a VAR model. The results show the presence of a unidirectional causal relationship, which starts from energy consumption to economic growth, thus demonstrating that the consumption of electricity and oil are responsible for economic growth. On the other hand, the study confirmed the presence of bidirectional causality in the transportation sector and economic growth.

At the Latin American level, the research results show interesting and relevant results. An example of this are the findings of Zeeshan (2021) when evaluating the relationship between energy use, foreign direct investment, natural resources and economic growth in Latin American nations, using an autoregressive model of educated lags (ARDL) addressing the period 1990-2018. The results indicate that foreign direct investment (FDI), energy consumption and natural resources have a positive and statistically significant association with economic growth.

Al-Mulali et al. (2014) for their part, carry out a study using panel data, Pedroni cointegration test, the DOLS method, the Granger causality framework with correction of errors, to examine the interaction between energy consumption, foreign direct investment, natural resources and economic growth in 18 Latin American countries during the period 1980-2010. The findings show the presence of cointegration, where variables such as gross fixed capital formation, energy consumption, labor force, and total trade have a positive and statistically significant effect on economic growth. Finally, the study tested the feedback hypothesis between all variables.

On the other hand, Solarin and Ozturk (2015) examined the link between hydroelectric energy use and economic development in a time period spanning from 1970 to 2012, in 7 Latin American nations. The results confirmed the long-term feedback hypothesis for the case of Argentina and Venezuela, while the growth hypothesis was verified in Chile, Ecuador, Brazil, Colombia and Peru. Pablo-Romero and De Jesus (2015) when trying to verify the statements of the mean curve of the environmental Kuznets curve (EKC) in 22 Latin American countries during the period 1990-2011, the authors discovered that these were not fulfilled, since the results were opposite to the postulates of EKC. On the other hand, Koengkan and Fuinhas (2020) analyzed the link between globalization, the use of renewable energies and economic growth in the member countries of MERCOSUR during the time period between 1980 and 2014. The results verified feedback hypotheses between the variables energy consumption and economic growth.

Worldwide, the findings vary, and clear examples are the results that tested the growth hypothesis in the studies carried out by Bowden and Payne (2010), Payne (2011), Salahuddin and Gow (2014), Charfeddine and Khediri (2016), Ben Mbarek et al. (2018), Gyamfi et al. (2020), Salari et al. (2021), Bouyghrissi et al. (2021), Doytch and Narayan (2021). In relation to this and as a mere expansion of what was mentioned above, Bowden and Payne (2010), when examining the relationship between the use of renewable and non-renewable energy (by sectors) and the Gross Domestic Product (GDP) in the United States during the period 1949-2006, through the Toda-Yamamoto causality test they found that there is a unidirectional relationship between residential consumption, industrial consumption of non-renewable energy and GDP.

Likewise, Payne (2011) investigated the causal relationship between energy consumption, specifically biomass (renewable energy) and the real GDP, in the United States of America during the time period between 1948 and 2007. To carry out this analysis, the Toda-Yamamoto causality test was used. The findings made it possible to validate the growth hypothesis, which indicates a unidirectional relationship between energy consumption and economic growth/GDP. Similarly, Ben Mbarek et al. (2018) tests the short-term growth hypothesis by studying the relationship between environmental degradation, renewable and non-renewable energy consumption and economic growth in Tunisia for the period from 1990 to 2015, through the use of the causality framework by VECM Granger. Likewise, Salari et al. (2021) investigated the relationship between energy consumption (renewable, industrial, residential) and economic growth in the United States of America over the period between 2000 and 2016. The findings enabled the verification of growth prostheses. The causality starts from the energy consumption of the industrial, residential and renewable sector towards economic growth, while, in the case of total energy consumption, the feedback hypothesis was verified.

On the other hand, authors such as Sadorsky (2009), Menyah and Wolde-Rufael (2010), Ocal and Aslan (2013), Caraiani et al. (2015), Aneja et al. (2017), Rasoulinezhad and Saboori (2018), Chen et al. (2019), Rahman and Velayutham (2020), Bhowmik et al. (2022) and Raihan and Tuspekova (2022) test the conservation hypothesis. In this sense, Menyah and Wolde-Rufael (2010), when investigating the causal relationship between the consumption of renewable energy, carbon dioxide emissions, nuclear energy and GDP during the period 1960-2007 in the United States of America, found that there is a causal relationship unidirectional between nuclear energy consumption and carbon dioxide emissions, this scenario was repeated for the variables growth and renewable energy consumption, thus verifying the presence of the conservation hypothesis.

Similarly, Rasoulinezhad and Saboori (2018) examined the long-term causal relationships between economic growth, carbon dioxide emissions, renewable and non-renewable energy consumption, composite trade intensity, and the Chinn-Ito index, using the use of panel data from the Commonwealth of Independent States (CIS) for the period 1992-2015. The findings allowed us to verify the hypothesis of long-term feedback between all the variables of the 12 countries studied except for the variables economic growth linkage of the use of renewable energy, while, in the short term, the presence of a unidirectional panel causality was verified, which part from economic growth, financial and commercial openness to carbon dioxide emissions and from the consumption of energy from fossil fuels to the use of energy from renewable sources.

Now, the presence of studies for different countries, economic coalitions among others makes it possible to have a wide range of results, which is why the findings of authors such as Gurgul and Lach (2012), Long et al. (2015), Koçak and Şarkgüneşi (2017), Soava et al. (2018), Saint Akadiri et al. (2019), Aydin (2019), Azam et al. (2021), Brini (2021), Gyimah et al. (2022) and Alkasasbeh et al. (2023) who tested the feedback hypothesis. Gurgul and Lach (2012) investigated the causal link between industrial and total electricity consumption in relation to GDP in Poland during the period 2000-2008. No results found allowed us to verify what was argued by the feedback hypothesis, this in turn is verified in the existing relationship between total energy consumption and GDP, this scenario is repeated between total electricity consumption and employment.

Similarly, Koçak and Şarkgüneşi (2017) examined the relationship between energy consumption and economic growth during the period 1990-2012 in 9 Balkan and Black Sea countries, using the cointegration estimation methods of Pedroni panel and the Dumitrescu and Hurlin heterogeneous panel causality estimation techniques. The findings prove the presence of a long-term relationship between renewable energy consumption and economic growth, while the results of the causality analysis prove the growth hypothesis in Bulgaria, Macedonia, Ukraine, Russia and Greece. Likewise, the study finds support by testing the feedback hypothesis in Georgia, Romania, and Albania; hypothesis of neutrality in Türkiye. Finally, and based on the characteristics of the panel data set that takes into consideration the 9 nations studied, the results support the feedback hypothesis. For its part, Brini (2021) explores a set of 16 African countries during the period 1980-2014, with the aim of knowing the dynamic causality between the consumption of renewable and non-renewable energy, economic growth and climate change, through the application of a panel pooled mean distributed lag autoregressive model and Granger causality tests. The short-term findings prove that there is directionality between the consumption of non-renewable energy towards climate change, at the same time the presence of unidirectional causality is verified from climate change towards the consumption of renewable energy (Dogan, 2016).

Finally, authors such as Acaravci and Ozturk (2010), Menegaki (2011), Alper and Oguz (2016), Bhattacharya et al. (2016), Adams et al. (2018), Ozcan and Ozturk (2019), Tuna and Tuna (2019), Fan and Hao (2020), Banday and Aneja, (2020), Krkošková (2021) and Dissanayake et al. (2023). Acaravci and Ozturk (2010) analyzed the causal link between electricity consumption and economic growth for a set of 15 economies in transition during 1990-2006; This analysis was carried out through the use of the techniques proposed by Pedroni; The findings confirmed that there is not enough evidence to reach a consensus on the determination of the direction of electricity consumption on economic growth, due to the orientation that policies related to consumption have. On the other hand, Alper and Oguz (2016), when examining the causality between the labor force, energy consumption, capital and economic growth in member countries of the European Union for the period 1990-2009, through the application of a causality model asymmetric and the ARDL model. The findings confirmed the presence of the neutrality hypothesis in Hungary, Hungary, Cyprus, Slovenia and Poland, while the growth and conservation hypothesis was verified in the rest of the countries.

Likewise, Ozcan and Ozturk (2019) carry out an analysis for a set of 17 emerging economies to understand the relationship between renewable energy consumption and economic growth during the period 1990-2016, using the Boostrap causality test for panels. The findings confirm what is indicated by the neutrality hypothesis, which was fulfilled in all countries except the case of Poland, because in this nation evidence was found that verifies the growth hypothesis. On the other hand, the theoretical link that proves the relationship between the variables used in the study is supported by the formulations executed in the works of authors such as Solow (1956), Romer (1990) and Pokrovskii (2018). Solow (1956) points out that long-term economic growth is a function of the rate of investment in capital and the speed of technological progress, since these are responsible for progress in the productivity of goods and services. For his part, Romer (1990) indicates that technological progress/change is relevant to achieving economic growth. Without forgetting that it is considered an endogenous factor that is motivated by factors such as investment in research, development and education.

In this sense, what is formulated within the theories described by Solow (1956) and Romer (1990) point out and justify the existence of a relationship between energy consumption and economic growth, from the approach that these theories provide when addressing changes and technological advances that exist within the economy, an example of which are the changes and advances within the electricity generation and consumption sector, which are easy to perceive given the current context. On the other hand, Pokrovskii (2018) provides a concise explanation to justify the link between the variables. This explanation is based on the use of the law of substitution and Smith-Marx's theory of work within the framework of the definition of value within of the economy. The author points out that the work performed by the workforce within the economy can be replaced by the work of machines, which are driven by energy. The latter tends to become a substitute job from the perspective of the law of substitution, since it has all the characteristics to be considered a factor of production (Destek and Aslan, 2017), which is used in different models of economic growth. This statement is supported by the formulations of the first law of thermodynamics.

## 3. METHODOLOGICAL ASPECTS

The study uses variables such as gross fixed capital formation (FBKF), per capita consumption of renewable electrical energy (CPPER) and labor force (FL). In addition, it used annual time series data for the period 1990-2021. Next, equation one gives the form of the energy demand function.

$$Y_t = f(CPEER_t * FBKF_t * L_t) \quad (1)$$

A logarithmic transformation was applied to the series used, in order to compress the measurement scale between the variables. Next, equation 2 details the general form of applying logarithms to each of the variables.

$$lnPIBPC_t = \beta_1 + \beta_2 \, ln\, CPEER_t + \beta_3 \, \ln FBKF_t + \beta_4 \, lnFL_{,t} + u_i \quad (2)$$

Where:

$lnPIBPC_t$: Logarithm of economic growth per capita (thousands of USD).

*ln* $CPPER_{t:}$ Logarithm of per capita consumption of renewable electrical energy (Kilowatts/hour).

*ln* $FBKF_{t:}$ Logarithm of gross fixed capital formation (millions of dollars).

*ln* $LF_t$: Logarithm of the labor force (millions of people).

To achieve the object of study, the methodology created by Pesaran et al. was applied. (2001), which is known as the ARDL limits test, this test is characterized by being flexible and at the same time has the probability of accommodating and identifying relationships in the long term when there is no linear and asymmetric component between variables. On the other hand, this methodology is advantageous when the time series used have a heterogeneous (mixed) order of integration, that is, variables that are I(0) and I(1) (Narayan and Smyth, 2005).

Compared to other cointegration techniques, the limits test provides greater robustness and provides valid inferences even when the size of the data period used is small (Ozturk, 2013). Continuing with the procedure, in order to implement the ARDL limits test it is necessary to transform minute 28 equation 3 into an unconditional error correction model (UECM), and it is described as follows.

$$\Delta \ln Y_t = c_0 + \sum_{i=1}^{p} c_i \Delta \ln Y_{t-i} + \sum_{i=1}^{p} d_i \Delta \ln CPEER_{t-i} + \sum_{i=1}^{p} d_i \Delta \ln FBKF_{t-i} + \sum_{i=1}^{p} d_i \Delta \ln FL_{t-i} + \pi_1 \ln Y_{t-1} + \pi_2 \ln CPEER_{t-1} + \pi_3 \ln FBKF_{t-1} + \pi_4 \ln FL_{t-1} + u_t \quad (3)$$

$$\Delta \ln CPEER_t = c_0 + \sum_{i=1}^{p} c_i \Delta \ln Y_{t-i} + \sum_{i=1}^{p} d_i \Delta \ln CPEER_{t-i} + \sum_{i=1}^{p} d_i \Delta \ln FBKF_{t-i} + \sum_{i=1}^{p} d_i \Delta \ln FL_{t-i} + \pi_1 \ln Y_{t-1} + \pi_2 \ln RE_{t-1} + \pi_3 \ln FBKF_{t-1} + \pi_4 \ln FL_{t-1} + u_t \quad (4)$$

$$\Delta \ln FBKF_t = c_0 + \sum_{i=1}^{p} c_i \Delta \ln FBKF_{t-i} + \sum_{i=1}^{p} d_i \Delta \ln Y_{t-i} + \sum_{i=1}^{p} d_i \Delta \ln CPEER_{t-i} + \sum_{i=1}^{p} d_i \Delta \ln FL_{t-i} + \pi_1 \ln Y_{t-1} + \pi_2 \ln CPEER_{t-1} + \pi_3 \ln FBKF_{t-1} + \pi_4 \ln FL_{t-1} + u_t \quad (5)$$

$$\Delta \ln FL_t = c_0 + \sum_{i=1}^{p} c_i \Delta \ln FL_{t-i} + \sum_{i=1}^{p} d_i \Delta \ln Y_{t-i} + \sum_{i=1}^{p} d_i \Delta \ln CPEER_{t-i} + \sum_{i=1}^{p} d_i \Delta \ln FBKF_{t-i} + \pi_1 \ln Y_{t-1} + \pi_2 \ln CPEER_{t-1} + \pi_3 \ln FBKF_{t-1} + \pi_4 \ln FL_{t-1} u_t \quad (6)$$

Where:

$\Delta$: *Prmer operador diferente*.

$C_0$ y $d_0$: *Componentes de deriva.*

Now, the ARDL limits test has 1 step, this is the joint significance test of the variables called the F test, which has a null hypothesis that indicates the absence of cointegration and an alternative hypothesis that indicates the presence of cointegration. Equation 7 and 8 illustrate the F-test hypotheses.

$$H_0: b_{1j} = b_{2j} = b_{3j} = 0 \quad (7)$$

$$H_1: b_{1j} \neq b_{2j} \neq b_{3j} \neq 0 \quad (8)$$

This test has the ability to generate upper and lower critical limits for 1%, 2.5%, 5% and 10% of significance, and thus verify the existence or not of cointegration between variables. The prior conditioning to reject the null hypothesis is that the value of the statistic called f is greater than the upper critical limit, and only then can the null hypothesis of no cointegration between variables be rejected. On the other hand, if the value of the f statistic is less than the lower critical limit, the null hypothesis is accepted, which means absence of cointegration.

Furthermore, for the tension and determination of long- and short-term coefficients, the error correction model (ECM) was used; the results of this test must have a coefficient of negative sign and at the same time be statistically significant. On the other hand, the study included diagnostic tests such as serial correlation, normality and heteroscedasticity in order to have robust estimates. Finally, to determine long-term and short-term causal relationships between the variables, the vector correction method (VECM) and the Engle and Granger causality framework were applied.

Below, Equation 9 illustrates the VECM.

$$\begin{bmatrix} \Delta lnY_t \\ \Delta lnCPEER_t \\ \Delta lnFBKF_t \\ \Delta lnLF_t \end{bmatrix} = \begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \\ b_5 \end{bmatrix} + \begin{bmatrix} B_{11,1} & B_{12,1} & B_{13,1} & B_{14,1} \\ B_{21,1} & B_{22,1} & B_{23,1} & B_{24,1} \\ B_{31,1} & B_{32,1} & B_{33,1} & B_{34,1} \\ B_{41,1} & B_{42,1} & B_{43,1} & B_{44,1} \end{bmatrix} *$$

$$\begin{bmatrix} \Delta lnY_{t-1} \\ \Delta lnCPEER_{t-1} \\ \Delta lnFBKF_{t-1} \\ \Delta lnLF_{t-1} \end{bmatrix} + \ldots + \begin{bmatrix} B_{11,m} & B_{12,m} & B_{13,m} & B_{14,m} \\ B_{21,m} & B_{22,m} & B_{23,m} & B_{24,m} \\ B_{31,m} & B_{32,m} & B_{33,m} & B_{34,m} \\ B_{41,m} & B_{42,m} & B_{43,m} & B_{44,m} \end{bmatrix} *$$

$$\begin{bmatrix} \Delta lnY_{t-1} \\ \Delta lnCPEER_{t-1} \\ \Delta lnFBKF_{t-1} \\ \Delta lnLF_{t-1} \end{bmatrix} + \begin{bmatrix} \zeta_1 \\ \zeta_2 \\ \zeta_3 \\ \zeta_4 \end{bmatrix} * ECM_{t-1}) + \begin{bmatrix} \mu_{1t} \\ \mu_{2t} \\ \mu_{3t} \\ \mu_{4t} \end{bmatrix} \quad (9)$$

Long-term causality will depend on the degree of significance of the coefficient for ECMt-1, through the use of the statistic that the t test yields. While, for the short term, the F statistic is used for the first lagged and differentiated independent variables.

## 4. EMPIRICAL RESULTS AND DISCUSSION

Within the methodology for the treatment of time series, it is necessary to stabilize the series in variance and in means, in order to rule out problems of heteroscedasticity, auto-correlation and seasonality. In this sense, the Levene, Bartlett and Brown-Forsythe tests, by showing probabilities <0.05%, allow us to accept the null hypothesis; however, we proceed to transform the series into logarithms in order to have better results due to the difference in the scale of measurements of the variables.

On the other hand, to verify the unit root properties of the variables, the Dickey and Fuller (1981), Ng and Perron tests were applied. (2001), the results are seen in Table 1. It was found that the series are not stationary in means by applying the unit root contrasts with intercept, trend and intercept and without trend or intercept in levels; However, the application of a first regular difference to the series using the different contrasts would allow us to reject the null hypothesis of the presence of unit roots, which implies that the variables present an integration of order 1.

However, the unit root tests used do not usually take into account what macroeconomic variables they have. In this sense, Perron (1997) points out that the majority of macroeconomic variables have a constant trend and slope, however, in many cases these they have sudden changes. Therefore, to solve this problem and obtain results with a high degree of veracity, the unit root test with structural break proposed by Clemente et al. (1998) is applied, which is characterized by detecting structural break, the test detected a structural break in the years 2000, 2014, 1999 and 2016 in the series GDP per capita, per capita consumption of renewable electric energy (CPEER), labor force (LF) and gross fixed capital formation (FBKF), under the approach of typical additive value. In this sense, applying first differences we reach the conclusion that they are integrated of order 1 and they become stationary in averages see Table 2.

Continuing with the procedure and once the degree of integration of the variables was determined, the cointegration was verified using the combined cointegration criterion postulated by Engle and Granger (1987), Bayer and Hanck (2012). However, before applying this test it is necessary to first determine the optimal number of lags, which according to the statistics obtained in Tables 3 and 4, this maximum length is a function of what is indicated by the AIC criterion.

On the other hand, Table 4 shows the results of the different tests carried out in the present study; these results in turn allowed us to reject the null hypothesis of no cointegration between variables.

The results provided by the combined cointegration test are efficient and robust, however, and in order to have a contrast with additional tests, the ARDL limits test was applied considering the number of optimal lags for the model, following the AIC criteria. The results obtained by the ARDL limits test verify and verify the findings of the cointegration test of Johansen and Juselius (1990), Bayer and Hanck (2012). In the case of the cointegration test of Johansen and Juselius, Table 5 indicates the presence of at least 3 cointegrated vectors (none, at most 1, at most 3), while the limits test in the same way checks and verifies what was obtained by the two tests mentioned above, and this is because the F statistic is greater than the upper limits, which translates into a presence of a long-term relationship, as illustrated in Table 6.

Now, the results for both the short and long term are shown in Table 7. In that sense, it is stated that the per capita consumption of renewable electrical energy (CPEER) has a negative impact and is not statistically significant on growth economic of Ecuador in the long term. It was found that for a 1% increase in per capita consumption of renewable electrical energy, economic growth will be boosted by −0.0085%. On the other hand, the impact of gross fixed capital formation (FBKF) is positive and statistically significant, even at 1% and it is shown that for a 1% increase in the FBKF, economic growth will be boosted by 0.3767%. Finally, the workforce has a negative and statistically significant impact, where a 1% increase in the workforce (LF) will boost economic growth by −0.1618% in the long term.

The short-term results show that the CPEER has a positive and statistically significant impact on economic growth, this scenario is repeated for the labor force, while gross fixed capital formation has a negative and statistically significant impact.

**Table 1: Unit root analysis**

| Variables | Augmented dickey fuller | | | | | | Ng-Perron | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | None | | Intercept | | Intercept and trend | | $MZ_{to}$ | $MZ_t$ | MSB | MPT |
| | t-statistical | P | t-statistical | P | t-statistical | P | | | | |
| ln $GDPPC_t$ | 1.3441 | 0.951 | −0.9877 | 0.74 | −0.944 | 0.937 | −0.392 | −0.301 | 0.770 | 32.704 |
| ln $CPEER_t$ | 1.42 | 0.95 | 1.13295 | 0.99 | −1.917 | 0.62 | 0.2808 | 0.1174 | 0.4180 | 16.010 |
| ln LF | 4.72 | 1.00 | −1.1273 | 0.69 | −2.958 | 0.160 | −1.268 | −0.510 | 0.4023 | 11.926 |
| ln$FBKF_t$ | 1.61 | 0.97 | −1.0935 | 0.70 | −1.141 | 0.90 | −0.190 | −0.150 | 0.7907 | 35.808 |
| Δ ln $GDPPC_t$ | −4.14 | 0.0000 | −4.2555 | 0.00 | −4.196 | 0.01 | −14.19 | −2.654 | 0.1869 | 1.7632 |
| Δ ln $CPEER_t$ | −5.61 | 0.0000 | −5.7938 | 0.00 | −6.216 | 0.0000 | −32.67 | −4.041 | 0.1237 | 0.7502 |
| Δ ln $LF_t$ | −1.57 | 0.108 | −5.5533 | 0.001 | −5.580 | 0.0004 | −14.95 | −2.521 | 0.1685 | 2.4091 |
| Δ ln$FBKF_t$ | −4.58 | 0.0000 | −4.8200 | 0.0005 | −4.789 | 0.0031 | −14.77 | −2.717 | 0.1839 | 1.6582 |

The table shows the oil root tests in levels and first differences. LF: Labor force, CPEER: Capita consumption of renewable electric energy, FBKF: Fixed capital formation

**Table 2: Clemente, Montañes, and Reyes unit root test of structural breaks (no trend-first difference)**

| Variable | Innovative outliers | | Additive outlier | |
|---|---|---|---|---|
| | Statistics t | Structural breakage (year) | Statistics t | Structural breakage (year) |
| ln $GDPC_t$ | −2.540331 | 2000 | −2.991990 | Nineteen ninety five |
| ln $CPEER_t$ | −4.717841* | 2014 | −5.107416* | 2013 |
| ln $LF_t$ | −2.703323 | 1999 | −5.477030* | Nineteen ninety five |
| ln$FBKF_t$ | −2.695639 | 2016 | −2.509223 | 2021 |

The table shows the results of the unit root tests with structural rupture. LF: Labor force, CPEER: Capita consumption of renewable electric energy, FBKF: Fixed capital formation

**Table 3: VAR delay order selection criteria**

| Lag | LogL | LR | FPE | AIC | SC | HQ |
|---|---|---|---|---|---|---|
| 0 | 89.58314 | NA | 2.60e-0.8 | −6.113082 | −5.922767 | −6.054901 |
| 1 | 200.3579 | 181.9870* | 3.03e-11 | −12.88270 | 11.9311* | 12.5918* |
| 2 | 215.3661 | 20.36832 | 3.52e-11 | −12.81175 | −11.09903 | −12.28823 |
| 3 | 236.4754 | 22.61715 | 3.03e-11* | −13.17682 | −10.70272 | −12.42046 |
| 4 | 253.0667 | 13.03756 | 4.64e-11 | −13.2191* | −9.983839 | −12.23011 |

*Indicates the order of delay according to the criterion. LR: Final prediction error, FPE: Final prediction error, AIC: Akaike information criteria, SC: Schwarz information criteria, and HQ: Hannan-Quinn information criteria

**Table 4: Bayer and Hanck cointegration analysis**

| Estimated model | EG-JOH | EG-JOH-BO-BDM | Cointegration |
|---|---|---|---|
| $F_{GDPPC}$ (GDPPC/CPEER, FBKF, LF) | 55.827564** | 113.53524** | FORKS |
| $F_{CPEER}$ (CPEER/GDPPC, FBKF, FL) | 4.4109202 | 16.009253 | NO |
| FLF (LF/GDPPC, CPEER FBKF) | 56.305478** | 111.56872** | FORKS |
| $F_{FBKF}$ (FBKF/GDPPCCPEER, LF) | 56.256216** | 78.514265** | FORKS |

**Represents significance at 5%. The critical values at the 5% level are EG-JOH: 10.637 EG-JOH-BO.BDM: 20.486

**Table 5: Johansen and Juselius cointegration analysis**

| Estimated model | Johansen and Juselius | | | |
|---|---|---|---|---|
| | Hypothesized number of CE (s) | Trace statistics | Critical value | P-value |
| $FGDP_{PC}$ (GDPPC/CPEER, FBKF, LF) | None* | 89.73503 | 55.24578 | 0.0000 |
| | At most 1* | 41.80290 | 35.01090 | 0.0081 |
| | At most 2 | 17.05876 | 18.39771 | 0.0762 |
| | At most 3* | 5.584167 | 3.841465 | 0.0181 |

The table shows the results of the cointegration analysis. LF: Labor force, CPEER: Capita consumption of renewable electric energy, FBKF: Fixed capital formation

Finally, the study employed the VECM Granger causality framework to determine causality between the variables. Table 7 shows the results of the tests, which enable the affirmation of the presence of causality in the long term and therefore a unidirectional causal relationship, this relationship starts from GDP per capita, FBKF and LF to CPPER. In this sense, the unidirectional relationship is verified in the long term, this is because Landa (ECM) is statistically significant at 1%.

The short-term results show the existence of unidirectional causality between CPEER and FBKF being significant at the 1% level, resulting in CPPER causing FBKF, in the same way with a 5% significance level, the existence of a causal relationship that starts from FL towards the GDP per capita and the CPEER, thus proving a unidirectional causality between the variables described above.

## 5. DISCUSSION

The findings of the research allow us to conclude that the CPEER has an impact of 5.32% on the economic growth of Ecuador in the short term, which represents a positive and statistically significant

**Table 6: Autoregressive distributed lag model cointegration test**

| ARDL limits test | | | | Diagnostic tests | | | |
|---|---|---|---|---|---|---|---|
| Estimated models | ARDL model selected | F-statistical | Structural rupture | $X^2$ normal | $X^2$ ARCH | $X^2$ RESET | $X^2$ SERIAL |
| FGDP PC (GDPPC/CPEER, FBKF, LF) | 3,4,3,1 | 10.9262 | 2000 | 0.8333 | 0.5307 | 0.9692 | 0.8523 |
| F CPEER (CPEER/GDPPC, FBKF, LF) | 1,3,0,0 | 3.0241 | 2014 | 0.6933 | 0.4599 | 0.0570 | 0.0522 |
| F LF (LF/GDPPC, CPEER, FBKF) | 3,3,4,3 | 3.7270 | 2016 | 0.8293 | 0.7068 | 0.6883 | 0.1206 |
| F FBKF (FBKF/GDPPC, CPEER, LF) | 3,3,4,1 | 7.3841 | 1999 | 0.8242 | 0.8453 | 0.3196 | 0.0101 |

| Significance level | Critical values | |
|---|---|---|
| | Lower limits | Upper limits |
| 1% level | 3.65 | 4.66 |
| 5% level | 2.76 | 3.67 |
| 10% level | 2.37 | 3.2 |

The table shows the results of the cointegration analysis of the ARDL test. LF: Labor force, CPEER: Capita consumption of renewable electric energy, FBKF: Fixed capital formation

**Table 7: Short and long term results**

| Variables | Coefficient | SE | T- statistician | P-value |
|---|---|---|---|---|
| Long-term analysis | | | | |
| ln $CPEER_t$ | −0.008528 | 0.025793 | −0.330650 | 0.7462 |
| ln $FBKF_t$ | 0.376787 | 0.017856 | 21.10100 | 0.0000 |
| Ln $FL_t$ | −0.161818 | 0.033352 | −4.851772 | 0.0003 |
| Short-term analysis | | | | |
| Δln $CPEER_t$ | 0.053288 | 0.016096 | 3.310644 | 0.0056 |
| Δln$FBKF_t$ | −0.141297 | 0.034133 | −4.139586 | 0.0012 |
| Δln $FL_t$ | 0.306115 | 0.048659 | 6.291081 | 0.0000 |
| $NDE_{t-1}$ | −0.880420 | 0.104164 | −8.452284 | 0.0000 |
| R2 | | 0.969199 | | |
| Durbin-Watson | | 1.906976 | | |
| F-statistical | | 10.92629 | | |

The table shows the results of the ARDL test in the long and short term. SE: Standard error, LF: Labor force, CPEER: Capita consumption of renewable electric energy, FBKF: Fixed capital formation

impact. This indicates that the higher the CPEER, the higher the economic growth. However, the incidence shows an inverse relationship in the long run, showing that growth will contract by 0.85% as the CPEER increases. Furthermore, it is evident that there is a causality from the CPEER to the FBKF in the short term with the results that were obtained. Likewise, a unidirectional causality was demonstrated that starts from LF to the GDPPC and CPEER. On the other hand, a long-term causal relationship was verified from the GDPPC, FBKF and LF to the CPEER, which demonstrated the unidirectional causal relationship.

The derivations of the long-term results are conclusive when contrasting the findings of Sadorsky (2009), Menyah and Wolde-Rufael (2010), Gurgul and Lach (2012), Ocal and Aslan (2013), Solarin and Ozturk (2015), Caraiani et al. (2015), Aneja et al. (2017), Rasoulinezhad and Saboori (2018), Rahman and Velayutham (2020), Balsalobre-Lorente and Leitão (2020) and Raihan and Tuspekova (2022). These, regardless of the nation or economic coalition analyzed, concluded that renewable energy consumption has a impact on GDP or GDP per capita and in turn verify the conservation hypothesis.

The existing short-term causality from CPEER to FBKF indicates that CPEER has the ability to cause FBKF, and this result can be generally confirmed in the findings of Kahia and Charfeddine (2016) within the framework of the study of renewable energies and the consumption of non-renewable energies, which is where the causal relationship is found both in the short and long term between gross fixed capital formation (FBKF) and energies renewables, which in turn have a significance level of 5%.

Also I know found evidence that demonstrates a unidirectional relationship that starts from LF towards GDPPC and CPEER, in terms of causality between LF and GDPPC. Kargi (2014) mentions that the labor force can have a causality with economic growth. However, the workforce as a total group that participates in production work is incorrect, due to the existence of different subsets that compose it and only a fraction of it participates in productive activities within the workforce.

In summary, it can be established that per capita consumption of renewable electrical energy has an impact on economic growth in the short term despite the lack of causality between them. Consequently, it can be stated that the hypothesis proposed is met in the sense that the per capita consumption of renewable electrical energy has a positive short-term impact on the economic growth of Ecuador for the period 1990-2021.

## 6. CONCLUSIONS

In conclusion, each of the variables analyzed has an impact in the long and short term, however, only some are statistically significant. In this sense, the study demonstrates that per capita consumption of renewable electrical energy has the capacity to contribute to Ecuador's economic growth prospects. On the other hand, long-term FBKF and LF are statistically significant even at the 1% level; however, the coefficient of LF is negative, while the coefficient of FBKF is positive. On the other hand, in the short term it can be verified that all the variables are statistically significant, however, there is a negative coefficient for FBKF and positive coefficients for LF and CPEER.

Finally, the findings of the causality tests allow us to verify the existence of causality in the long term, which goes from GDP per capita, FBKF and LF to CPPER, thus proving a unidirectional causal relationship between the variables described above and therefore the verification of the conservation hypothesis. The results of the short-term causality test also show a unidirectional causality between CPEER and FBKF, in the same way that the presence of a causal relationship was found that starts from LF towards economic growth, which includes GDP per capita and CPEER.

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