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Factors Affecting Carbon Emissions in Emerging Economies in the context of a Green Recovery: Implications for Sustainable Development Goals

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Factors Affecting Carbon Emissions in Emerging Economies in the context of a Green Recovery: Implications for Sustainable Development Goals

Abstract

As governments, business leaders, and other stakeholders discuss green recovery, this research examines the combined effects of energy poverty, renewable energy consumption, gross domestic product, gross domestic product square, natural gas consumption and trade freedom on CO₂ emissions in developing countries during the period 2001-2019. A panel quantile regression is used to examine the heterogeneity of the distribution among various CO₂ quantiles. This research contributes to understanding to what extent energy poverty and the other driver variables determine the achievement of Sustainable Development Goal 7 (SDG7): affordable and clean energy. The results show that energy poverty should be reduced as a priority in developing countries in order to achieve SDG7 and reduce CO₂ emissions. Finally, the study reveals several implications for policymakers in the sample countries in order to achieve environmental sustainability by means of renewable energy, economic activity, and trade freedom.

Keywords: Clean energy; Carbon emissions; Low Carbon Economy; Green Recovery; Sustainability; Sustainable development.

1. Introduction

The UN's seventh Sustainable Development Goal (SDG7) aims to provide access to affordable, reliable, efficient and clean energy, and, as a result, achieve the reduction of carbon emissions (CO₂) (United Nations, 2020). The ultimate aim is to achieve a greener and carbon-free economy in the long term, with the use and production of clean energies (Balezentis et al., 2021). This aim is based on the alarming degradation of the environment registered in recent decades due to polluting gases in the atmosphere (Munir et al., 2020; Shahbaz et al., 2017) and high primary energy intensity (US Stats, 2021). This degradation of the environment is also related to the accelerated growth of economic activity, due to the large amount of energy required in production processes (Churchill et al., 2019; Kacprzyk and Kuchta, 2020; Liu et al., 2020). However, previous literature has identified that there are several other factors that drive CO₂ emissions, which are also related to access to clean

fuels (Balezentis, 2020; Lin and Li, 2020; Su et al., 2018). Investigating those factors is vitally relevant towards a green recovery of the economy.

As an example of this, Murthy et al.'s research (1997) is an important study which identifies that poverty is another factor that contributes significantly to increased CO₂ emissions, since a considerable part of the worldwide population is living below the poverty line and does not have the necessary resources to meet their primary needs, as well as having much less access to environmentally friendly energy sources. Income poverty does not clearly distinguish the type of fuel or energy used (Boardman, 2020; Hill 2011), so the concept of energy poverty (EP) takes on a more significant connotation (DellaValle, 2019) when describing the efficiency of energy usage and its consequences on the environment (Birol, 2007). According to information provided by World Energy Outlook (2020), over the next ten years, access to clean technologies for cooking in developing economies could prevent approximately 12 million deaths associated with the pollution generated by consuming polluting fuels.

EP does not have a universally accepted definition, so it can be measured in various ways, such as access to urban/rural electricity, clean cooking technologies, heating or cooling of the home, and use of fossil fuels vs. electric vehicles, among others. These factors generally describe the comfort and well being of individuals (Alem and Demeke, 2020; Hassani et al., 2019; Mahoney et al., 2020). Although there is no clear consensus on the measurement of EP, there is a differentiation in the conception of EP between developed and developing countries. In developed countries, EP is generally related to the lack of clean fuels for heating homes, while for developing countries, EP is associated with access to electricity (Awaworyi et al., 2020; Sadath and Acharya, 2017). Therefore, access to electricity is synonymous with reducing EP because it allows for the substitution of fossil fuels that deteriorate the environment (Lin and Li, 2020). Furthermore, EP has profound microeconomic and macroeconomic implications in developing economies. From the microeconomic point of view, there is a limitation on individuals carrying out their daily activities, such as cooking, access to electricity, heating and use of electrical devices, among others; while from the macroeconomic side, it can lead to slow economic growth, environmental pollution, labor unproductivity and efficiency failures, among others (Qurat-Ul-Ann and Mirza, 2020). At present, according to statistics published by the BP Statistical Review of World Energy (BP, 2020), the consumption of energies that are not

environmentally friendly – that is, associated with EP – are the most prevalent sources worldwide: oil (33.06%), natural gas (24.23%) and coal (27.03%), ranking above nuclear or hydroelectric energy.

Thus, EP is a consequence of lack of access to clean and affordable energy (Alem and Demeke, 2020; Hasanov et al., 2019; Khan, Ali et al., 2020; Xu and Lin, 2019), hampering the achievement of SDG7. In this context, EP requires various efforts from economic agents in order to achieve the sustainable development of modern society (Alem and Demeke, 2020).

Based on the above arguments, this research examines the determinants of CO₂ emissions in developing countries, considering EP as one of the main driving forces behind CO₂ emissions in such countries. Furthermore, according to our literature review, a number of other relevant factors have neither been jointly addressed in previous studies in the context of developing countries, nor addressed using advanced econometric techniques. Consequently, this research considers the integrated role of energy poverty (EP), Renewable energy consumption (REC), Gross domestic product (GDP), gross domestic product square (GDP²), natural gas consumption (NGC) and trade freedom on CO₂ emissions during the period 2001-2019. Consequently, the panel quantile regressions (PQR) technique is used to examine the heterogeneity of the distribution among various quantiles of CO₂ (You et al., 2015). The advantage of PQR is that it examines distributive heterogeneity to provide a detailed description of the link between CO₂ emissions and explanatory variables at different CO₂ levels. Furthermore, PQR does not only focus on the conditional mean of the dependent variable. Consequently, PQR allows us to examine the variation of CO₂ among the different quantiles. In addition, an Auto-Regressive Integrated Moving Average (ARIMA) forecast model is used to examine the behavior of the variables in the coming years.

In this context, like previous studies such as those carried out by Ikram et al. (2020), Lin & Li (2020) and Rodrigues et al. (2020), this research uses the variable ‘access to rural electricity’ to represent EP, since this geographical area has been forced to use fossil fuels or firewood, due to the lack of accessibility for the consumption of clean energy (Santos Pereira & Cardoso Marques, 2020). Furthermore, the environmental Kuznets curve (EKC) hypothesis, proposed by Kuznets (1955), is validated. Unlike studies such as that of Ikram et al. (2020) or Rasoulinezhad and Saboori (2018), this study

examines rural areas' access to electricity in developing countries. Additionally, this research contributes to understanding how EP and the other driver variables affect the achievement of SDG7. Furthermore, it provides findings regarding heterogeneous emissions of CO₂ in different quantiles, as well as forecasting emissions behavior in the coming years. Consequently, the study establishes a set of hypotheses to be validated, described in Section 2.

The article is structured as follows: Section 2 contains a review of the relevant prior literature and a statement of our hypotheses. Section 3 describes the data, model, and econometric methodology used. The results of the research and the discussion in relation to previous studies are described in Section 4. Finally, Section 5 contains our conclusions and the development of policy implications.

2. Literature Review

This section is divided into five sub-sections, according to each of the explanatory variables used in the model.

2.1. Energy poverty and carbon emissions

A study carried out by Lin and Li (2020) across 114 countries shows that access to electricity is negatively associated with CO₂ emissions; in contrast, economic growth and industrialization worsen environmental pollution. Similarly, Rodrigues et al. (2020), in their study developed for the European Union, find that the correct use of electricity and access to renewable electricity contribute to the mitigation of CO₂. In a study carried out in China, Han et al. (2020) find that reducing photovoltaic poverty in Chinese households and raising households above the poverty line has a significant advantage in reducing CO₂. Also, access to clean energy is positively related to air quality in China (Li, Hong, and Wang, 2020). On the other hand, in Chile, Reyes et al. (2019) mention that large quantities of firewood are demanded during the winter, while the concentrations of PM_{2.5} in the atmosphere exceed international standards. In Ethiopia, Alem and Demeke (2020) show that an increase in kerosene price is positively associated with CO₂ since it increases charcoal consumption, which is used as a substitute fuel but is highly polluting. The same occurs in Indonesia, where households having access to clean energy reduces indoor pollution (Imelda, 2020).

On the other hand, there are also studies that mention a negative relationship between EP and CO₂. For example, in their research in France, Santos Pereira and Cardoso Marques (2020) affirm that an increase in the price of electricity at peak hours leads to substituting the consumption of fossil fuels for renewable energies, which mitigates CO₂. Likewise, Ikram et al. (2020) examine the drivers of polluting gas emissions in South Asian Association for Regional Cooperation (SAARC) countries. The results prove that access to electricity is positively related to CO₂.

Hypothesis 1 (H1): Increased energy poverty is positively associated with carbon emissions.

2.2. Renewable energy consumption and carbon emissions

Environmental degradation can be significantly reduced by good environmental practices, such as consuming renewable energy (Bekun et al., 2019; Charfeddine and Kathia, 2019). Saidi and Omri (2020) assess the factors driving CO₂ in Organization for Economic Cooperation and Development (OECD) countries. Their findings confirm that investment and renewable energy consumption (REC) reduce environmental pollution. In their study carried out in the BRICS countries (i.e., Brazil, Russia, India, China, and South Africa), Khattak et al. (2020) find that REC contributes to the mitigation of environmental pollution and confirms the existence of EKC. Similarly, Rasoulinezhad and Saboori (2018) examine the long-term relationship between renewable and non-renewable energy, Gross Domestic Product (GDP), and CO₂ in developed countries. Their study shows the negative effects caused by polluting energy sources and economic growth, while renewable energy contributes to the improvement of the environment.

Similarly, in MERCOSUR (Spanish acronym for The Common Market of South America) countries, REC alleviates environmental pollution while non-renewable energy and GDP aggravate environmental deterioration (de Souza et al., 2020). For their part, Ummalla and Samal (2019) indicate that in emerging economies such as China and India, increased natural gas consumption (NGC) and REC have led these economies to reduce CO₂. Finally, Moutinho et al. (2018) use the complete additive decomposition technique to evaluate the behavior of CO₂ in the 23 TOP countries in renewable energy. Their findings mention a negative effect on CO₂ caused by increased REC and financial development, while fossil fuels increase CO₂.

Hypothesis 2 (H2): Renewable energy consumption reduces carbon emissions.

2.3. GDP and carbon emissions

CO₂ emissions are mainly generated due to economic development (Gong et al., 2020; Kacprzyk and Kuchta, 2020; Munir et al., 2020). Some studies, such as that by Cheikh, Zaid, and Chevallier (2021), carried out in countries in the Middle East and North Africa (MENA) region using a threshold model, find that CO₂ emissions depend on the economic level of each country; the more significant the country's economic development and consumption of energy, the more CO₂ tends to decrease. Similarly, in a study of 121 economies worldwide, Kacprzyk and Kuchta (2020) find an inverted U-shaped relationship between CO₂ and economic development. Ren et al. (2020) also find an inverted U-shaped relationship between CO₂ and GDP in the lowest regression quantiles through a quantile regression panel in the BRICS countries. Similar results are found by Ridzuan et al. (2020) in Malaysia. However, Boufateh and Saadaoui (2020) find ambiguous evidence in their results regarding 22 African countries, indicating that EKC is only significant in the long term.

In contrast, some studies affirm that CO₂ emissions do not depend on a country's income level; that is, environmental pollution increases as economic growth increases (Zafar et al., 2019, Malumfashi et al., 2020; Ren et al., 2020; Zhu et al., 2016). For example, Munir et al. (2020), in their research carried out in Asian countries, state that CO₂ depends positively on economic growth, regardless of income level. The same result has been found in Australia; Nasir et al. (2021) show that CO₂ maintains a positive relationship with economic growth.

Hypothesis 3a (H3a): Increased GDP is associated positively with carbon emissions.

Hypothesis 3b (H3b): Increased GDP² is negatively associated with carbon emissions.

2.4. Consumption of natural gas and carbon emissions

Some studies, such as that of Wang et al. (2019), find that natural gas consumption (NGC) is a fuel option which can reduce environmental pollution. For example, a recent study by Lin and Agyeman (2020) examines the effect of NGC on the environment in Sub-Saharan Africa (SSA). Their novel results indicate that NGC is positively correlated with environmental degradation when the relationship is analyzed linearly. However, when

addressing this relationship in a non-linear form, it is found that NGC is negatively associated with CO₂ through improved technological progress. Another study carried out in China by Xu and Lin (2019) with non-linear models finds that NGC and CO₂ have an inverted U-shaped relationship in the Eastern Region, while in the Central and Western Regions, the relationship is U-shaped. Similarly, Li et al. (2020) conduct a study of China's provinces, finding that technological improvement causes NGC to contribute to the mitigation of CO₂. Also, Dong, Sun, Hochman, Zeng, & Li (2017) mention that in China, natural gas is a good substitute for more polluting fuels such as coal or firewood, such that a 1% increase in its consumption represents a decrease in CO₂ between 0.03% to 0.05%.

On the other hand, Dong, Sun, and Hochman (2017) use the augmented means group (AMG) in the BRICS countries to examine the drivers of CO₂. Their results affirm that the consumption of natural gas and renewable energy contributes to the mitigation of environmental pollution. Similarly, Dong et al. (2018), using second-generation long-term equilibrium techniques, confirm the existence of the EKC in Asia-Pacific countries and affirm that air quality can increase with increasing NGC.

Hypothesis 4 (H4): Increased natural gas consumption is negatively associated with carbon emissions.

2.5. Trade freedom and carbon emissions

One of the most recent studies developed by Wang and Zhang (2021) analyzes the decoupling of CO₂ in 182 countries classified according to their income level. The results show that trade openness allows for the reduction of CO₂ emissions in high-income and upper-middle-income countries; however, this effect disappears in lower-middle-income countries and increases CO₂ in low-income countries. These results are contrary to those found by Vural (2020), who shows that commercial freedom leads to increased CO₂ in selected Sub-Saharan African Countries. However, the study by Khan, Ali, Jinyu et al. (2020) in nine oil-exporting countries shows that exports increase emissions, while imports positively affect environmental pollution. According to Hasanov, Liddle, and Mikayilov (2019), the positive effects of imports and the adverse effects of exports on CO₂ remain if only the developing oil-exporting countries are considered.

In the same way, Safi et al. (2020) perform an analysis which separately disaggregates the effect of imports and exports on CO₂ in seven countries with developed economies (G-7). These findings reveal that imports increase CO₂, while exports and financial instability reduce them. In OECD countries, the increase in exports reduces CO₂ from consumption, more than or equal to that from the territory (Liddle, 2018). On the other hand, in a study carried out in China (Wang et al., 2020), one of the countries causing the highest amounts of CO₂, indicates that while the technological progress in companies exporting new technologies generates a decrease in CO₂ in developed countries, at the same time it increases CO₂ in undeveloped countries.

Hypothesis 5 (H5): Increased trade freedom is negatively associated with carbon emissions.

3. Data, Model, and Econometric Approach

3.1. Data

This research examines the determinants of CO₂ emissions in developing countries, considering EP as one of the main driving forces behind CO₂ emissions in such countries. According to the literature review, several other factors have not been jointly addressed in previous studies within developing countries. Consequently, this research considers the integrated role of energy poverty (EP), Renewable energy consumption (REC), Gross domestic product (GDP), gross domestic product square (GDP²), natural gas consumption (NGC) and trade freedom on CO₂ emissions in the period 2001-2019. Gross domestic product per capita square (GDP²) is incorporated into the analysis to validate compliance with EKC. Annex 1 presents some of the key previous studies that examine the determinants of CO₂; additionally, the explanatory variables that each study uses are detailed. In this sense, this literature review contributes to defining the factors affecting CO₂ and this study's contribution to the current state of the art. The defined factors have not previously been used to examine CO₂, and these relationships have not been examined in developing countries.

Consequently, their contribution is unprecedented and significant to understanding how these factors determine SDG7. Accordingly, Figure 1 describes in detail the process for selecting the explanatory variables of the study. First, a literature review process was carried out on the determinants of CO₂. After reviewing the documents, gaps in the

literature in developing countries about CO₂ were identified. Next, the factors used in other previous studies to define the variables of the present study were examined. Then, the availability of information was verified in various databases; consequently, the 25 countries with information available for the period under review were selected. Finally, having defined the countries under study and the variables for analysis, econometric estimates were made.

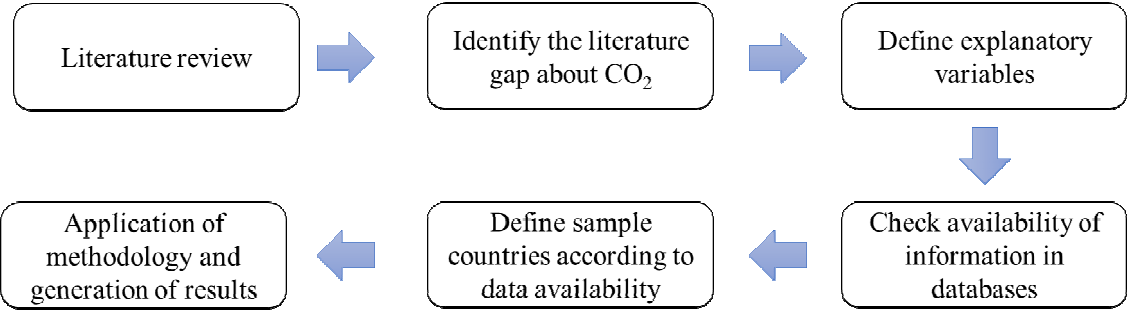


Figure 1. Definition of variables

This research uses official sources from 25 developing countries (see Annex 2) from 2001 to 2019. The dependent variable EP is measured based on "access to rural electricity". The data was obtained from the World Bank Development Indicators. This data is available for 59 countries; however, 28 out of 59 are developing countries. We found that information was not available for 3 out of the 28 countries; thus, 25 developing countries with complete information for the period were reviewed. The dependent variable represents the amount of CO₂ in the air. Additionally, taking into account the various definitions of EP from the work of Hassani et al. (2019), this study considers the percentage of people in rural areas without access to electricity as a proxy variable for EP. This variable was calculated as follows: from 100% of the rural population, people in the rural sector with access to electricity were subtracted. Figure 2 shows the average EP in the period examined.

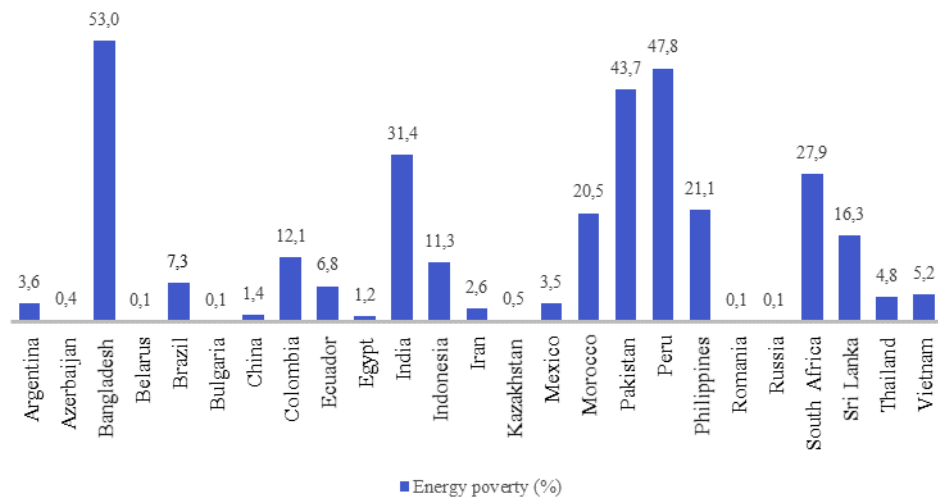


Figure 2. Energy Poverty (%).

Source: Own elaboration based on WDI (2020).

The explanatory variables, REC (Bhattacharya et al., 2020), GDP / GDP² (Huang et al., 2020), NGC (Naseem et al., 2020) and TF (Vural, 2020), were selected according to the previous analysis of the literature review, since these variables help to explain the behavior of EP in relation to environmental pollution. Following previous research (Khattak et al., 2020, Dong et al., 2018), the square of GDP (GDP²) is used to evaluate the EKC hypothesis proposed by Kuznets (1955). EKC establishes that in the initial phase of countries' economic growth, CO₂ pollution increases, while CO₂ pollution decreases when countries have achieved significant economic growth. Table 1 presents the description and data sources used in the research.

Table 1. Description of variables

Variable	Description	Symbol	Data source
Carbon emissions	Carbon emissions in tons	CO ₂	Statistical Review of World Energy (2020)
Energy poverty	Percentage of people in rural areas without access to electricity.	EP	World Bank Indicators (2020)
Renewable energy consumption	Renewable energy consumption (kWh)	REC	Statistical Review of World Energy (2020)
Gross domestic product	GDP per capita (constant 2010 US\$)	GDP	World Bank Indicators (2020)
Gross domestic product per capita square	GDP per capita (constant 2010 US \$) squared	GDP ²	World Bank Indicators (2020)
Natural gas consumption	Natural gas consumption (kWh)	NGC	Statistical Review of World Energy (2020)
Trade freedom	Trade freedom index, in which 0 indicates high tariff rates and 100 indicates the absence of tariff rates that limit trade.	TF	Heritage Foundation (2020)

Table 2 shows the statistics of the variables used in the model. The skewness and kurtosis statistics describe the distribution of the variables. The Jarque-Bera probability allows rejection of the null hypothesis of normality between the variables, which argues that using the quantile regression panel is adequate to examine the heterogeneous effect of the explanatory variables on CO₂.

Table 2. Descriptive statistics

Statistic	CO ₂	EP	REC	GDP	GDP ²	NGC	TF
Mean	19.0188	7.418512	24.55175	15594.36	5.37e+08	8.199255	71.8273
Median	18.97506	1.132645	24.56596	9018.759	8.13e+07	8.757124	72.2
Minimum	16.82514	0.01	18.15003	541.2917	292996.7	3.79846	41.4
Maximum	23.00828	83.90425	29.23198	65147.43	4.24e+09	11.99644	88
Standard Dev.	1.495731	14.29879	2.091962	17177.79	1.03e+09	1.903552	10.11997
Kurtosis	3.170066	14.50893	3.953619	4.039998	5.700779	2.59291	3.072589
Skewness	0.7756779	3.183105	-0.4336291	1.611124	1.999784	-0.6045443	-0.5324175
Jarque-Bera	30.85***	2191***	21.05***	145.2***	295***	20.62***	14.43***
Correlation	-	-0.2049**	0.6263**	-0.2455**	-0.3300**	0.6333**	-0.2537**
Observations	475	475	475	475	475	475	475

Note: ***, and ** shows significance level at 0.1% and 5% respectively.

3.2. Econometric approach

Before validating the long-term cointegration test, the cross-sectional dependence between the study variables should be considered in order to estimate efficient results (Yao et al., 2020). The cross-section dependency test identifies whether interdependence exists between the countries examined (Zeqiraj et al., 2020; Zhao et al., 2020). The interdependence that exists between countries is generally associated with economic, commercial, social and political relations, among others, that usually exist between countries (Khan, Ali, Dong et al., 2020), and generate the existence of dependence between the set of study variables (Breusch and Pagan, 1980). Consequently, the cross-sectional dependency (CD) test of Pesaran (2004) is used to control this problem (Liddle and Huntington, 2020) and adequately define the root test unit suitable for the following steps. Pesaran's (2004) test establishes the null hypothesis of non-dependence between variables. This test can be written as follows:

$$CD = \sqrt{\frac{2}{N(N-1)} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^N T_{it} \hat{p}_{ij}^2 \right)} \rightarrow N(0,1) \quad (1)$$

In Equation (1), $\hat{\rho}_{ij}$ represents the correlation coefficients calculated from the model residuals, assuming that the mean value is zero and the variance constant. Next, the existence of cross-section dependence in the model variables suggests applying second-generation unit root tests instead of first-generation tests (Malumfashi et al., 2020). In this sense, following Qiao et al. (2019), the series' stationarity is examined with the cross-sectional augmented Im, Pesaran, and Shin (CIPS) test and the cross-sectional augmented Dickey-Fuller test (CADF) developed by Pesaran (2007). The null hypothesis establishes the non-stationarity of the series. The CADF test can be written as follows:

$$\Delta y_{i,t} = \alpha + \beta_i y_{i,t-1} + \gamma_i \bar{y}_{t-1} + \sum_{j=0}^p \theta_{it} \Delta \bar{y}_{t-j} + \sum_{j=1}^p \tau_{ij} \Delta y_{i,t-j} + \mu_{it} \quad (2)$$

In Equation 2, \bar{y}_{t-1} and $\Delta y_{i,t-j}$ represent the averages of time T of the N countries examined. Next, the CIPS test is formalized, according to Equation 3:

$$CIPS = N^{-1} \sum_{i=1}^N t_i(N, T) \quad (3)$$

Where $t_i(N, T)$ represents the t statistic defined in Equation 3, an indispensable requirement for examining the long-term equilibrium between the model variables is that the variables are stationary; otherwise, the long-term tests may be biased and spurious (Jiang et al., 2020). Consequently, the second-generation Westerlund (2007) test is developed to examine the long-term equilibrium relationship, which controls heterogeneity and cross-sectional dependence. Westerlund's test (2007) examines four statistics, two of which are termed mean group statistics (G_t, G_α), while the other two are panel statistics (P_t, P_α). The null hypothesis establishes the non-cointegration of the study variables. The four statistics being estimated are described as follows:

$$G_t = \frac{1}{N} \sum_{i=1}^N \frac{\delta'_i}{SE(\delta'_i)} \quad (4)$$

$$G_\alpha = \frac{1}{N} \sum_{i=1}^N \frac{T\delta'_i}{\delta'_i(1)} \quad (5)$$

$$P_t = \frac{\delta'}{SE_{\delta'}} \quad (6)$$

$$P_\alpha = T\delta' \quad (7)$$

Where δ^f represents the error correction term, which is calculated by substituting it in Equation 7; the same term represents the adjustment speed towards equilibrium. Additionally, following Huang et al. (2020), Malumfashi et al. (2020), and Xu and Lin (2020), the long-term cointegration results are contrasted with the cointegration methods of Pedroni (2004) and Kao (1999).

The steps developed above are necessary to ensure that the long-term estimates are reliable and efficient (Koengkan and Fuinhas, 2020). The quantile regression model panel is then used to examine the nexus between CO₂ and explanatory variables. One of the many advantages that this method offers is that it allows us to examine all the independent variables on different points of the CO₂ variable (Guang et al., 2019), unlike other methods, such as OLS, which tend to focus only on the mean effects of the dependent variable. This can generate biased and inefficient estimators (Dogan et al., 2020), because in general, the data distributions of the variables from any study follow asymmetric distributions, with several inflexion points or heteroscedasticity (Akram et al., 2021).

Regarding this concern, following Koenker and Bassett (1978), PQR is used to examine the relationship between CO₂ and EP, REC, GDP, GDP², NGC, and TF. This approach is advantageous in studying phenomena related to the environment since environmental degradation depends mainly on the country's economic categorization (Luo et al., 2020), and this method divides the distribution of the dependent variable into several quantiles (Muhammad et al., 2020). Thus, the estimation of CO₂ by quantiles can be formalized as follows:

$$Q_{y_{it}}(\pi|X_{it}) = X_{it}^{\pi}V_{\pi} + \delta_i \quad (8)$$

In Equation 8, $Q_{y_{it}}(\pi|X_{it})$ represents CO₂ in various quantiles π^{th} , X_{it}^{π} is a vector that contains the effect of the explanatory variables, defined in the section before π^{th} quantiles. V_{π} measures the sensitivity of CO₂ caused by the explanatory variables. Δ_i symbolizes the fixed effect for country $i = 1, 2, 3, \dots, N$ in the period $t = 2001, 2002, 2003, \dots, T$. Based on Equation 8, the panel estimate for the present investigation can be estimated as follows:

$$Q_{CO2_{it}}(\pi|X_{it}) = \alpha_{1\pi}EP_{it} + \alpha_{2\pi}REC_{it} + \alpha_{3\pi}GDP_{it} + \alpha_{4\pi}GDP_{it}^2 + \alpha_{5\pi}NGC_{it} + \alpha_{6\pi}TF_{it} + \delta_i \quad (9)$$

In Equation 9, CO₂ represents carbon emissions; EP is energy poverty, REC is renewable energy consumption, GDP is economic growth, GDP² is the square of GDP,

NGC is natural gas consumption and *TF* is the trade freedom. The variable *GDP*² was included to validate EKC in the model at π^{th} quantiles. If $\alpha_{3\pi} > 0$ and $\alpha_{4\pi} < 0$, EKC is fulfilled and ensures the existence of an inverted U-shaped relationship between CO₂ and GDP, controlled by the effect of EP.

Then, when estimating Equation 9, when generating the regressions in the different π^{th} quantiles, the explanatory variables' effect depends on the quantile but not on the fixed effect of each country (Goetzke and Vance, 2020). In this sense, Koenker (2004) solves this problem by including a term called a penalty, which minimizes the variation caused by the estimated coefficients. Thus, the expression can be defined as follows:

$$\min_{(\varphi, \omega)} \sum_{k=1}^K \sum_{t=1}^T \sum_{i=1}^N W_k v_{\pi_k} (y_{it} - \varphi_i - X_{it}^T \omega(\pi_k)) + \theta \sum_i |\varphi_i| \quad (10)$$

In Equation 10, $k = \pi_1, \pi_2, \pi_3, \dots, \pi_n$, $t = 2001, 2002, 2003, \dots, 2019$ and $i = 1, 2, 3, \dots, 25$. X represents the set of regressor variables, and v_{π_k} is the lost function of the quantiles. W_k measures the weighting to the kth quantile.

4. Results and Discussion

This study examines the long-term equilibrium relationship between CO₂ and its driving variables in 25 developing countries during the period 2001-2019. A number of econometric approaches have been designed to explain the relationship in question. Consequently, a list of explanatory variables is used that has not been addressed in previous studies in these developing countries. Before examining the results of the relationship between CO₂ and EP, REC, GDP, GDP², NGC and TF, the cross-sectional dependency of the sections is evaluated, along with other studies that examine the behavior of CO₂ with PQR (Ren et al., 2020). According to the probabilities of the Pesaran (2004) CD tests (shown in Table 3), the null hypothesis of cross-sectional dependence between the variables is accepted. As a product of trade relations and globalization, among other factors, the countries in this study are interdependent, such that their behavior is reflected in the development of the others and vice versa (Malumfashi et al., 2020).

Table 3. Cross-sectional dependence test

CD test								
Sample countries	Variables	CO ₂	EP	REC	GDP	GDP ²	NGC	TF

Statistic	7.81***	33.80***	36.72***	67.21***	65.86	33.33***	33.59***
p-value	0.000	0.000	0.000	0.000	0.000	0.000	0.000

*** indicates statistical significance at 0.1 % level.

After confirming the presence of cross-sectional dependence, second-generation unit root tests were employed. The CIPS and CADF unit root tests performed by Pesaran (2007) were used, which control cross-sectional dependence in each section. Table 4 presents the results obtained from both tests. According to the probabilities shown, the null hypothesis of non-stationarity is rejected. The variables are non-stationary in level, while in their first difference, they become stationary and have order of integration I (1).

Table 4. Second-generation panel unit root test

Variable	CIPS		CADF	
	Level	Δ	Level	Δ
CO ₂	-1.880	-3.789***	-1.436	-2.153**
EP	-1.982	-3.392***	-1.112	3.413***
REC	-2.871***	-4.309***	-1.903	-2.481***
GDP	-0.837	-2.604***	-0.816	2.502***
GDP ²	-1.759	-3.185***	-1.705	-2.683**
NGC	-2.529***	-4.380***	-1.622	-2.308**
TF	-2.707***	4.237***	-1.614	-2.046*

Note: Δ represents the first differences, ***, **, and * indicate statistical significance at 1%, 5%, and 10% level, respectively.

An essential requirement to evaluate long-term cointegration is to ensure that the series is stationary; otherwise, the estimators are biased and inefficient, and the estimates become spurious (Malumfashi et al., 2020). In this context, the second-generation Westerlund (2007) test was used to examine the cointegration relationship. The results of Table 5 show that at 0.1% of significance, the null hypothesis of no cointegration is rejected; that is, the existence of a long-term equilibrium relationship between CO₂ and EP, REC, GDP, GDP², NGC, and TF. Like other studies (Huang et al., 2020; Malumfashi et al., 2020; Xu and Lin, 2020), the Kao (1999) and Pedroni (2004) test was used as a robustness test to validate long-term cointegration. Similarly, at 0.1% significance, the null hypothesis of no cointegration between the model variables is rejected. That is, long-term cointegration in the model variables is confirmed.

Table 5. Panel cointegration tests

Test	Statistic	Value	p-value	Cointegration
Westerlund cointegration	panel Gt	-3.392***	0.000	Yes
	Ga	-3.639***	1.000	No
	Pt	-13.785***	0.000	Yes

	Pa	-5.107***	0.987	No
Pedroni panel cointegration	Statistic Within			
	Panel v-statistic	-3.313***	0.000	Yes
	Panel rho-statistic	2.85***	0.000	Yes
	Panel PP-statistic	-3.633***	0.000	Yes
	Panel ADF-statistic	9.379***	0.000	Yes
	Statistic Between			
	Group rho-statistic	4.449***	0.000	Yes
	Group PP-statistic	-3.222***	0.000	Yes
	Group ADF-statistic	-10.39***	0.000	Yes
Kao panel cointegration	Dickey-Fuller	-12.0893***	0.000	Yes
	Augmented Dickey-Fuller	-7.6044***	0.000	Yes
	Unadjusted Dickey-Fuller	-13.4284***	0.000	Yes

Notes: ***, ** and * indicates significance at 0.1%, 1% and 5% levels.

After verifying the long-term equilibrium relationship between the model variables, the quantile regression panel was estimated, which allows us to examine the effects of EP, REC, GDP, GDP², NGC, and TF on CO₂ at different quantile points (Zhang et., 2016). Table 6 shows the relationships between the explanatory variables and CO₂ in the 10th – 90th quantiles. It shows the heterogeneity of the coefficients of the explanatory variables according to the quantile of CO₂.

Table 6. The results of panel quantile regression estimation

Quantiles	EP	REC	GDP	GDP ²	NGC	TF
10 th	0.0009152** (0.013)	- 0.0360202*** (0.000)	0.000056*** (0.000)	-4.93e-10*** (0.000)	0.2146948*** (0.000)	- 0.0005679*** (0.000)
20 th	0.0010631** (0.034)	- 0.0389734*** (0.000)	0.0000593*** (0.000)	-4.82e-10*** (0.000)	0.2149809*** (0.000)	- 0.0006063*** (0.000)
30 th	0.00112** (0.024)	-0.037895*** (0.000)	0.0000545*** (0.000)	-4.73e-10*** (0.000)	0.2230107*** (0.000)	-0.0005665** (0.004)
40 th	0.0007925*** (0.000)	- 0.0357726*** (0.000)	0.0000568*** (0.000)	-4.90e-10*** (0.000)	0.2074552*** (0.000)	- 0.0005117*** (0.000)
50 th	0.0005259** (0.026)	- 0.0489181*** (0.000)	0.000055*** (0.000)	-4.28e-10*** (0.000)	0.1929008*** (0.000)	- 0.0004985*** (0.000)
60 th	0.0010562** (0.004)	- 0.0372981*** (0.000)	0.0000583*** (0.000)	-5.02e-10*** (0.000)	0.1998406*** (0.000)	-0.0006633** (0.004)
70 th	0.0015262*** (0.000)	- 0.0341315*** (0.000)	0.0000567*** (0.000)	-4.48e-10*** (0.000)	0.21378*** (0.000)	- 0.0004592*** (0.000)
80 th	0.0007618*** (0.000)	- 0.0405636*** (0.000)	0.0000591*** (0.000)	-4.66e-10*** (0.000)	0.2189927*** (0.000)	- 0.0003687*** (0.000)
90 th	0.0010876*** (0.000)	- 0.0418612*** (0.000)	0.0000548*** (0.000)	-4.36e-10*** (0.000)	0.2268399*** (0.000)	- 0.0007105*** (0.000)

Notes: ***, ** and * indicates significance at 0.1%, 1% and 5% levels. Values in parentheses represent p-values.

Figure 3 shows the effects of the explanatory variables on CO₂.

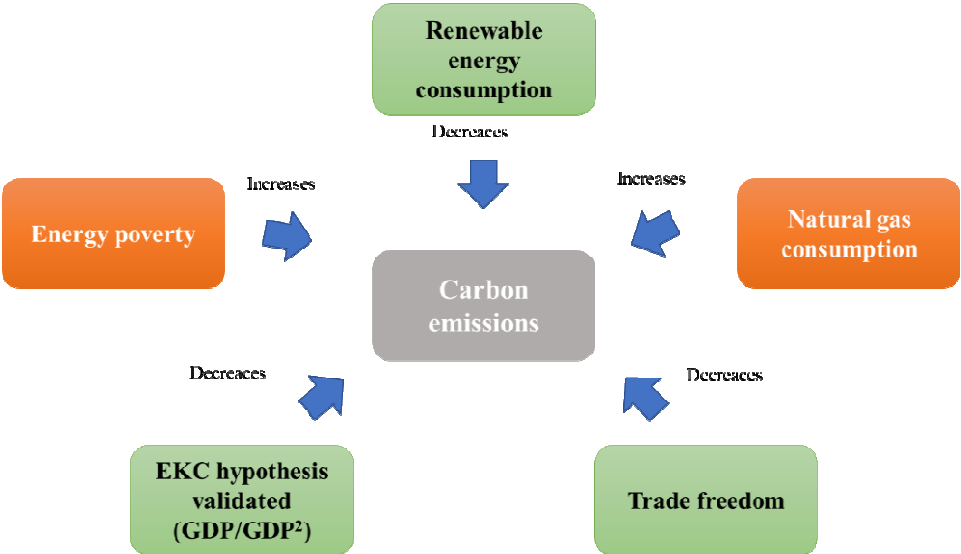


Figure 3. Summary of the results.

Source: Authors.

EP has a positive and statistically significant effect, shown overwhelmingly in all quantiles $\pi = 0.1$ to $\pi = 0.9$. Generally, EP is related to limited access to clean and sustainable energy for daily household activities in developing countries. EP is positively related to CO₂ throughout all quantiles and shows an effect that varies slightly, from $\pi = 0.1$ to $\pi = 0.9$. This behavior shows that EP affects lower levels of contamination, as well as higher levels. For example, when people do not have access to electricity, they cannot use modern cooking technologies, so they are forced to choose accessible and affordable fuels, such as firewood or fossil fuels, that cause environmental degradation, confirming hypothesis H1. These results support the findings of Alem and Demeke (2020), and Imelda (2020) in developing countries, such as Ethiopia and Indonesia; these studies mention that poor access to electricity leads to the use of polluting fuels in cooking food. In the same way, Reyes et al. (2019) indicate that not having access to clean energy for heating increases firewood demand, which in turn worsens air quality.

Next, REC has a negative and significant effect on CO₂, as described by hypothesis H2. The effect of REC is higher at the highest levels of contamination compared to the lower quantiles. In other words, when there are high levels of contamination, REC has greater force, because REC is a driver to achieve efficient practices in the environment

(Khan et al., 2021). Clean energies come from renewable sources, which reduce CO₂ in the environment (Bhattacharya et al., 2020; Saidi and Omri, 2020). These results confirm the findings of Khattak et al. (2020) in a study conducted in the BRICS countries, as well as the findings of Rasoulinezhad and Saboori (2018) and de Souza et al. (2020) in a group of developing countries and MERCOSUR, respectively. Similarly, the increase in REC may be driven by its more affordable price, making it a good substitute for polluting energy (Ponce and Khan, 2021), according to the International Renewable Energy Agency (IRENA, 2018).

For its part, GDP maintains a positive and statistically significant relationship from quantile $\pi = 0.1$ to quantile $\pi = 0.9$. The same occurs with GDP², which shows a negative relationship in each quantile; this validates the existence of an inverted U-shaped relationship between economic growth and CO₂. In other words, EKC is fulfilled for this group of developing countries, which means that these countries' economic development contributes to the mitigation of environmental degradation in all quantiles. These two findings allow us to corroborate the suggestion of hypotheses H3a and H3b. GDP has a uniform effect from the lowest to the highest quantiles. In addition, the magnitude of the GDP² coefficient decreases at the highest levels of CO₂; however, the significance remains. These results are similar to those found by Huang et al. (2020), Ren et al. (2020), Salman et al. (2019), and Cheikh et al. (2021), who find an inverted U-shaped relationship in China, BRICS, ASEAN and MENA countries, respectively. It is also similar to the findings of Malumfashi et al. (2020), Ren et al. (2020), and Zhu et al. (2016), for their studies carried out in the West African developing countries, the BRICS and ASEAN countries, in which a U-shaped relationship between pollution and economic growth is identified.

Regarding NGC, in all quantiles, the relationship is positive and statistically significant. However, the findings are contrary to the proposal of H4. This contradiction may be explained by the fact that NGC emits less CO₂ than other types of fossil fuels. However, this does not mean that it stops polluting the environment altogether. Also, NGC grows slightly from the lowest to the highest quantiles, which shows that higher CO₂ is associated with higher NGC levels. This relationship may be because NGC is associated with a higher demand for this fuel in those regions with less access to electricity and is more affordable than energy from renewable energy sources. According to Naseem et al.

(2020) and Rafindadi and Yusof (2014), this situation occurs in developing countries since polluting energies are demanded in more significant quantities than energy consumption from renewable sources. However, these results are in contrast to the studies developed by Wang et al. (2019), Xu and Lin (2019), and Lin and Agyeman (2020), who mention that the consumption of natural gas reduces CO₂ emissions in China and Sub-Saharan Africa, since it is a less polluting type of fuel than coal or firewood.

As a final point, the results presented regarding TF show evidence of a negative relationship with CO₂. The behavior of CO₂ does not show a marked trend progressing through the quantiles. These findings prove that having more commercial exchange options for the consumption of goods and services by companies and households, as well as companies' commercialization and production, generates a decrease in environmental pollution. This information confirms hypothesis H5. The results are consistent with the findings of Wang and Zhang (2021), who find that TF reduces CO₂ in high- and upper-middle-income countries. In contrast, Vural (2020) finds that TF increases CO₂ in Sub-Saharan African countries. However, when compared to studies that examine imports and exports separately, the comparison varies. Several studies affirm that exports mitigate CO₂, and the increase in imports degrades air quality (Khan, Ali, Jinyu et al., 2020; Safi et al., 2020; Hasanov et al., 2019).

The findings corroborate the importance of examining the driving variables of CO₂ in the sample countries, which have not been addressed in previous studies. In addition, these factors emerge from detailed information on various quantiles of CO₂, which suggests a definition of various policy measures to achieve SDG7 according to different levels of contamination.

Likewise, Figure 4 graphically summarizes the effect of the estimated coefficients in different areas and the response of CO₂ to the variation of the explanatory variables in the different quantiles examined.

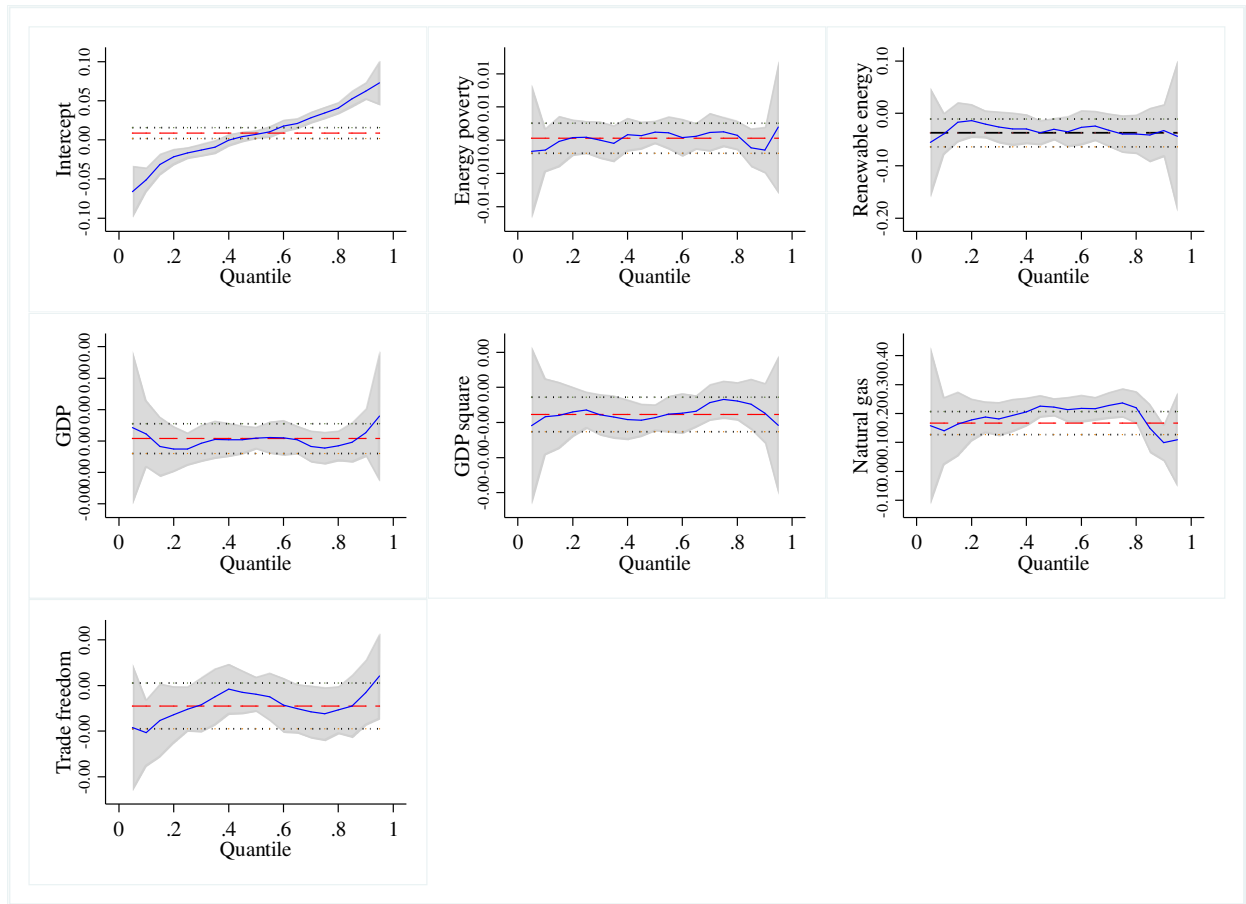


Figure 4. Quantile distribution explanatory variables on CO₂.

Note: The blue line represents a 95% confidence level for the quantile estimates. The grey area means the confidence interval for quantile estimates. The red dashed line represents the corresponding OLS estimate with a 95% confidence interval represented by the black dashed line.

In this sense, quantile analysis identifies and provides important information for the definition of targeted policy measures to reduce CO₂ emissions, based on the explanatory factors identified (Koengkan and Fuinhas, 2020). Through probabilistic forecasting, it is possible to make predictions and define correct decisions to mitigate the increase in CO₂ in future in any other economy (Luo et al., 2020). According to Table 6 and Figure 4, heterogeneity can be identified in the conditional distribution of CO₂, therefore, it is expected that decision-making to mitigate CO₂ emissions will be heterogeneous. In economies with relatively high CO₂ levels, located in the upper quantiles, stronger policies will be required, compared to economies with CO₂ levels located in the lower quantiles. The selection of measures aimed at reducing CO₂ must consider the context in which they are developed; quantile prediction provides this information for efficient decisions

(Muhammad et al., 2020). This type of policy targeting allows for an efficient decision on the use of resources to achieve SDG7.

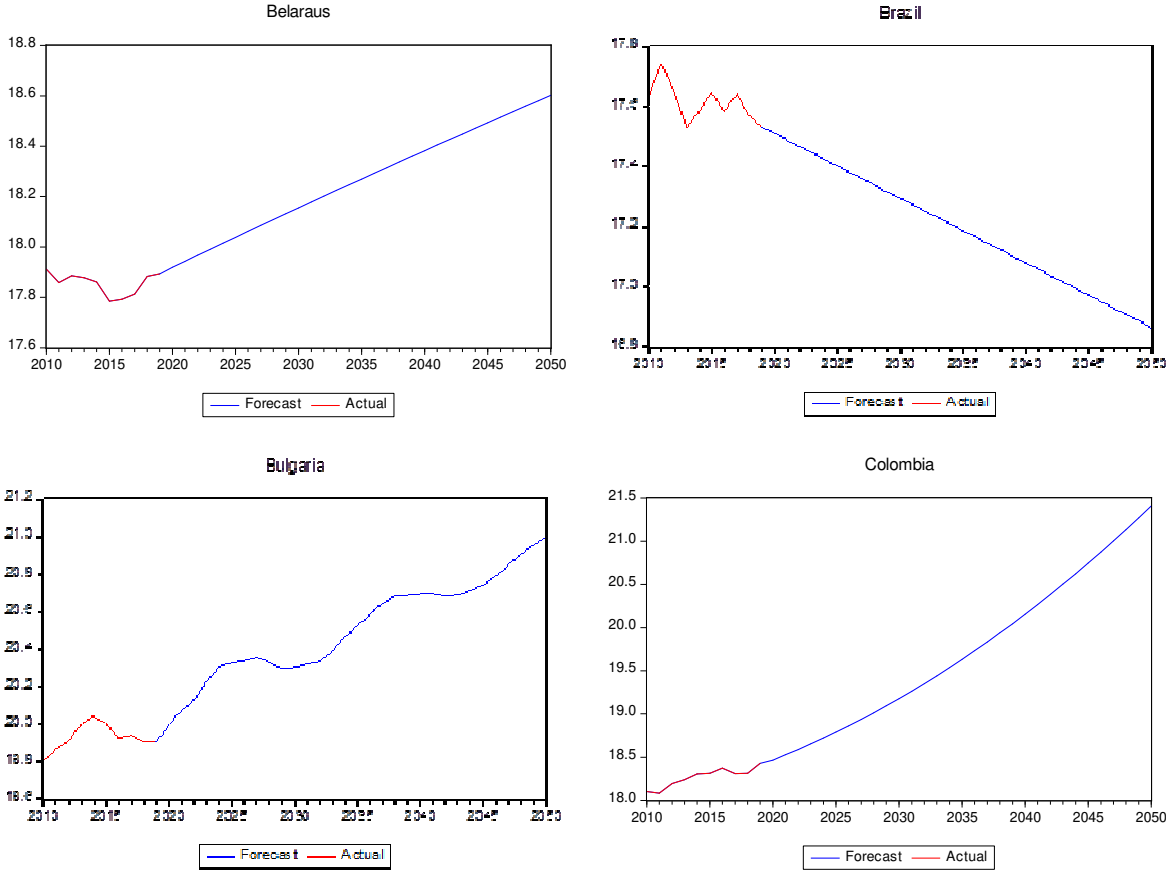
On the other hand, the predictive quality of the quantiles is essential to ensure the results described above. In this sense, the intervals produced in the quantiles are annual and are highly calibrated. It was stated above that the quantile forecast is within the 95% confidence intervals and differs significantly from a regression by OLS (Goetzke and Vance, 2020). The predictive quality of the quantiles can be seen in Figure 4.

At the same time, knowing the independent variables' impact on CO₂ is as important as knowing their behavior in the future. For this reason, an ARIMA model is used to validate the predictive quality of the variables used in the model (Aladağ, 2021), which is based on error. Due to the limited availability of data, only six countries were selected with the minimum of observations to fulfill the essential criteria of the ARIMA. Thus, using the Akaike Information Criterion (AIC) and the Bayesian Information Criterion (BIC), the most suitable model for each country was chosen, respectively. Furthermore, the smaller AIC and BIC values provide information on the best model for prediction (Akaike, 1974).

Next, the precision of each predictive model was evaluated employing the mean absolute percentage error (MAPE), root mean squared error (RMSE), mean absolute error (MAE) and coefficient of determination (R²). The MAPE, MAE and RMSE values, shown in Annex 3, are the lowest values of the chosen models, which suggests the highest precision in predicting the model variables (Armstrong and Collopy, 1992). Additionally, the MAPE values registered are less than 10%; that is, the variables have a high degree of prediction (Barrow, 2016). On the other hand, the R² values measure the predictive power of each variable, which are high and reveal a solid prediction of each variable; the values are between 61.3% and 93.2%.

In other words, each of the driving variables statistically fulfills the ability to predict their behavior in the future, which can be used to determine how the factors will modify CO₂ emissions in the coming years. Consequently, this forecast becomes an important element of analysis in order to correctly define public policies to mitigate CO₂ emissions in the future. In this sense, through an accurate forecast of CO₂ drivers, a promising scenario is generated to achieve SDG7 in relation to environmental efficiency (Song et al., 2012).

Likewise, through the ARIMA estimation, a forecast of the behavior of CO₂ can be generated up to the year 2050. In this way, Figure 5 provides information about CO₂ levels in the coming years. Compared to 2019, it is expected that by 2030 CO₂ will be reduced in Romania (1.79%), Brazil (1.35%), and in the Russian Federation (0.27%). Meanwhile, an increase in CO₂ is expected in Colombia (4.97%), Bulgaria (2.02%) and Belarous (1.46%). Additionally, concerning the forecast for the year 2050, the variation is more considerable. CO₂ emissions will decrease in Romania (5.06%), Brazil (3.80%) and Russian Federation (1.20%). Moreover, in Colombia (16.48%), Bulgaria (5.50) and Belarous (3.96) the CO₂ will increase.



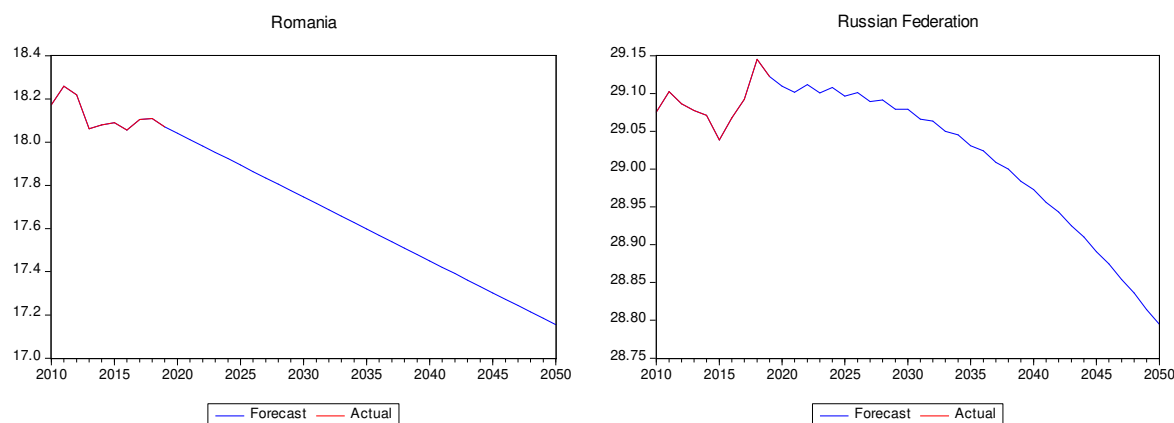


Figure 5. Forecast of CO₂ behavior in the coming years

Note: The blue line represents the predicted values up to the year 2050

Subsequently, based on the predicted values in the 2020-2050 period for each country, an estimate can be made using the ARIMA model, which can be seen for each country in Table 7. According to the estimated coefficients for each regression, it is predicted that REC, GDP² and TF will decrease CO₂. On the other hand, EP, GDP and NGC are catalysts of CO₂. These findings reiterate the effect that the explanatory factors will have on CO₂ in the future.

Table 7. ARIMA estimations over the period 2020-2050.

Variables	Belarus	Brazil	Bulgaria	Colombia	Romania	Russian Federation
EP	0.00046** (0.032)	0.0085** (0.001)	0.00002** (0.002)	0.00916* (0.065)	0.0036** (0.000)	0.00018** (0.000)
REC	-0.06842** (0.026)	-0.04124** (0.004)	-0.08156** (0.001)	-0.06987** (0.008)	-0.05684** (0.018)	-0.07819** (0.038)
GDP	0.000086** (0.012)	0.00036** (0.045)	0.000035** (0.036)	0.000054** (0.004)	0.000047** (0.005)	0.00084** (0.006)
GDP ²	-3.56e-10* (0.059)	-2.58e-10* (0.096)	-1.96e-10* (0.065)	-2.85e-10* (0.0738)	-4.36e-10** (0.004)	-4.96e-10* (0.032)
NGC	0.62571* (0.062)	0.54127** (0.011)	0.69851* (0.075)	0.86417* (0.085)	0.74582** (0.006)	0.56114* (0.091)
TF	-0.00096** (0.021)	-0.00012* (0.059)	-0.00058** (0.026)	-0.00054* (0.074)	-0.00014** (0.046)	-0.00581* (0.058)

Notes: ** and * indicates significance at 5% and 10% respectively. P-values are reported in parentheses.

The effect of these factors on CO₂ can be corroborated by analyzing the decomposition of variance (Goetz et al., 2021). In this way, Figure 6 presents the impulse-response functions of the explanatory factors on CO₂ (for the next 31 years, until 2050) with a 95% confidence interval. In other words, the error variance decomposition calculates the effect of each type of shock from the explanatory factors to the forecast error

variance, thereby validating the effect of the explanatory variables in the coming years. In other words, the factors examined can predict the future behavior of CO₂, generating a range of options to improve environmental sustainability.

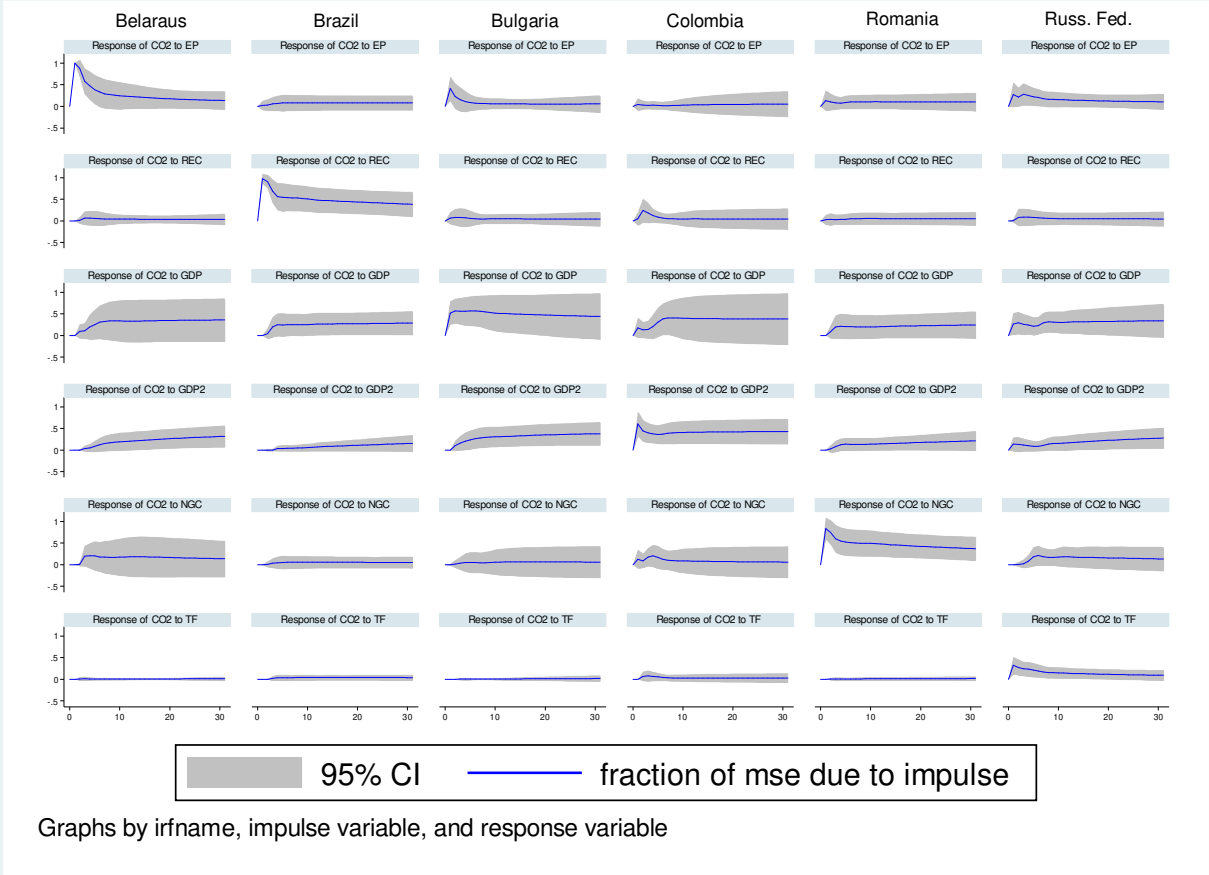


Figure 6. Impulse - response functions.

5. Conclusion and Policy Implications

Despite significant recent advances made in energy consumption, such as access to electricity, electrical technologies and increased REC, EP persists, along with its negative consequences for the environment. Unlike previous studies, such as that of Ikram et al. (2020) or Rasoulinezhad and Saboori (2018), this study considers the effect of rural access to electricity on CO₂ across 25 developing countries. The period examined is from 2001 to 2019, with other explanatory variables, such as REC, GDP, GDP², NGC, and TF, also being considered. These variables provide valuable information to understand the behavior of CO₂ at different levels of the conditional distribution. Then, using Pesaran (2015), cross-section dependence between the variables was verified, with the second-generation unit root and long-term cointegration tests being used in the analysis. Subsequently, the quantile regression panel examined the behavior of CO₂ in various quantiles.

The effect of EP on CO₂ was examined, showing low access to electricity causes increases in CO₂. Furthermore, the results show a direct relationship between NGC and CO₂. Concerning economic growth, the fulfillment of the EKC hypothesis is confirmed; the increasing development of economic activity is related to beneficial effects on the environment. For its part, REC shows evidence that the choice of this type of energy is the way towards air conservation. In the same way, TF allows the free choice to exchange goods and services and mitigate CO₂. These findings provide valuable insights regarding the behavior of CO₂ at various levels, which is valuable information to help mitigate CO₂ in developing countries. Moreover, this research provides valuable elements to draw a roadmap for the achievement of SDG7. Therefore, according to the results presented above for PQR and ARIMA, this study recommends that policymakers from the developing countries consider the following policy measures to achieve environmental sustainability:

- 1) Currently, in the examined countries, of the total available energy, oil is the most in-demand (on average 37.10%) while renewable energy is the least consumed (on average 3.44%). Therefore, REC should be further promoted through incentive programs with preferential residential and industrial consumption rates.
- 2) In Bangladesh, Peru, Pakistan, India, South Africa, Morocco, and the Philippines, the lack of electricity access in rural areas is between 53% and 21%.

Therefore, governments should increase access to electricity through investment in infrastructure, so that the energy network reaches these countries' entire territory. The above arguments should be considered in order to displace the consumption of polluting energies in these countries, since oil (35.47%), natural gas (31.61%), and coal (23.15%) are the most consumed fuels in these developing countries.

3) The expansion of electricity coverage in rural areas must be accompanied by programs that provide, free of charge or at low prices, electrical appliances for domestic tasks; for example, induction cookers, electric heating equipment, electric showers, among others.

4) Increased economic activity generates a reduction in CO₂, which is why laws or regulations could be established in these countries so that a certain amount of GDP or company profits is allocated to improve energy intensity.

5) The NGC is the second-most in-demand fuel (30.07%), and is considered as a clean technology for cooking. However, it is a fossil fuel, and a substitute for electric stoves, which is more accessible due to the limited access to electricity service in rural areas. Therefore, taxes could be established, or subsidies eliminated and transformed into incentives for renewable energies or to promote electrical household appliances.

6) The precision of the future model variables offers the opportunity to establish future strategies regarding CO₂ factors, which allows for the definition of future public policies to achieve SGD7.

Finally, like most scientific research, this study has certain limitations regarding the availability of information. First, country data is limited, so the number of countries per continent is better represented in some continents than in others. Another limitation is the availability of information on variables that allow us to understand aspects such as the percentage and type of electrical appliances used in the home or the elasticity of the price of energy for the price of fossil fuels. Furthermore, according to the literature review, access to electricity is one of the proxy variables for EP in developing economies. However, it is unknown whether household purchasing power conditions the lack of access to electricity.

In this sense, the limitations of the research may become future research questions. Therefore, according to the conditions and possibilities of authors to collect

primary information from households, the authors recommend examining EP in a number of developing countries to capture the economic and social conditions surrounding EP. Future research could also examine the relationship between environmental degradation and access to technologies at home.

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Annex 1. Determinants of CO2 examined in previous studies.

Author	Title	Explanatory variables
Lin and Li (2020)	Is more use of electricity leading to less carbon emission growth? An analysis with a panel threshold model.	<ul style="list-style-type: none"> • Energy use. • Electric power consumption. • Electricity production from clean energy. • Gross domestic product. • Population. • Urban population of total. • Industry value added of GDP.
Li, Hong, and Wang (2020)	Evaluating the impact of clean energy consumption and factor allocation on China's air pollution: A spatial econometric approach.	<ul style="list-style-type: none"> • Clean energy consumption. • Coal consumption/fossil energy consumption. • The ratio of energy consumption to capital stock. • The ratio of energy consumption to labor.
Reyes et al. (2019)	Controlling air pollution in a context of high energy poverty levels in southern Chile: Clean air but colder houses?	<ul style="list-style-type: none"> • Energy deficit. • Household income. • Dwelling age.
Alem and Demeke (2020)	The persistence of energy poverty: A dynamic probit analysis.	<ul style="list-style-type: none"> • Real prices of major fuel types. • Head characteristics. • Household characteristics. • Location.
Santos Pereira and Cardoso Marques (2020)	Could electricity demand contribute to diversifying the mix and mitigating CO 2 emissions? A fresh daily analysis of the French electricity system.	<ul style="list-style-type: none"> • Electricity produced. • Electricity consumption. • Electricity price. • Degree of diversification of electricity sources. • Mean temperature.
Ikram et al. (2020)	Towards a sustainable environment: The nexus between ISO 14001, renewable energy consumption, access to electricity, agriculture and CO 2 emissions in SAARC countries.	<ul style="list-style-type: none"> • Renewable energy consumption. • Environmental Management System. • Access to electricity. • Agriculture value added.
Bekun et al. (2019)	Toward a sustainable environment: Nexus between CO 2 emissions, resource rent, renewable and nonrenewable energy in 16-EU countries	<ul style="list-style-type: none"> • Gross domestic product. • Total natural rent. • Renewable energy consumption. • Nonrenewable energy consumption.
Charfeddine and Kathia (2019)	Impact of renewable energy consumption and financial development on CO 2 emissions and economic growth in the MENA region: A panel vector autoregressive (PVAR) analysis	<ul style="list-style-type: none"> • Gross domestic product. • Renewable energy consumption • Domestic credit to private sector. (Financial development). • The gross capital formation (Capital). • Labor forces.
Saidi and Omri (2020)	Progress in Nuclear Energy Reducing CO 2 emissions in OECD countries: Do renewable and nuclear energy matter?	<ul style="list-style-type: none"> • Nuclear energy. • Renewable energy. • Economic growth. • Financial development. • Trade openness.
Boufateh and Saadaoui (2020)	Do Asymmetric Financial Development Shocks Matter for	<ul style="list-style-type: none"> • Gross domestic product. • Gross domestic product square.

	CO2 Emissions in Africa? A Nonlinear Panel ARDL-PMG Approach	<ul style="list-style-type: none"> • Urbanization rate. • Energy consumption. • Financial development index.
Zafar et al. (2019)	From nonrenewable to renewable energy and its impact on economic growth: The role of research & development expenditures in Asia-Pacific Economic Cooperation countries	<ul style="list-style-type: none"> • Renewable energy consumption. • Trade openness. • Capital formation. • Nonrenewable energy consumption.
Kacprzyk and Kuchta (2020)	Shining a new light on the environmental Kuznets curve for CO2 emissions	<ul style="list-style-type: none"> • Real per capita gross domestic product. • Real per capita gross domestic product square.
Lin and Agyeman (2020)	Impact of Natural gas consumption on Sub-Saharan Africa's CO2 emissions: Evidence and Policy Perspective	<ul style="list-style-type: none"> • Urbanization. • Energy efficiency. • Economic growth. • Natural gas consumption. • Coal consumption. • Output side real Gross domestic product. • Capital stock. • Persons employed.
Dong, Sun, and Hochman (2017)	Do natural gas and renewable energy consumption lead to less CO2 emission? Empirical evidence from a panel of BRICS countries	<ul style="list-style-type: none"> • Gross domestic product. • Gross domestic product square. • Natural gas consumption. • Renewable energy consumption.
Vural (2020)	How do output, trade, renewable energy and non-renewable energy impact carbon emissions in selected Sub-Saharan African Countries?	<ul style="list-style-type: none"> • Gross domestic product. • Electricity generation from renewable sources. • Electricity generation from non-renewable sources. • Trade openness. • Population.

Annex 2: sample countries

Sample countries	Description
Developing countries	Argentina, Azerbaijan, Bangladesh, Belarus, Brazil, Bulgaria, China, Colombia, Ecuador, Egypt, India, Indonesia, Iran, Kazakhstan, Mexico, Morocco, Pakistan, Peru, Philippines, Romania, Russia, South Africa, Sri Lanka, Thailand, Vietnam.

Annex 3: Goodness of fit of the ARIMA models.

	CO ₂	EP	REC	GDP	GDP ²	NGC	TF
	Belarus						
RMSE	15.7	15.3	8.3	91.2	143.9	5.3	18.3
MAE	6.4	4.5	6.5	85.4	111.8	2.6	14.5
MAPE (%)	3.2	1.3	4.4	2.5	2.8	1.7	9.3
R - square	0.734	0.826	0.759	0.852	0.742	0.823	0.639
	Brazil						
RMSE	21.5	11.5	14.6	81.2	145.6	5.6	24.9
MAE	13.4	8.8	12.4	54.6	128.3	4.4	18.9
MAPE (%)	1.3	3.6	1.8	3.5	2.4	4.7	7.8
R - square	0.823	0.684	0.785	0.824	0.741	0.765	0.863

Bulgaria							
RMSE	22.2	14.8	19.6	91.5	169.2	2.6	24.8
MAE	9.2	10.3	15.2	86.7	148.8	1.8	21.1
MAPE (%)	2.8	1.3	2.8	2.9	6.7	8.8	8.5
R - square	0.812	0.725	0.745	0.863	0.841	0.713	0.798
Colombia							
RMSE	18.9	8.6	17.6	101.8	365.9	6.3	25.1
MAE	8.3	2.3	14.4	96.3	221.2	4.3	14.7
MAPE (%)	3.5	5.3	8.8	7.7	5.1	2.4	8.5
R - square	0.613	0.785	0.741	0.885	0.812	0.863	0.796
Romania							
RMSE	19.3	11.6	10.9	142.8	169.3	7.6	10.6
MAE	11.1	5.5	6.8	101.1	151.7	6.8	9.5
MAPE (%)	1.8	9.3	2.4	8.8	1.7	4.8	5.3
R - square	0.783	0.732	0.748	0.768	0.816	0.874	0.897
Russian Federation							
RMSE	25.7	12.6	15.6	136.4	159.6	6.7	22.9
MAE	11.6	6.8	6.5	121.6	141.6	5.4	11.3
MAPE (%)	8.3	6.8	9.4	9.8	8.7	1.8	1.8
R - square	0.834	0.823	0.714	0.798	0.932	0.889	0.798

Annex 4: Abbreviations

Abbreviations	Description
AMG	Augmented means group
AIC	Akaike Information Criterion
ARIMA	Auto Regressive Integrated Moving Average
BIC	Bayesian Information Criterion
BP	BP Statistical Review of World Energy
BRICS	Brazil, Russia, India, China, and South Africa
CADF	Cross-sectional augmented Dickey-Fuller
CD	Cross-section dependence
CIPS	Cross-sectional augmented Im, Pesaran, and Shin
CO ₂	Carbon emissions
EKC	Environmental Kuznets curve
EP	Energy poverty
G-7	Developed economies
GDP	Gross domestic product
GDP ²	Gross domestic product per capita square
IRENA	International Renewable Energy Agency
H1- 5	Hypothesis 1 – 5
MENA	Middle East and North Africa
MERCOSUR	For its acronym in Spanish: The Common Market of the South
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
NGC	Natural gas consumption

OECD	Organization for Economic Cooperation and Development
PQR	Panel quantile regressions
REC	Renewable energy consumption
R ²	Coefficient of determination
RMSE	Root mean square error
SAARC	South Asian Association for Regional Cooperation
SDG7	Sustainable Development Goals seven
SSA	Sub-Saharan Africa
TF	Trade freedom
