# Consumption of Energy, Economic Growth, and Carbon Dioxide Emissions in Colombia

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## Abstract

This paper presents an analysis for the case of Colombia on the relationship between economic growth, energy consumption and carbon dioxide emissions using the vector autoregressive (VAR) methodology and the Granger causality test, with which it was intended to find evidence of a causal relationship between the variables for the period 1971-2014. It is concluded, like the existing academic literature, that there is a direct relationship between energy consumption and production, and energy consumption towards carbon dioxide emissions.

Article derived from an undergraduate thesis carried out at the Universidad Industrial de Santander entitled: “Relación del consumo de energía eléctrica, el crecimiento económico y las emisiones de dióxido de carbono en Colombia para el periodo 1971-2014”.

**Keywords:** economic growth, energy, $CO_2$, pollution, Colombia, VAR, Granger causality.

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## Resumen

En este trabajo se presenta un análisis para el caso de Colombia sobre la relación entre crecimiento económico, consumo de energía y emisiones de dióxido carbono utilizando la metodología de vectores autoregresivos (VAR) y prueba de causalidad de Granger con el cual se pretendió encontrar evidencia de una relación directamente proporcional entre las variables para el periodo de 1971-2014. Se concluye, al igual que la literatura académica existente, que existe una relación positiva entre el consumo de energía y la producción y del consumo de energía hacia las emisiones de dióxido de carbono.

Artículo derivado de una tesis de pregrado realizada en la Universidad Industrial de Santander titulada: “Relación del consumo de energía eléctrica, el crecimiento económico y las emisiones de dióxido de carbono en Colombia para el periodo 1971-2014”.

**Palabras clave:** Crecimiento económico, energía, $CO_2$, contaminación, Colombia, VAR, Causalidad en el sentido de Granger.

## I. Introduction

In recent years, countries have been immerse in a transformation phase towards the exploitation of unconventional sources of electric energy to reduce dependence on the importation of energy from fossil resources to highly volatile prices, to diminish the emissions of greenhouse gases produced mainly by the liberation of carbon dioxide, methane and nitrous oxide from the energy sector, and thus contribute to mitigating the negative effects of climate change. The serious ecological disasters caused by the evolution of human activity have caused enormous concern as a consequence of the strong impact that the satisfaction of needs has had on the environment and life. Thus, the correlation between a country’s economic growth and its environmental quality has been controversial given the various existing approaches. Many authors among economists and scientists justify such concerns, arguing that the increase in Gross Domestic Product (GDP) has

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negative effects on the natural environment by increasing the disproportionate use of energy and exploitation of not regulated natural resources. However, other authors maintain that countries can continue to grow without damaging the quality of the environment as long as there is a positive relationship with technological progress.

The above establishes that the income level-environment relationship can be projected as an inverted U curve. Indeed, Correa (2005) has approached the problem from differing positions, showing that in the case of some countries with a higher degree of industrialization, environmental indicators concerning economic growth behave in an inverted U-shape following the hypothesis of an environmental Kuznets curve (ECK). Colombia has an energy matrix that contains both, fossil fuels and renewable resources, but as a consequence of its high consumption of primary resources of fossil origin, considered 76.7 % in 2014 according to World Bank (2019), the impact on air quality is worrisome and the need for environmental control policies is essential to mitigate the negative effect that their use could bring.

The Colombian energy sector has been an important element on which the development of the country has been promoted (Serrano-Gomez, 2001). Its contribution to economic growth, job creation, increased private investment, social investment, does not go unnoticed. It is essential not only in terms of growth, but also in terms of development, and although the country has been actively pursuing the participation of agreements such as the International Energy Charter (2015), conceived as an instrument to support international cooperation to contribute to the development of world energy markets; it is essential to outline the behavior of the sector concerning the polluting effects of carbon emissions in Colombia and to inquire whether the behavior of this relationship corresponds to the possible existence of an environmental Kuznets curve for Colombia. In this sense, to achieve these objectives, the research is subdivided as follows: this section is the introduction. In section II, the background of the study is discussed at length. The third section, entitled Methodology, discusses the variables and the statistical technique used. Section IV presents the main research findings, as well as the discussion of these results. Finally, the conclusions are offered.

## II. Literature review

Gómez (2011) determined the empirical relationship between energy consumption, economic growth and polluting emissions in Mexico. This study was carried out for the Mexican economy between 1980 and 2015 through the methodology of time series and economic cycles (VAR methodology with Granger causality test and impulse response functions). The study found that there is a direct relationship between the variables studied: higher economic growth leads to increased consumption of fossil fuels and thus to the increase of the pollutant emissions ($CO_2$). Likewise, Masoud, Nassor, and Baka (2015) investigated the relationship between environmental pollution, energy consumption and economic growth in Tanzania using time series for the period 1975-2013. For this evaluation, the methodology of the non-causality test of Toda and Yamamoto (1995), the Dickey-Fuller and the Phillips-Perron test were used. The study showed that both the variable of economic growth and that of energy consumption per capita are unidirectional and exert negative effects on the environment through the emission of $CO_2$.

Now, Squalli (2007), makes an important contribution with the study of the relationship existing between economic growth and energy consumption from 1980 to 2003 in countries such as Algeria, Kuwait, Indonesia, Iran, Nigeria, Iraq, Libya, Qatar, United Arab Emirates, Venezuela, and Saudi Arabia; countries that belong to the Organization of Petroleum Exporting Countries (OPEC). The research used the limit test of Pesaran et al. (2001) and the non-causality test of Toda and Yamamoto (1995). The limits test provides evidence of a relationship between the economic growth and the consumption of electricity per capita on a long-term measured in real GDP per capita in all OPEC members. There is a strong dependence on economic growth with electricity consumption between Indonesia, Iran, Nigeria, Qatar, and Venezuela, with evidence of a complementary relationship between electricity and economic growth for Iran and Qatar.

Also Saatcý and Dumrul (2013) conducted an empirical analysis in which the role of energy consumption in the growth of economy in Turkey is studied. The data used includes annual energy consumption and economic growth series measured by GDP for the period from 1960 to 2008. Aggregated and disaggregated data on energy consumption, including oil, electricity, coal, and renewable energy, were used for this study. The Lee-Strazicich unitary root test is applied with structural breaks, for determining if there is a long-term relationship between the two variables, the cointegration structural failure of Kejriwal test is made. The main conclusion of the study is that the consumption of energy in Turkey and economic growth have a direct relationship which varies in quantity with structural breaks. In the same context, Catalan (2014) suggests estimating a Kuznets environment curve for a group of 144 countries by the specification of a panel data model through minimum square ordinary for the period 1990-2010. The results disclosed that the relationship between the per capita emissions of carbon dioxide-$CO_2$ and GDP per capita behaves like a curve as N, demonstrating that higher growth can generate transient benefits through reduction of $CO_2$ emissions. The authors affirms that variables such as the protection of resources and energy efficiency play a fundamental role in mitigating the impacts of energy consumption.

It is important to mention Paul and Bhattacharya (2004) whom examine the causal relationship between energy consumption and economic growth in India. Applying the Engle-Granger cointegration methodology combined with the Granger standard causality test for the period 1950-1996 and the Johansen multivariate cointegration technique on the set of variables. The analysis has shown that the causal relationship between energy consumption and economic growth in India is mixed or conflicting.

Similarly, Soytas, Sari, and Ozdemir (2001) propose to investigate the relationship between economic growth, energy consumption, and $CO_2$ emissions in Turkey from 1960 to 2000, a still-emerging economy. The analysis is based on time series techniques from a long-term Granger causality perspective, in a multivariate framework that controls gross fixed capital investment and labor by the procedure of Toda and Yamamoto (1995). Toda and Yamamoto's (1995) approach eliminates the need for pretesting for cointegration and thus avoids pretest bias and applies to any arbitrary level of integration for the series used. The results show that the absence of a long term causal relationship between income and emissions may imply that Turkey does not have to give up the economic growth to reduce carbon emissions, but yet some energy efficiency strategies could be implemented.

In turn, Correa, Vasco and Pérez (2005) developed an investigation focused on Colombia to corroborate the veracity of the hypothesis of the EKC and thus provide contributions to the existing problem between the environment and economic growth. The objective is to determine the incidence of the influence that the increase in per capita income causes on the quality of the environment, estimated using the main air pollutants, such as sulfur dioxide ($SO_2$) from 1975 to 1990, carbon dioxide ($CO_2$) from 1975to 2000 and from water pollutants, such as the Biological Oxygen Demand (BOD) from 1980 to 1998. Ocampo and Olivares (2013) studied the relationship that exists between GDP, the energy consumption and the emission of carbon dioxide, to different countries such as Indonesia, Turkey, Vietnam, Colombia, Egypt and South Africa from 1985-2007. The objective of the investigation is to verify the possible behavior of an EKC for the mentioned countries, utilizing the non-stationary panel data methodology, these relationships are evaluated employing cointegration and unit root tests. The results show that, that here is evidence of a causal relationship between Gross Domestic Product (GDP) emissions of $CO_2$, which means that long-term, the climate change is influenced by economic growth through increased $CO_2$ emissions, only in the case of the countries studied.

As a result, the study of the problem shows contradictory findings in terms of the existence and direction of the relationship of causality between energy consumption and economic growth and therefore the impact on emissions of pollutants. There are few study references for Colombia, however, there are analyzes for economies with growth dynamics approximately similar to those of the Colombian case, so it is expected that the causal relationship between GDP and energy consumption will present a similar result to of these. On the other hand, the importance of the implementation of environmental control policies as a tool for reducing environmental deterioration is highlighted.

## III. Methodology

Throughout this section, the most appropriate statistical technique is described to address and understand the study problems raised, as well as the sources of information required for the research and how they were collected. To examine the dynamics of the variables in this study, initially a descriptive analysis of the annual time series of GDP (per capita at constant prices), electricity consumption (kWh per capita) and $CO_2$ (metric tons per capita) (see table 1). The study was based on data from the World Bank to Colombia in the period 1971-2014, with a VAR methodology and Granger causality tests. Such analysis was carried out using the R (3.4.6) statistic, an ideal software for the econometric analysis of time series thanks to the wide range of libraries, statistical and graphical functions and techniques that it has and which allows a detailed estimation of thedynamic models. The data provided by the World Bank (2019) was collected through various sources for each of the study variables.

**Table 1.** Description of the study variables.

| Variable | Source | Description |
|---|---|---|
| Electric energy consumption (kWh per capita) | International Energy Agency (IEA) | Measurement of the production of power plants and plants substracting the losses caused during the distribution, transformation, and consumption of energy. |
| $CO_2$ (metric tons per capita) | Carbon Dioxide Information Analysis Center, Division of Environmental Sciences, Oak Ridge National Laboratory (Tennessee, United States ). | They include carbon dioxide resulting from the burning and exploitation of fossil fuels (solid, liquid, and gaseous fuels) and the manufacture of cement. |
| Economic growth- (GDP per capita) | National accounts of the World Bank. | Gross domestic product divided by midyear population. |

Source: Authors' elaboration.

The VAR econometric model was first proposed by Sims (1980). This model is defined as a system of variables that achieves that every variable in the model has a function of both its past and the past of the other endogenous variables. According to the literature, the VAR model for multiple time series, which essentially wants to obtain the dynamic interactions of the variables through the impulse response function (FIR). VAR models in general terms work under the assumption that economic variables tend to move over time, some around the other and also to be autocorrelated. The VAR has an order, which is equivalent to the number of lags with which the variables enter the equation. A VAR model of order *n*, with endogenous variables, is specified as follows:

$$Yt = A_0+\sum_{s=1}^{n} A_s\, Y_{t-s}+ GW_t + u_t \tag{1}$$

Where $Y_t$ is a column vector $kx1$; $A_0 = \begin{pmatrix} b_{10} \\ b_{20} \end{pmatrix}$, the element ($i$; $j$) in the matrix $A_s$, measures the direct or parcial effect of a change in $Y_j$ in time $t$, on the numerical values of $Y_i$ in a time frame of $s$ periods; $n$ is the order of the VAR model or the number of lags of each variable in each equation, and, $u_t$ is a vector k x 1 of innovations, that is, processes without autocorrelation, with $Var(u_t) = \Sigma$ *constant*. $W_t$ is a vector of exogenous variables. For example, mention is made of VAR models of order 1, in these, the explanatory variables appear only with a delay. An autoregressive vector of order one, VAR (1), has its primitive form as follows (Enders, 2010):

$$\begin{aligned} y_t &= b_{10} - b_{12}\, Z_t + \gamma_{11}\, y_{t-1} + \gamma_{12}\, Z_{t-1} + \varepsilon_{yt} \\ Z_t &= b_{20} - b_{21}\, y_t + \gamma_{21}\, y_{t-1} + \gamma_{22}\, Z_{t-1} + \varepsilon_{zt} \end{aligned} \tag{2}$$

Or,

$$\begin{pmatrix} 1 & b_{12} \\ b_{21} & 1 \end{pmatrix} \begin{pmatrix} y_t \\ Z_t \end{pmatrix} = \begin{pmatrix} b_{10} \\ b_{20} \end{pmatrix} + \begin{pmatrix} \gamma_{11} & \gamma_{12} \\ \gamma_{21} & \gamma_{22} \end{pmatrix} \begin{pmatrix} y_{t-1} \\ Z_{t-1} \end{pmatrix} + \begin{pmatrix} \varepsilon_{yt} \\ \varepsilon_{zt} \end{pmatrix} \tag{3}$$

That is equivalent,

$$Bx_t = \Gamma_0 + \Gamma_1\, x_{t-1} + \varepsilon_t \tag{4}$$

Where the vector $x_t$ gathers the endogenous variables, matrix $B$ groups the coefficients of the contemporary effects of the vector $x_t$, while the matrix contains the coefficients of the past effects on $x_t$. Before determining the impact between the variables of the model, it is necessary to analyze if the variables cause each other, in this way the predictive causality between them is specified, and in which direction it occurs. For this use is made the Granger causality test, where the null hypothesis is that the variable $X$ does not cause $Y$.

This test involves the preparation of two models, one restricted and other unrestricted to the first regression of Y is performed with the terms behind thereof, but not including lagged terms of $X$. For the second model, the same regression of $Y$ *is performed*, but including both the lagged terms of $Y$ and $X$ (Gujarati and Porter, 2004). Now, to test the null hypothesis, the Fisher test is applied:

$$F = \frac{(SCR_R - SCR_{NR})/m}{SCRN_{NR}/(n\text{-}k)} \tag{5}$$

Where $SCR_R$ is the sum of squares of the restricted model and $SCR_{NR}$ is the sum of squares of the unrestricted model, where $m$ and *(n-k)* number of degrees of freedom. If the calculated $F$ value exceeds the critical $F$ at the specified level of significance, the null hypothesis is rejected, that is, the lagged values of $X$ cause $Y$ (Gujarati and Porter, 2004). Then it is proceed in the same way to determine if $Y$ causes $X$. The impulse response function is a way of estimating the results in the VAR. This function shows the response of the explained variables to changes in errors. The function can be exposed and formulated as follows for a VAR model with 2 variables:

$$\begin{aligned} Y_{1t} &= a_{11}\, Y_{1t\text{-}1} + a_{12}\, Y_{2t\text{-}1} + \ldots + \varepsilon_{1t} \\ Y_{2t} &= a_{21}\, Y_{1t\text{-}1} + a_{22}\, Y_{2t\text{-}1} + \ldots + \varepsilon_{1t} \end{aligned} \tag{6}$$

In agreement, a change of any variable of the model in a period *i* will achieve a shock both in the variable that changed and in the others, therefore, from the dynamic structure of the model, it will be possible to appreciate how the change of a variable affects to it and the rest of the variables explained in the long term. The usual steps, identification and estimarion of the VAR model, followed by the statistical validation of the model, the Granger causality test and finally, the impulse response function.

## IV. Results

The Colombian economy obtained significant growth during the second half of the 20th century, the production systems of products such as coffee, leather, flowers, corn, bananas, palm trees, among others, specialized and the search for new forms of negotiation, policies, free trade agreements, and guaranteed production improved. The import of goods also had an increase in real terms as a consequence of the rapid growth of the production of goods and services in the country, causing an increase in domestic demand that was largely covered by imported goods. According to Cardenas (2005) and in contrast with the global general economic trends, the minning essentially oil and coal - recorded a strong expansion during the eighties and nineties and in the same way the services experienced high growth during the period 1990-2000. Faced with the behavior of the Colombian economy in early 2000, Botero Lopez, Posada, Ballesteros, and Garcia (2015) claim that Colombia has achieved two-period of remarkable growth separated by the beginning of the crises in the United States as a consequence of the Great Recession. On one side the period from 2003 to 2007 in which was achieved one growth of 5.5% in response to proposed policies, Alvaro Uribe, during his gobernment in which the country managed to stand out as one of the emerging economies with better performance.

According to Marrugo (2013), when analyzing the operation of the Colombian economic sectors, it could responds in large part to the strengthening of the mining-energy sector; which shows favorable fluctuations since 2005 enabling it to achieve growth of 9.6%, 11.0% and 12.2% in 2008, 2009 and 2010 respectively. Now, according to the theory, once the level of wealth of a country increases, the operation of the economy requires a greater amount of energy for the performance of its industry, to guarantee mobility and transportation, domestic consumption and to ensure the growing consumer demand of the population to recharge household appliances and technological equipment. (García, 2016) Colombia is no stranger to this behavior and the increase in energy demand over time has been significant; the country has grown simultaneously with the growth of the economy along with energy consumption. From this behavior, it can be deduced that a large part of the functioning of our economy depends on the availability of energy supply sources, which, like consumption, has been increasing. The increase in the residential sector equals 2.0% of total greenhouse gas emissions, within this percentage $CO_2$ emissions represent 65.4% and are mainly generated by the high consumption of natural gas and the continued growth of gas refrigerants in recent years.

**Table 2.** Variable correlation matrix.

| Variable correlation matrix | $CO_2$ emissions | Energy Consumption | GDP per capita |
|---|---|---|---|
| CO2 emissions | 1.0000 | 0.3878 | 0.3085 |
| Energy consumption | 0.3878 | 1.0000 | 0.9485 |
| GDP per capita | 0.3085 | 0.9485 | 1.0000 |

Source: Own elaboration based on the results obtained in R.

To contrast, the existent relationship between the variables, a matrix of correlation coefficients is made, between the variables (see table 2). In the results it can be observed that correlations are significantly higher among the growth and energy consumption with a value of 94.8%, while with emissions of carbon dioxide the correlation is one bit lower around 30.8%; regarding energy consumption and carbon dioxide emissions, the ratio increases with a value of 38.7%. For this reason, a direct relationship between GDP, energy consumption and $CO_2$ emissions is evident in the Colombian case for the period 1971-2014.

## IV.1 Identification and estimation of the VAR model

In the proper identification and estimation of the model, the variables considered in the study have to comply with the condition of stationarity. To this aim, a series of transformations is performed using the logarithm in the series and the first difference of these. To find the ideal transformation is necessary to apply the Augmented Dickey-Fuller test to evaluate the root unit followed, the test of Kwiatkowski, Phillips, Smichdt, and Shin (KPSS) are performed, and so help to determine if series are stationary. To apply the Augmented Dickey-Fuller (ADF) unit root test, the following working hypotheses are established; $H_o$: Variable *X* does not have a unitary root and $H_a$: Variable *X* has a unitary root. In this way, the ADF test is applied without constant or trend.

**Table 3.** Increased Dickey-Fuller Test

| Variable | Deterministic term | Test value | Lags | Critical value | | |
|---|---|---|---|---|---|---|
| | | | | 1% | 5% | 10% |
| **GDP** | without constant and trend | 2.7994 | 1 | -2.62 | -1.95 | -1.61 |
| | constant | -2.9192 | 1 | -3.58 | -2.93 | -2.60 |
| | trending | -3.4963 | 1 | -4.15 | -3.50 | -3.18 |
| **Log (GDP)** | without constant and trend | 2.719 | 1 | -2.62 | -1.95 | -1.61 |
| | constant | -3.527* | 1 | -3.58 | -2.93 | -2.60 |
| | trending | -3.613* | 1 | -4.15 | -3.50 | -3.18 |
| **ΔLog(GDP)** | without constant and trend | 1.7383 | 1 | -2.62 | -1.95 | -1.61 |
| | constant | -5.0016* | 1 | -3.58 | -2.93 | -2.60 |
| | trending | -4.9353* | 1 | -4.15 | -3.50 | -3.18 |
| **Energy** | without constant and trend | 3.2669 | 1 | -2.62 | -1.95 | -1.61 |
| | constant | -4.3140* | 1 | -3.58 | -2.93 | -2.60 |
| | trending | -4.3232* | 1 | -4.15 | -3.50 | -3.18 |
| **Log(Energy)** | without constant and trend | 3.3674 | 1 | -2.62 | -1.95 | -1.61 |
| | constant | -4.7693* | 1 | -3.58 | -2.93 | -2.60 |
| | trending | -4.8148* | 1 | -4.15 | -3.50 | -3.18 |
| **ΔLog(Energy)** | without constant and trend | 1.4359 | 1 | -2.62 | -1.95 | -1.61 |
| | constant | -5.8720* | 1 | -3.58 | -2.93 | -2.60 |
| | trending | -5.7943* | 1 | -4.15 | -3.50 | -3.18 |
| **$CO_2$** | without constant and trend | 0.6816 | 1 | -2.62 | -1.95 | -1.61 |
| | constant | -5,1362* | 1 | -3.58 | -2.93 | -2.60 |
| | trending | -5.0733* | 1 | -4.15 | -3.50 | -3.18 |
| **Log($CO_2$)** | without constant and trend | 0.4808 | 1 | -2.62 | -1.95 | -1.61 |
| | constant | -5.0228* | 1 | -3.58 | -2.93 | -2.60 |
| | trending | -4.9589* | 1 | -4.15 | -3.50 | -3.18 |
| **ΔLog($CO_2$)** | without constant and trend | -1.6482 | 1 | -2.62 | -1.95 | -1.61 |
| | constant | -5.5593* | 1 | -3.58 | -2.93 | -2.60 |
| | trending | -5.4879* | 1 | -4.15 | -3.50 | 3.18 |

Note: "*" means an statistical significance of 0.05 in the stationary test.
Source: Own elaboration based on the results obtained in R.

To determine if the variables comply with the assumption of stationarity, the ADF test is carried out which has as a null hypothesis ($H_o$) that the variable does not have a unitary root, that is, it is not stationary and as an alternative hypothesis ($H_a$) that the variable is stationary. Evidencing the test values and critical values to meet the assumption of a stationary variable must reject the null hypothesis, in our case, the value of the test must be less than the critical values at 5%, therefore, is it is possible to verify that in the GDP variable without constant and trend, the test value is 2.7994. This ADF statistic has test values greater than the established critical values, so the null hypothesis that the variable is accepted it is not stationary.

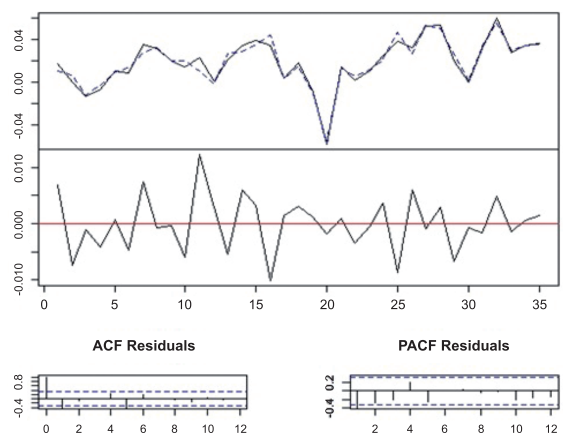
On the other hand, in the case of the variable of the logarithm of the GDP without constant and trend, it does not comply with the assumption of stationarity taking into account that the value of the test is 2,719, being greater than the determined critical values, in terms of constant and trend there is evidence that the null hypothesis is rejected and therefore the variable is stationary. Now, the difference of the logarithm of the GDP with constant and trend shows a value of -4.9353, this result is less than the critical values, therefore the null hypothesis that the variable does not have a unit root is rejected and it is considered stationary.

For the variable of energy consumption without constant and trend, a value of 3.2669 is determined, this being greater than the critical values of 1%, 5% and 10% as a consequence, the variable is not stationary, however, for the logarithm of the energy consumption with constant and trend the value obtained in the test is -4.7693 and -4.8148 indicating that they are less than the critical values and therefore fall within the rejection zone of the null hypothesis. The difference in the logarithm of energy consumption shows values of -5,8720 with constant and -5.7943 with constant and trend, which allows us to infer that the null hypothesis is rejected and meets the assumption of stationarity. Finally, the $CO_2$ variable rejects the null hypothesis in the deterministic term with constant and trend since it gives a value of -5.1362 and -5.0733 respectively, being lower than the critical values. Similarly, the logarithm of $CO_2$ and the difference of the logarithm fulfill the stationarity condition, rejecting the null hypothesis that the variable does not have a unitary root. In summary, the variables of the logarithm when it is already differentiated and transformed are stationary since it is in the rejection zone both at 1% and at 5% and 10%.

After making the relevant changes to the series fulfill the condition of stationarity, next stepis to identify the right amount of backlogs to explain the behavior of the variables in the VAR model proposed. For this objective, the criteria Akaike (AIC), Hanna-Quin (HQ), Schwarz (SC) and the Final prediction error (FPE) are evaluated, where the number of lags in which these criteria show the least value before an increase in them is selected. Following the AIC, HQ, SC and FPE criteria eight lags are obtained as the number of delays suitable for correct model specification. It is evident that the roots of the characteristic polynomial are less than one, so the estimated VAR model with 8 lags meets the stability condition.

## IV.2 Validation of the VAR model

Obtained the optimal number of lags, the VAR model is carried out, for this the studied variables are graphed to verify if the behavior of the last variables adjusts to the first ones, in the same way, to be able to establish if the model satisfies the assumptions, how the residual correlograms behavior is visualized (see graph 1) and the Portmanteau correlation tests, normality, homoscedasticity, stability and test of Johansen. According to the autocorrelation test, the null hypothesis ($H_o$) that the residuals are not correlated is rejected and therefore the alternative hypothesis of the existence of a serial correlation between the residuals is accepted. Next, the Jarque-Bera test is performed and it is evident that this and the curtosis present a normal distribution of the residues with a significance level of 5%. The test is carried out to establish that the model meets the normality assumption.




**Graph 1.** Adjusted graph and correlograms of the residuals of GDP per capita.

Source: Own elaboration based on the results obtained in R.

Subsequently, the ARCH test is applied to determine if the residues are homoscedastic. This test sets a p-value of 0.6120. Finally, the series used to estimate the model are found to be integrated, for this, the Johansen test is applied in which ($H_o$) is r = 0, which indicates that the vectors and the hypothesis are not the cointegrated alternatives is $r$ = 1, $r$ = 2 and $r$ = 3, that is, there are one, two or three cointegrated vectors. Thus, there is evidence that at least two vectors are cointegrated at a significance level of 10%.

## IV.3 Granger causality test

At this point and to establish whether the variables studied cause each other and if this occurs, in which direction happens; the Granger causality test is used. The results showed that in the long term GDP does not cause emissions of $CO_2$ with a p-value of 0.2431 on the contrary, energy consumption does show a causal relationship in carbon dioxide emissions with a p-value of 0.9600 at a significance level of 5%. In the same way, a direct relationship of energy consumption to GDP is determined with a p-value of 0.7991.

**Table 4.** Granger's causality test.

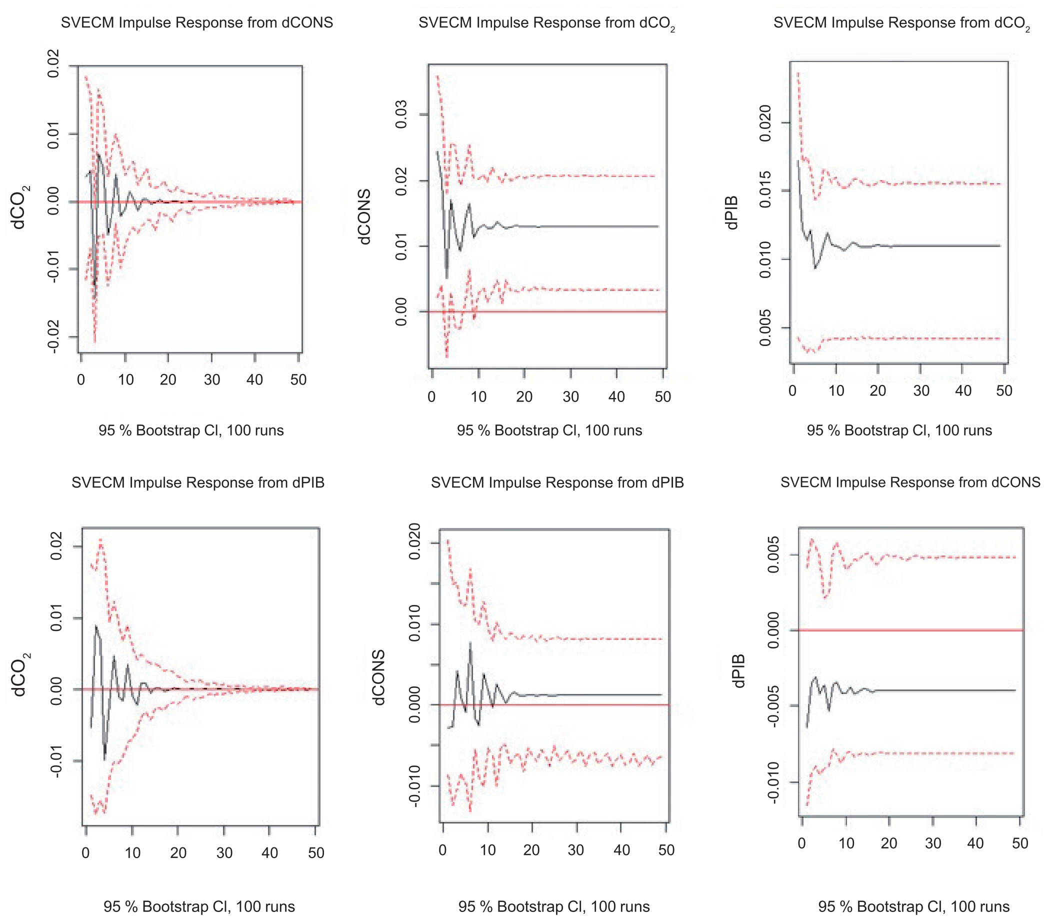
| $H_0$ | F statistic | Probability |
|---|---|---|
| GDP does not cause in the sense of Granger $CO_2$ | 1.4050 | 0.2431 |
| Energy does not cause in the sense of Granger $CO_2$ | 0.0024 | 0.9612 |
| $CO_2$ does not cause in the sense of Granger Energy | 3.4334 | 0.0714 |
| PIB does not cause in the sense of Granger Energy | 1.393 | 0.2221 |
| $CO_2$ does not cause in the Granger sense GDP | 2e-04 | 0.9880 |
| Energy does not cause in the Granger sense GDP | 0.0657 | 0.7991 |

Source: Own elaboration based on the results obtained in R.

A more detailed analysis of cointegration relationships suggests that according to (Lee and Lee, 2010), energy consumption is relatively inelastic. This underscores the theoretical expectation that energy use is primarily a necessity. The results of the causality established that long - term behavior of this variable is readjusted to after a crash towards a balanced relationship. An increase in energy consumption leads to an increase in economic growth and vice versa. Therefore, it appears that Colombia exhibits a type of energy dependency in the sense that an adequately large energy supply appears to ensure further economic growth.

## IV.4 Impulse-response function

The impulse-response evaluation shows the responses of GDP, energy consumption and $CO_2$ emissions to a standard deviation. The graphs obtained show the initial impact of the shock of a standard deviation of one variable on another in question, as well as evalysing the persistence of the effect in the study time.




**Graph 2.** Impulse-response function.
Note: the CONS variable corresponds to the consumption of electrical energy.
Source: Own elaboration based on data from the World Bank 2019.

As seen in graph 2, a shock from the consumption of energy to GDP cause effects to the period 17, however, the effect has a behaves lie almost zero. From the above, it can be inferred that the growth of the economy responds positively to changes in the demand for energy consumption. This behavior shows the importance of including new sources of electrical energy in the Colombian energy matrix so that the competitiveness of the economic sectors that contribute to GDP growth is guaranteed. Similarly, carbon dioxide emissions respond directly to variations in energy consumption, so it could be deduced that strategies for energy efficiency and regulated use of energy could contribute to the reduction of pollutants and therefore care of environmental quality. Clashes both energy consumption and $CO_2$ emissions are initially positively but become insignificant over time. Although the effects appear to be transitory, the responses of the boost to economic growth (GDP), energy consumption and carbon dioxide emissions provide evidence of an interactive link in the short term.

However, according to the impulse-response of the GDP towards $CO_2$ emissions (see graph 3), a behavior consistent with the hypothesis of an environmental Kuznet curve is evident. The result is attributed to the possible relationship between economic growth and the quality of the environment given that in the short term positive changes in the trend of GDP per capita growth cause an impact on air quality. On the contrary, in the long term, the effect on emissions decreases significantly, becoming almost null, according to theory, the reduction of impact could be related, among other aspects, to the implementation of environmental protection tools and better use of energy as the economy improves income levels. The foregoing allows to infer that the increase in GDP is being equivalent to a greater amount of $CO_2$ emissions in the short term and, therefore, to greater contamination of the environment in Colombia. Once it is said, carbon dioxide emissions are apparently at the growing stage of an environmental Kuznets curve.

## V. Conclusions

The results found imply that there is a direct relationship between energy consumption and GDP, and energy consumption towards carbon dioxide emissions, in the same way, the result of the Granger causality test coincides with other studies in which it is determined that increases in energy consumption have a direct effect on growth, that is, energy consumption causes economic growth. These findings allow to establish that in the long term economic growth is a determinant of energy consumption and this of climate change through $CO_2$ emissions, at least for the case of Colombia. The above suggests that energy consumption and economic growth are interrelated and have a dependency relationship, the design of efficient energy use measures, as well as conservation policies should consider the impact of energy consumption on economic growth and its feedback.

The main conclusion on the empirical result of causality of energy to the GDP per capita could be that energetic policies as dedicated to reduce emissions of greenhouse gases should emphasize on the use of alternative or non-conventional sources of energy renewable rather than just trying to reduce total energy consumption to facilitate the tradeoff between energy consumption and economic growth. Significantly, the causal relationship between these two variables not necessarily mean that the regulation of energy affects economic growth, in fact, a reduction in the consumption of energy due to increases in energy efficiency through technological improvements or deploying new sources energy can increase the productivity, which in turn leads to stimulate the grow economically. Therefore, moving from less efficient and more polluting energy sources to more efficient ones in addition to reducing the impact on the environment would translate into greater competitiveness. In this way, efficient and renewable energy options can establish a stimulus rather than an obstacle to economic development.

The empirical results also suggest that the EKC theory for $CO_2$ emissions is valid for Colombia. This indicates that, although a short-term growth of GDP per capita increases the level of $CO_2$ emissions, this rise is stabilized and eventually begins to descend the degree of $CO_2$ emmisions per capita. This decrease translates that as countries have more regulation, become more energy-efficient and improve production conditions, improve production processes and thus become less polluting therefore in the long term increase in GDP per capita would not be the main reason for contamination levels.

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