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Renewable and Non-renewable Energy Consumption, CO_2 Emissions, and Responsible Economic Growth with Environmental Stability in North America

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ABSTRACT

This paper examines the impact of the consumption of non-renewable energies (gasoline and gas), as well as the consumption of renewable energies (solar and wind) and CO_2 emissions (one of the main pollutants) on Economic Growth (EG) in North America. The data comes from the public sources of the World Bank and British Petroleum annually from 1966 to 2020. A Vector Autoregressive (VAR) model is estimated to analyze relationships among the variables under study. Likewise, tests to confirm the non-presence of serial correlation in the residuals of the VAR are carried out. Subsequently, Granger causality tests and an analysis of impulse-response functions are performed. The EG for Canada is explained by a lag from the previous year with a small positive effect. Likewise, the Consumption of Non-Renewable and Renewable Energies (CNRARE) similarly affects EG in a slightly negative way and CO_2 emissions are not significant to explain EG. The US and Canada share similar dynamics concerning CNRARE, but the CO_2 emissions that accompany the industry do positively affect growth. Mexico differs from Canada and US in that the consumption of non-renewable energy (NRE) has a positive effect on economic growth, although it is not significant, and CO_2 emissions negatively affect EG. This is due to a timeless change in industrial development that US and Canada went through previously in their process of industrialization and technological modernization. Finally, in Mexico and Canada, unlike US, a positive response from the EG is observed due to a shock from renewable energy. This investigation differs from current literature in the following: (1) many studies have been carried out on the subject in many countries and regions, but none have addressed the case of North America, to the extent that the authors are aware, (2) conducts an assessment of responsible growth with environmental stability in North America, and (3) provides public policy recommendations to promote the use of renewable energy in all sectors of production while respecting the environment in the long term.

Keywords: Economic Growth, Non-renewable and Renewable Energies, CO_2 Emissions, VAR Model, Granger Causality Tests
JEL Classifications: O47, P18, Q53, C10

1. INTRODUCTION

The links among economic development, responsible consumption and growth, and environmental stability, is frequently known in the literature as sustainable development and refers to development that meets the needs of a population in the present without endangering the capacity of the next generations to satisfy their own needs with environmental stability (United Nations General Assembly, 1987, p. 43). Although this concept might seem somewhat vague, its objective is very clear and is to maintain human progress and economic progress while protecting the environment in the long term. In the same way, the United Nations Framework Convention on Climate Change establishes that in a sufficiently long term, ecosystems must adapt themselves to climate change, ensuring that consumption and production are not affected for present and future generations and, at the same time, environmental stability is achieved (United Nations, 1992).

The new trade agreement among Mexico, Canada, and US that replaces the North American Free Trade Agreement (NAFTA), the US–Mexico–Canada Agreement (the USMCA) considers the North American Agreement on Environmental Cooperation (NAAEC, 1993, Article 10), which contemplates the heading "Reduce pollution and support low-emission" since among the main causes of environmental deterioration in North America stands out the industrial activity and the generation of energy with fossil fuels (oil, gas, and coal) and, as a consequence, there are large CO_2 emissions. The foregoing is to achieve a better level of environmental stability that leads to sustainable development.

In the above context, sustainable development has as its main long-term objectives: (1) environmental protection, (2) progress towards green energy, (3) responsible consumption and growth, and (4) seeks to improve the welfare of the current population without compromising the quality of life of future generations. Of course, we have to be careful when using the terms social welfare and quality of life because there are very broad theories and several multidimensional indicators about them that give rise to different contexts. For the moment it is enough to link them and understand them in the following way: social welfare is the joint satisfaction of a series of needs of the members of society, thus welfare is an achieved condition. While the quality of life corresponds to specific aspects of an individual or group nature of the satisfaction of needs.

One of the dimensions that affect the welfare of individuals is environmental quality. Reducing the use of fossil fuels globally is a challenge for most economies, currently, many countries, including regions, are facing an energy transition towards clean energy. Despite the global awareness that the increase in CO_2 emissions from industrial development (energy, transport, construction, agriculture, etc.) is strongly linked to the consumption of non-renewable energy, very little has been done in the economies in developing countries, and also in some industrialized ones, to achieve an energy transition in favor of local, regional or global environmental stability.

Likewise, Perrings and Ansuategi (2000) highlight that among the threats to the environmental sustainability of development are the depletion of environmental resources caused by poverty in the developing world and the pollution of the biosphere driven by consumption in the developed world. The authors also mention that air and water quality indicators first worsen and then improve as per capita income increases. In their research, they find an empirical relationship between environmental quality, poverty measures, and human development indicators. Also, the authors mention that the deepening of poverty is associated with environmental effects that have immediate and local implications for health and welfare. Furthermore, increased wealth is associated with much more widespread and long-lasting environmental effects. The environmental consequences of growth tend more and more to be transmitted to other countries and regions, as well as to the next generations (Perrings and Ansuategi, 2000). Finally, Spangenberg (2004) points out that sustainable development takes into account four dimensions: economic, environmental, social, and institutional. The author highlights that the economic dimension, particularly, economic growth is an essential factor for sustainable development.

The three countries that make up North America, US, Canada, and Mexico experience different phases of economic growth with different ecological footprints, particularly in the consumption of renewable and non-renewable energy and CO_2 emissions. Regarding the phases of growth about the level of pollution, Stern (2004) suggests that in the early stages of economic growth pollution increases drastically and, with it, environmental degradation occurs, but once economic growth reaches a certain level, say, that of a "developed country," this behavior could be reversed through technological change seeking now to alleviate the damage caused to the environment (of course, when possible and not too late), and preferably do it sustainably. The economic growth of US and Canada has been different from that of Mexico in the previous decades and, consequently, the emissions are different at different times. Likewise, there are substantial differences in the use of renewable energies in the three economies and although these are commercially and industrially integrated into various value chains, they also form an important block in international geopolitics that has global effects on the environment.

Economic growth in the initial stage can be explained by multiple factors, with the level of industrialization and technological modernization undoubtedly being relevant aspects, although industrialization still requires the use of fossil fuels to function. However, the high costs of changing technologies (machinery and infrastructure) do not allow economies to make the transition so quickly. Thus, it is expected that in the early stage, there will be an inverse relationship between economic growth and environmental degradation, and it is desirable that in the long-term investment be made in the use of technologies that use less polluting energy (Lee et al., 2005).

The objective of this research is to carry out an analysis of the relations among consumption of renewable and non-renewable energies, CO_2 emissions, and economic growth of the three countries that make up North America in a sufficiently long period, more precisely 1966-2020. A second objective is to assess environmentally stable responsible growth in North America. The characteristics that distinguish the present investigation concerning the current literature on the subject are the following: (1) many studies have been carried out on the subject in many countries and regions, but none have dealt with the case of North America, as far as the authors know, (2) the analysis period has the longest possible historical period, (3) conducts an assessment of responsible growth with environmental stability in North America, and (4) provides public policy recommendations to promote the use of renewable energy in all sectors of production respecting the environment in the long term.

The organization of this research is as follows: Section 2 presents a brief review of the specialized literature on the subject; section 3 provides a description of the variables used; section 4 describes the VAR methodology, the econometric tests, and their respective analyses; section 5 presents and discusses the empirical findings of Granger causality test and the impulse-response functions; section

6 provides an evaluation of responsible growth with environmental stability in North America; finally, section 7 gives conclusions, provides policy recommendations and acknowledges limitations.

2. BRIEF LITERATURE REVIEW

The relationship between economic growth and environment tends to have discrepancies in the results of various empirical investigations (Le and Ozturk, 2020), since growth generates CO_2 emissions, at least in the first phase. On the other hand, consumption is not adjusted to the use of less polluting raw materials or environmentally friendly packaging, which generates environmental degradation at the global level (Munda et al., 1994).

Ozturk and Acaravci classic work (2010) offers a study on the relationships between CO_2 emissions, energy consumption, and economic growth. More recently, Le and Ozturk (2020) examine the impact of globalization on CO_2 emissions, energy consumption, and growth, among other variables, for 47 emerging and developing economies. On the other hand, Abbasi et al. (2022) examines the asymmetric relationship between the consumption of renewable energy, non-renewable energy (NRE) and international trade in Pakistan from 1970 to 2018. The results obtained suggest that the most effective strategy for Pakistan is to promote renewable energy by highlighting its advantages for the environment and industrial development, and reducing the use of non-renewable resources. Likewise, Adedoyin et al. (2021) investigate the role of policy uncertainty in the energy-growth-emissions nexus for 32 countries in sub-Saharan Africa over the period 1996-2014. The authors show that real GDP and non-renewable energy generation increase CO_2 emissions. However, while economic policy uncertainty also drives high levels of emissions in the region, its moderating effect on the impact of renewable and non-renewable energy generation leads to a reduction in the level of emissions in the region. This suggests the need to implement sound macroeconomic and energy policies in sub-Saharan Africa to mitigate the resulting impact on environmental degradation in the region. Similarly, Irfany et al. (2022) suggest that for the Organization of Islamic Cooperation (OIC) the mitigation of climate change in emissions should be carried out both in the short and long term to reduce its dependence on the use of fossil energy in both production and consumption, including environmentally friendly technologies. Finally, Awada et al. (2021) highlight the issue of energy conservation in Amman, Jordan, in terms of opportunities and challenges facing renewable energy technology.

On the other hand, Salazar-Núñez and Venegas-Martínez (2018) examine the impact of energy use and gross capital formation on economic growth using a panel data model in 73 countries grouped by income level and oil production. Similarly, Aali-Bujari et al. (2017) examine the impact of non-renewable and renewable energy consumption on economic growth of the main OECD economies through a panel data model in the period 1977-2014. Moreover, Valencia-Herrera et al. (2020) study the relationships between economic growth, energy and electricity consumption, CO_2 emissions, and urbanization in Latin America.

In the same way, Santillán-Salgado et al. (2020) study the interactions between CO_2 emissions, gross domestic product growth, energy consumption, electricity use, urbanization, and income inequality for a sample of 134 countries using a panel data model. Finally, Salazar-Núñez et al. (2022) examine with a panel data model the interdependence between renewable and non-renewable energy, economic growth, and CO_2 emissions in Mexico.

As previously mentioned, Stern (2004) suggests, in the early stages of economic growing, that pollution and environmental degradation is drastic, but once the level of a "developed" country is reached, there are enough resources to reverse the trend. In this sense, one of the most controversial theories of the relationship that may exist between economic growth and its impact on the environment is the Kuznets curve (1955), which establishes that in the early stages of growth, it is essential to pollute a lot and later when the economy has grown enough, the damage caused to the environment could be reversed. It is important to clarify here that Kuznets never suggested this relationship, rather Kuznets (1955) establishes that poor countries have, at first, a more egalitarian distribution of income, and as they develop, income begins to concentrate and, later, the distribution worsens. But once development has reached a certain level, these countries become egalitarian again. Thus, what is known as the environmental Kuznets curve is a reinterpretation of the above.

The environmental Kuznets curve has been highly questioned by various empirical studies that have been carried out in this regard (Santillán-Salgado et al., 2020). Olivares Mendoza and Rodríguez (2021) evaluated the main criticisms of the Kuznets curve and found that even though its objective is to use it as a technique to evaluate public policies that mitigate pollution, they highlight that the idea that has been generated that pollution is reduced by simply growing could be wrong. On the other hand, Santillán-Salgado et al. (2020) suggest that developed countries reach a turning point where their economic growth translates into a decrease in environmental impact, while developing countries maintain a positive relationship, indicating that their economic growth is not enough to reduce environmental impact. Finally, it is important to point out that several works relate economic growth to the environment, examples of which are: Gómez-Segura et al. (2021), Ortiz-Paniagua and Gómez (2021), Chamorro et al. (2022), and Song and Mei (2022).

3. DESCRIPTION AND NATURE OF THE VARIABLES

The data comes from the public sources of the World Bank and British Petroleum on an annual basis from 1966 to 2020. The annual growth rates of the Gross Domestic Product (GDP) are calculated with market prices in constant local currency and the aggregates are based on constant 2015 prices expressed in US dollars. The consumption of non-renewable and renewable energy is measured in kilotonne (thousand ton) of oil equivalent (ktoe). Finally, CO_2 emissions are measured in millions of tons.

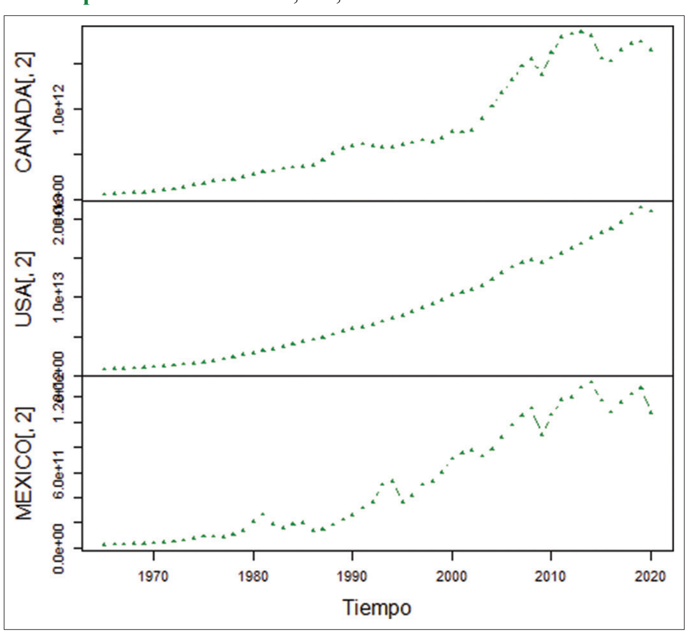
Below is the dynamic of the study variables in levels and growth rates; the latter is calculated as logarithmic differences. Observe first that Graphs 1 and 2 show the behavior of the GDP series and the GDP growth rate over time for the 3 economies that make up North America.

Graph 1 shows, in general, in the three countries an increasing trend over time, although with different scales and populations of very different sizes. However, US shows a more uniform growth, while Canada in recent years shows slight falls maintaining a constant trend. On the other hand, Mexico has a growing trend with more frequent falls throughout the period of analysis 1966-2020, accentuating more in recent decades. Finally, in all three countries, a synchronized decrease is observed during the period 2019-2020 due to the COVID-19 pandemic.

On the other hand, Graph 2 shows the economic growth rates of the three nations superimposed to be able to compare the variations over time regardless of the scale or size of the population. The dark line corresponds to Canada where oscillations are generally not very large. The red line corresponds to US and shows the lowest volatility of the 3 countries with a slightly downward growth. Lastly, the green line corresponds to Mexico, which shows a great variation with very relevant booms and busts, mainly in the 1980s and 1990s, but highlights the magnitude of the declines concerning the other two countries.

Graph 3 shows the CO_2 emissions of the three countries where it is important again to take into account the scales and magnitude of populations. Canada shows a growing trend with a slight decline as of 2015 and subsequently remains constant. On the other hand, US shows an accelerated increase between 1990 and 2000 and, subsequently, a very significant decline is observed. Mexico follows an almost always growing trend but does not oscillate as much as that of US, also Mexico has a downward trend since 2015. Of the three countries, US is observed with higher CO_2 emissions, which is due to its industrial progress and population growth.

Graph 1: GDP of Canada, US, and Mexico from 1965 to 2020

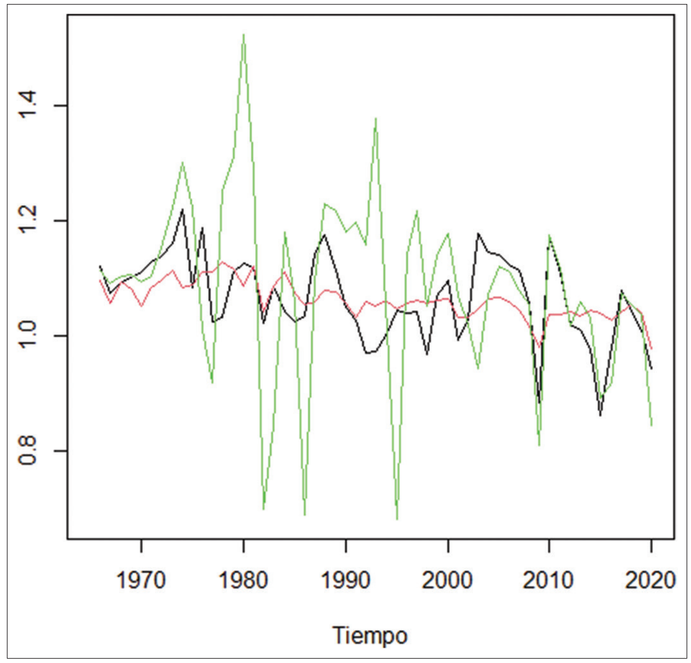


Source: Own elaboration with data from the World Bank and R.project

Finally, in the three countries, there is a synchronized decrease in 2019-2020 that, as before, is due to the Covid-19 pandemic.

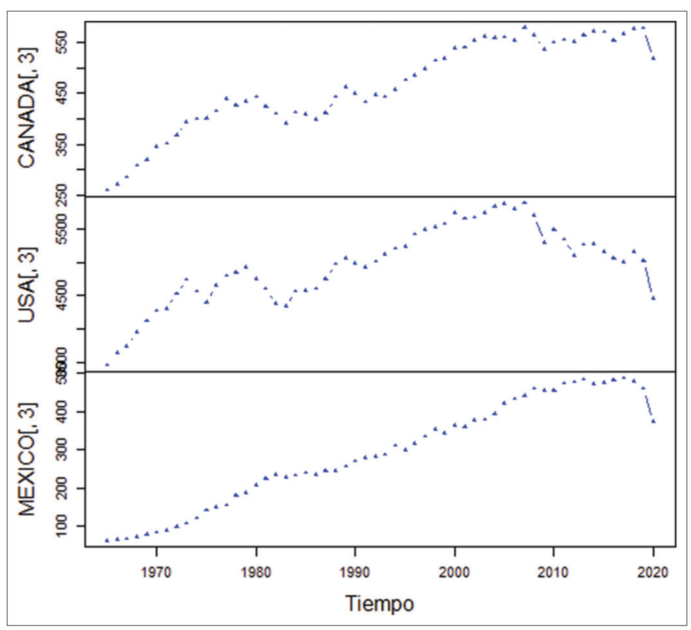
Graph 4 shows growth rates of CO_2 emissions, we must not lose sight of Mexico showing significantly higher variations between 1970 and 2010. In this period there is no comparison with US where rates oscillate closer over time. It is noteworthy that in recent years there is a significant fall in the rates of the three

Graph 2: Economic Growth of Canada, US, and Mexico from 1966 to 2020



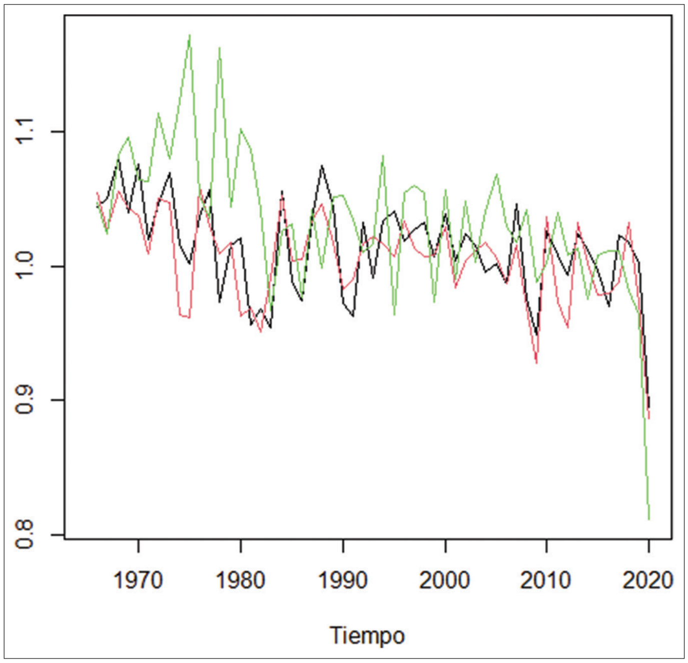
Source: Own elaboration with data from the World Bank and R.project

Graph 3: CO_2 emissions from Canada, US, and Mexico from 1965 to 2020



Source: Own elaboration with data from British Petroleum (2020) and R.project

Graph 4: The Growth rate of CO_2 emissions for Canada, US, and Mexico from 1966 to 2020



Source: Own elaboration with data from British Petroleum (2020) and R.project

countries, Mexico, on the green line, shows a greater decrease in CO_2 emissions concerning the 2019-2020 period, perhaps, as a result of the COVID-19 pandemic.

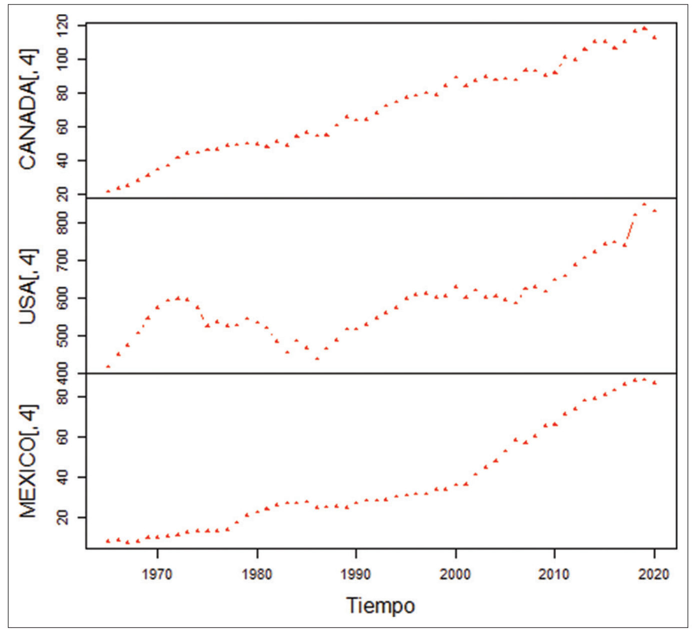
The non-renewable energies considered in the present investigation contemplate the consumption of gas and oil, being those who have suffered the greatest variations in their prices and also the most questioned by high pollution. Concerning renewable energy consumption, solar, and wind are fundamentally considered.

Graph 5 shows increasing series for Mexico and Canada of non-renewable energy consumption although with very different scales which confirms US as the great user of non-renewable energy. That is, according to the scales, US consumes much more non-renewable energy than Canada and, of course, than Mexico. In 2019-2020, a synchronized reduction due to the effects of the COVID-19 pandemic stands out, when industrial production fell significantly due to confinement and there was an almost total stoppage of economic activities for the entire region. Finally, between 1980 and 1990 a certain constancy in the consumption of non-renewable energy was observed in US, but since then growth has increased with slight oscillations.

Finally, Graph 6 shows the growth rates of non-renewable energy consumption, where variations are very similar in the and Canada. However, Mexico has greater increases between 1970 and 1990. In the case of the three countries in 2020, negative growth rates were explained, perhaps, by the Covid-19 pandemic; being the most accentuated fall that of Mexico.

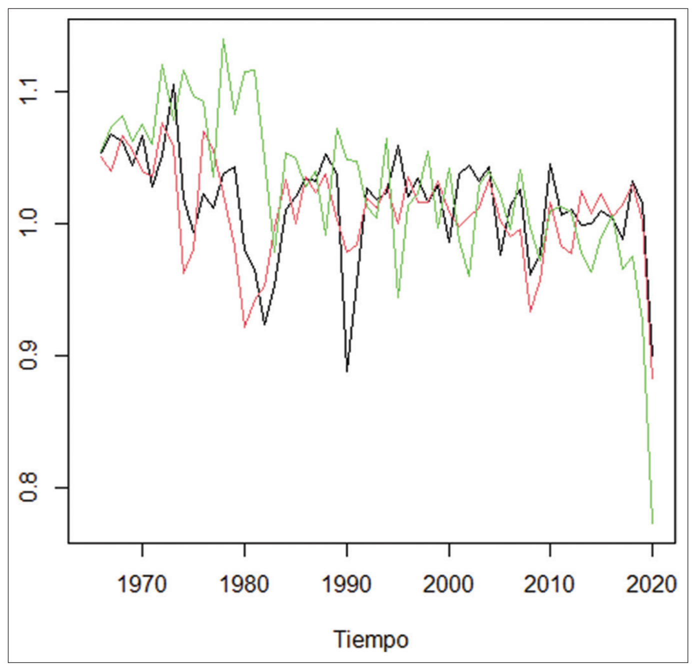
As expected, in Graph 7, it is observed that before 1990 the consumption of renewable energy is low in the region although

Graph 5: Non-renewable energy consumption in millions of cubic meters, in Canada, US, and Mexico from 1965 to 2020



Source: Own elaboration with data from British Petroleum (2020) and R.project

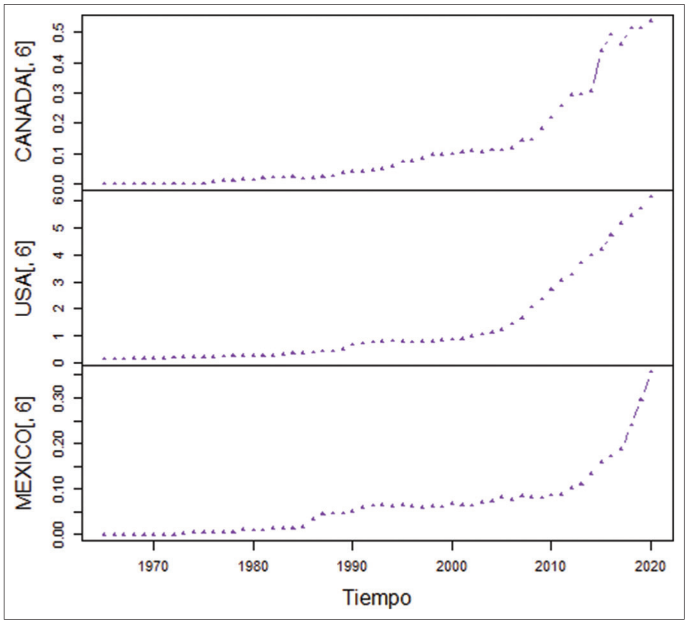
Graph 6: The growth rate of non-renewable energy consumption in Canada, US, and Mexico from 1966 to 2020



Source: Own elaboration with data from British Petroleum (2020) and R.project

with different scales and population sizes. At that time, policies were beginning to focus on environmental conservation in US and Canada, while in Mexico they were just barely insipient. Subsequently, there is a growing consumption trend. As of 2010, significant increases are observed when green energy begins to be taken into account and the concern about the effects of pollution gained awareness in the nations. The US is

Graph 7: Renewable energy consumption in millions of cubic meters, in Canada, US, and Mexico from 1965 to 2020



Source: Own elaboration with data from British Petroleum (2020) and R.project

the country with the highest renewable energy consumption, it may be because it is already in the last phase of the Kuznets environmental curve.

Finally, Graph 8 shows the growth rates of renewable energy consumption, observing important variations between 1975 and 1990, when the idea of clean energy consumption aroused. However, in recent years, the rates of the countries are very close, being Canada the one with the greatest oscillations.

4. METHODOLOGY AND ECONOMIC SPECIFICATIONS

This section establishes a model of autoregressive vectors VAR (k) where k is the number of lags to study the dependency relationships among the economic growth rate and the growth rates of CO_2 emissions, renewable and non -renewable energies as follows for each of the study countries:

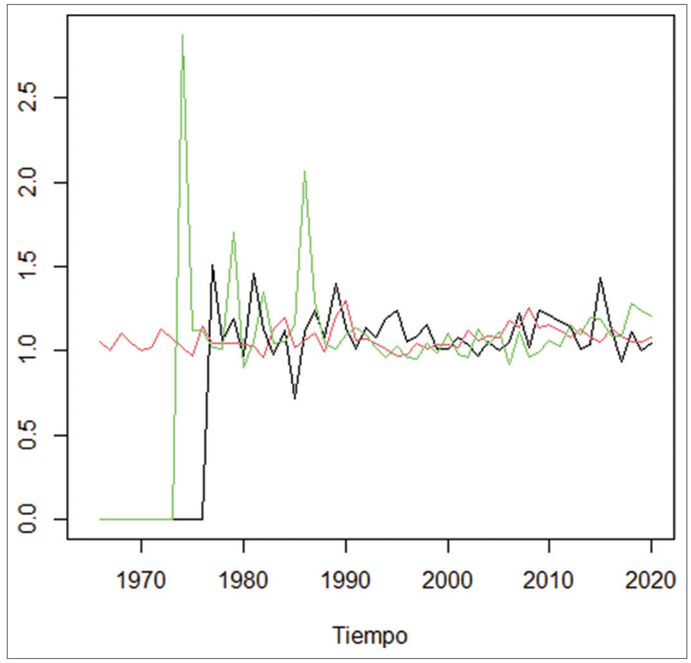
$$Y_t = \beta_1 Y_{t-1} + \beta_2 Y_{t-2} + \cdots + \beta_k Y_{t-k} + \Theta D_t + v_t \quad (1)$$

Where:
Y_t: Variable vector at time t,
k: Number of lags,
D_t: Vector of independent variables,
v_t: White noise, with zero average and constant variance,
β_i and Θ: Parameters.

4.1. Unit Roots Tests

This section presents the 3 standard unit root tests. Table 1 shows that the results of the Dickey-Fuller and Phillips Perron tests coincide, but there are certain differences with the KPSS test. For

Graph 8: The growth rate of renewable energy consumption for Canada, US, and Mexico from 1966 to 2020



Source: Own elaboration with data from British Petroleum (2020) and R.project

this research, only those tests that show greater coincidence in the results are taken into account.

4.2. Identification of the Number of Lags

Table 2 below shows the calculations for identifying the number of lags according to the Akaike Information Criterion (1974) (AIC), Hannan and Quinn (1979) (HQ) Information Criterion, Schwarz Bayesian Information Criterion (1978) (SC) and the Akaike Final Prediction Error (FPE). The four information criteria indicate the relative loss of information when the data is adjusted using different specifications. The chosen length of lag that produces the minimum value of the information statistic is $k = 1$, which agrees with the principle of parsimony.

In the case of all countries, we consider the minimum Schwarz criterion that supposes 1 lag. According to Lütkepohl (2005), the Bayesian information criteria of Schwarz provide consistent estimates of the true order of lag, while Akaike criteria overestimate the order of the lag with positive probability.

From the VAR models estimated for Canada, US and Mexico, we highlight the following:

In the case of Canada:

$$y_t = 0.34257 y_{t-1} - 0.17926 nr_t - 0.04028 r_t + 0.92029 + v_t$$
$$\text{P} - \text{value } (0.01960^*)(0.04297^*)(0.09642 \text{ a})(0.00192^{**})$$

$$\text{Corr}(v_t) = \begin{pmatrix} 1.0000 & 0.1413 & -0.3620 \\ 0.1413 & 1.0000 & -0.1657 \\ -0.3620 & -0.1657 & 1.0000 \end{pmatrix}$$

Table 1: Unit root tests

Country	Variable	Dickey-Fuller		Phillips-Perron		KPSS		Results
		Estimador	P	Estimador	P	Estimador	P	
Canada	Economic_growth	−5.1636	0.01	−36.543	0.01	0.56376	0.02731	Stationary
	GR_nonrenewable	−6.8472	0.01	−49.641	0.01	0.61385	0.02138	Stationary
	GR_renewable	−2.9845	0.1	−13.725	0.2906	0.77392	0.01	Nonstationary
	GR_emissions	−5.7927	0.01	−44.837	0.01	0.58025	0.02443	Stationary
US	Economic_growth	−4.929	0.01	−35.891	0.01	1.1827	0.01	Stationary
	GR_nonrenewable	−5.8843	0.01	−42.464	0.01	0.11243	0.1	Stationary
	GR_renewable	−5.404	0.01	−40.071	0.01	0.27684	0.1	Stationary
	GR_emissions	−5.6247	0.01	−40.693	0.01	0.68793	0.01464	Stationary
Mexico	Economic_growth	−5.6092	0.01	−33.287	0.01	0.43163	0.06352	Stationary
	GR_nonrenewable	−5.6682	0.01	−39.41	0.01	0.13803	0.1	Stationary
	GR_renewable	−4.9315	0.01	−32.937	0.01	0.40691	0.07418	Stationary
	GR_emissions	−5.6468	0.01	−52.911	0.01	0.94981	0.01	Stationary

Source: Own elaboration with data from the World Bank and British Petroleum (2020) and R.project

Table 2: Identification of the number of lags to include in the vector autoregressive models

AIC	HQ	SC	FPE
Canada			
9	9	1	10
US			
10	10	1	10
Mexico			
9	9	1	10

Source: Own elaboration with data from the World Bank and British Petroleum (2020) and R.project. AIC: Akaike information criterion, HQ: Hannan and Quinn, SC: Schwarz Bayesian Information Criterion, FPE: Final prediction error

In the case of US:

$$y_t = 0.55442 y_{t-1} - 0.26841 nr_t$$
$$-0.07961 r_t + 0.23994 e_t + 0.58817 + v_t$$
$$\text{P} - \text{value}\left(4.54\text{e}-05^{***}\right)\left(0.00784^{**}\right)$$
$$\left(0.07835\ \text{a}\right)\left(0.1\ \text{a}\right)\left(0.00015^{***}\right)$$

$$\text{Corr}\left(v_t\right) = \begin{pmatrix} 1.0000 & 0.2819 & 0.1226 & 0.5980 \\ 0.2819 & 1.0000 & 0.1689 & 0.5827 \\ 0.1226 & 0.1689 & 1.0000 & 0.1061 \\ 0.5980 & 0.5827 & 0.1061 & 1.0000 \end{pmatrix}$$

In the case of Mexico

$$y_t = 0.3208 y_{t-1} + 0.5210 nr_t - 0.5488 e_t + 0.7601 + v_t$$
$$\text{P} - \text{value}\ \left(0.0506\ \text{a}\right)\ \ \left(0.1\ \text{a}\right)\ \ \left(0.0372^{*}\right)\ \left(0.1\ \text{a}\right)$$

$$\text{Corr}\left(v_t\right) = \begin{pmatrix} 1.0000 & 0.2280 & 0.5696 \\ 0.2280 & 1.0000 & 0.4335 \\ 0.5696 & 0.4335 & 1.0000 \end{pmatrix}$$

Where:
y_t: Economic growth variable
r_t: Independent variable of renewable energy growth
nr_t: Independent variable for the growth of non-renewable energy
e_t: Independent variable for the growth of CO_2 emissions.
Levels of significance: "***" 0.001, "**" 0.01, "*" 0.05, "a" 0.1.

The VAR specification that turned out to be the most appropriate, for the 3 countries, show the effects of CO_2 emission growth rates and renewable and non-renewable energy consumption on economic growth. The impact is similar between Canada and US, but the case of Mexico is different in several aspects. The empirical results obtained are described and explained below:

In the case of Canada, it is observed that economic growth is explained by a lag from the previous year with a not very broad positive effect. This may be because growth depends on many other factors in such developed countries (*e.g.*, a deep financial system, industrialization permanently driven by technological modernization, extensive international trade, huge multinational corporations, legal certainty, etc.). Likewise, the consumption of non-renewable and renewable energy also negatively and slightly affects growth. This may be because green technologies are not yet to compensate for the negative effects of the industry due to the use of fossil energy. Finally, CO_2 emissions are not significant to explain economic activity.

The US behavior is a similar to that of the Canadian economy regarding the effects of consumption of non-renewable and renewable energy. This may be because both are developed countries where the industry and its resources try to be fully exploited, but, in turn, their economic growth continues to be slightly deteriorated by energy consumption. Unlike, Canada, for the US CO_2 emissions that accompany the industry positively affect economic growth.

Mexico is the only country in North America in the process of development, which means that it is still in the process of industrialization and technological modernization. This is reflected in the estimated model since unlike Canada and US, non-renewable energy consumption has a positive effect on economic growth although it is not significant. Possibly, Mexico is in an early phase of the Kuznets environmental curve with low green energy generation. Finally, CO_2 emissions negatively affect growth. This is due to a timeless change in industrial and technological development that is usually very expensive and through which US and Canada previously passed in their process of industrialization and technological modernization.

4.3. Autocorrelation Analysis in Residuals

Next, an autocorrelation analysis is carried out in the residuals of the VAR model to inquire about the presence of serial correlation in the residuals. This analysis is important to ensure consistent provided that the error terms are innovations and have an absence of autocorrelation, which can be concluded that for each equation the lowest number of lags allows for eliminating the residual autocorrelation of all equations. Although a VAR model is not estimated to make inferences of individual variables, in doing so jointly, a deep analysis of the coefficients associated with a block of lags is required. A stable model is reflected in non-explosive and economic sense behavior, so the adjustment and residual diagrams for the economic growth of Canada, US, and Mexico are presented below through Graphs 9-14.

The diagrams and residuals clearly show that there is no serial correlation in the residuals, which allows ratifying that the estimators are consistent. Most of the delays in the residual autocorrelation function are small, indicating that most of the temporal dependence has been collected in the estimate. Finally, it can be observed in the previous graphs that the first lag for the 3 countries is large.

5. GRANGER CAUSALITY AND IMPULSE-RESPONSE FUNCTIONS

In this section, causality tests in the Granger sense and an analysis of impulse-response functions is carried out with a detailed discussion of the empirical results obtained.

5.1. Granger Causality

Non-causality tests in the sense of Granger applied to VAR (1) models for Canada, US, and Mexico are presented in Table 3.

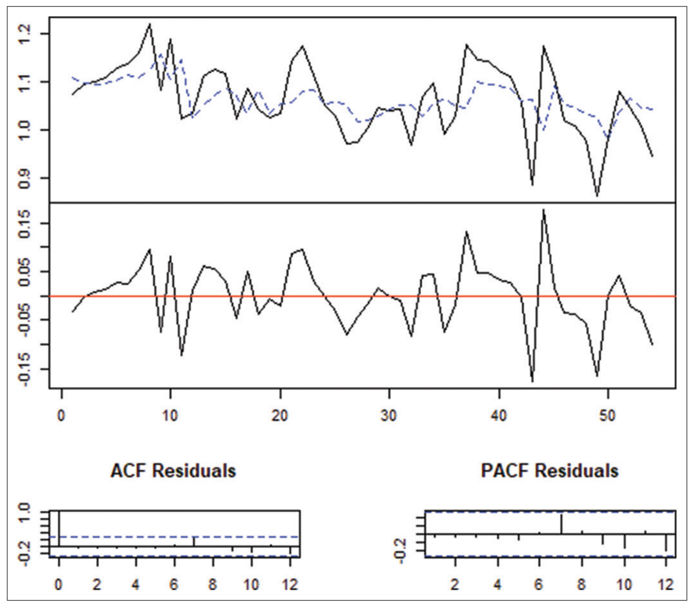
Table 3: Noncausality tests in the sense of Granger for the vector autoregressive (1) (1929-2009)

Null hypothesis	F	P
Canada		
y_t does not cause r_t	2.2887	0.1365
r_t does not cause y_t	0.7926	0.3775
y_t does not cause nr_t	0.0339	0.8547
nr_t does not cause y_t	1.7567	0.1909
US		
y_t does not cause r_t	4.5743	0.03727*
r_t does not cause y_t	3.2199	0.07868
y_t does not cause nr_t	6.0198	0.0176*
nr_t does not cause y_t	2.8911	0.09516
y_t does not cause e_t	0.0685	0.7945
e_t does not cause y_t	0.0035	0.9528
Mexico		
y_t does not cause nr_t	1.3151	0.2568
nr_t does not cause y_t	0.101	0.7519
y_t does not cause e_t	0.1132	0.7379
e_t does not cause y_t	0.9555	0.3329

*, ** indicates the rejection of the null hypothesis at 5 and 1% significance, respectively. Source: Own elaboration with data from the World Bank, British Petroleum (2020), and R.project

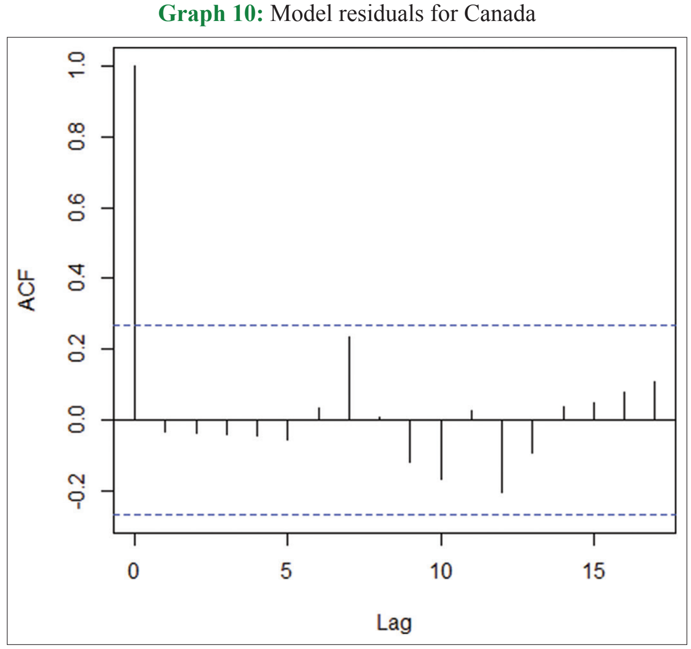
From the Granger causality tests is observed that in the Canada case, it is not possible to reject null hypotheses where economic growth causes in the Granger sense the growth rates of CO_2 emissions and the consumption of renewable and non-renewable energies in a long-term horizon. Moreover, independent variables in a strict sense do not cause economic growth in the Granger sense. In the US case, it is observed that economic growth causes in the Granger sense the growth rates of renewable and non-renewable energy consumption with a level of significance of 10%, which is due, as explained before, to the technological modernization that US possesses. However, it is not possible to reject the null hypothesis where CO_2 emissions cause economic in the Granger sense and reciprocally. Finally, in the Mexican case, it is clear that

Graph 9: Adjustment and residual diagram for Canada economic growth



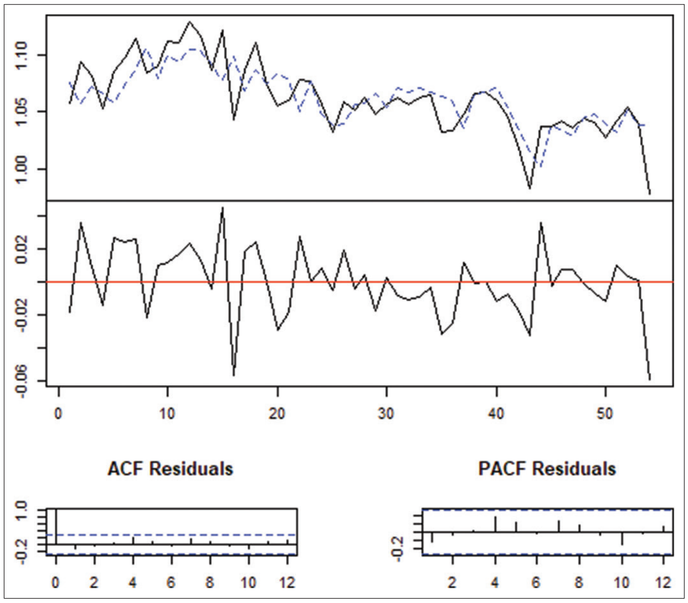
Source: Own elaboration with R.project

Graph 10: Model residuals for Canada



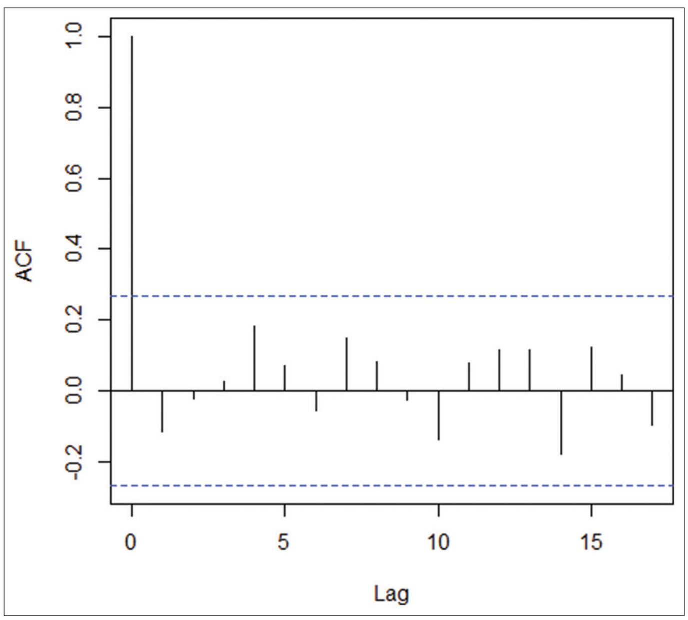
Source: Own elaboration with R.project

Graph 11: Adjustment and residual diagram for US economic growth



Source: Own elaboration with R.project

Graph 12: Model residuals for US



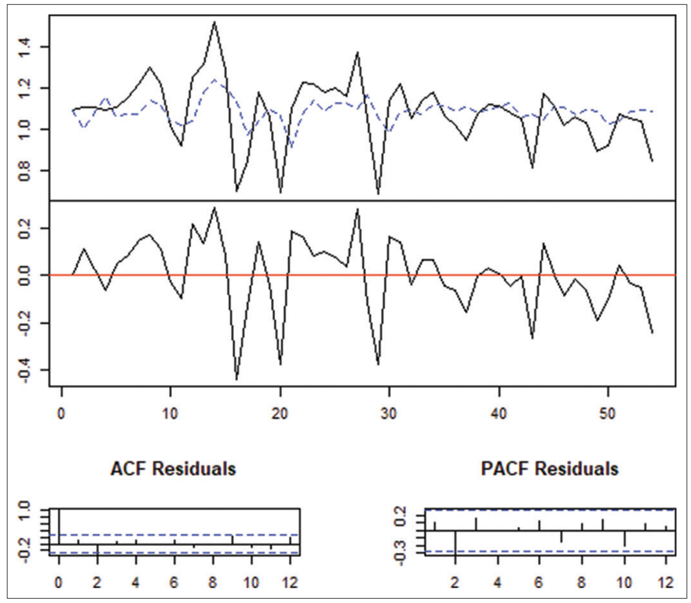
Source: Own elaboration with R.project

it is not possible to reject the null hypotheses since Mexico has experienced, in the time horizon analyzed, insufficient growth.

5.2. Impulse-response Functions

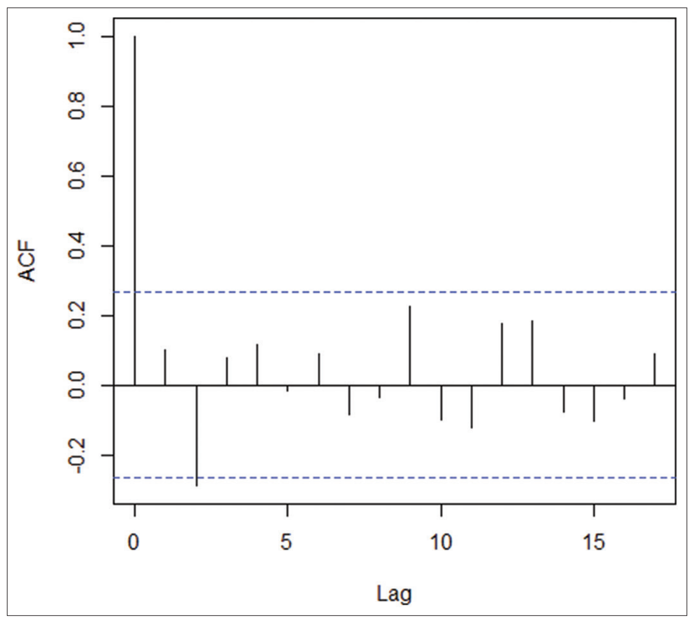
Below is an analysis of impulse-response functions with the VAR (1) estimated by the bootstrapping method, which allows observing the behavior of economic growth in the face of a shock in each of the independent variables (growth rates of CO_2 emissions, renewable and non -renewable energy consumption). Graph 15 shows that in the case of Canada, the only that was statistically significant was the response of the economic growth rate due to a shock in renewable energy in the second period in a positive way. In the US case, the response of economic growth is observed in the face of a shock of renewable energy and CO_2 emissions where both are significant and very

Graph 13: Adjustment and residual diagram for Mexico economic growth



Source: Own elaboration with R.project

Graph 14: Model residuals for Mexico



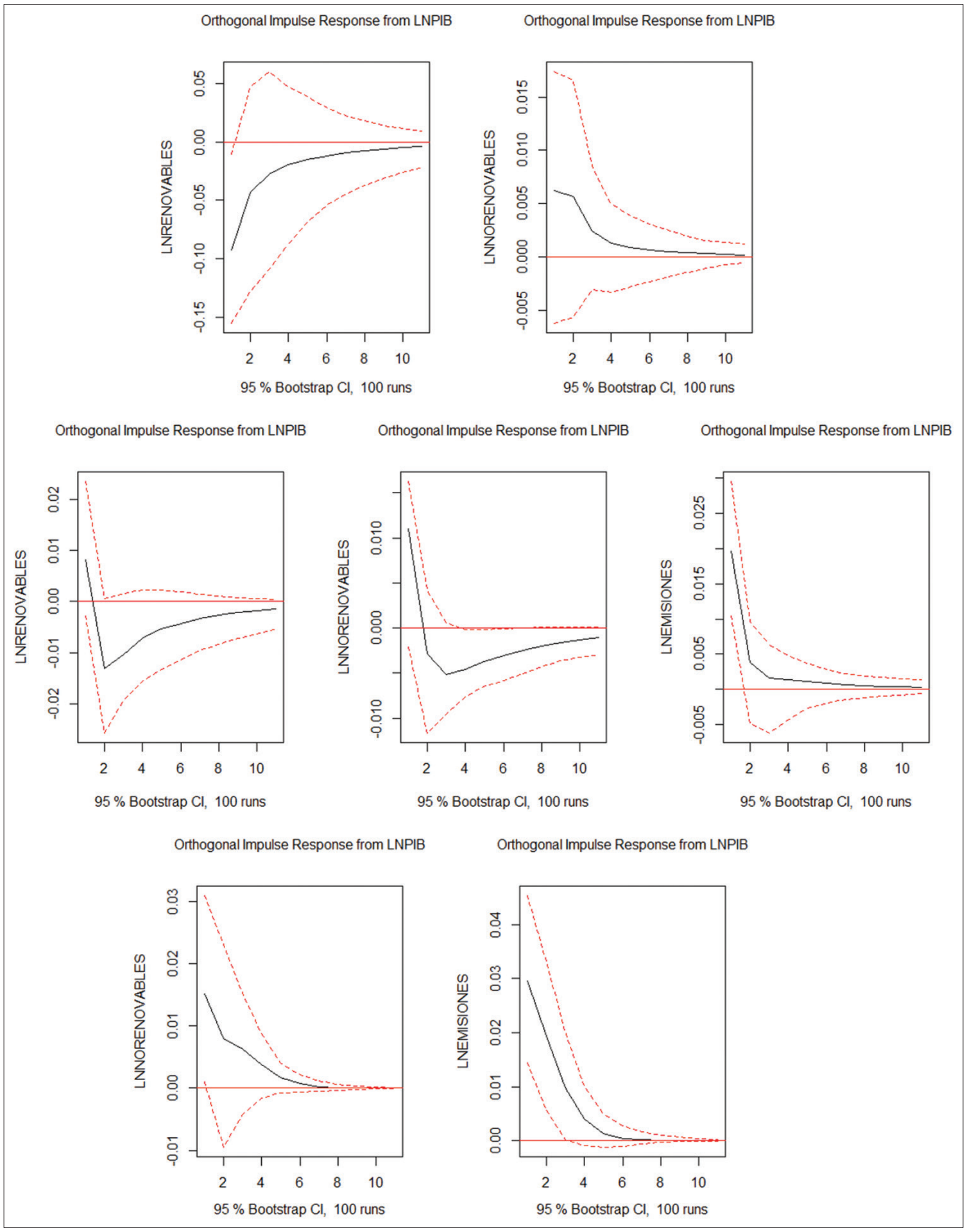
Source: Own elaboration with R.project

marked in the second period in a negative way. Finally, in Mexico, the response of economic activity due to a shock of renewable energy is observed from the first period in a positive sense. This response is mainly caused by the consumption of oil and gas, which has short-term effects despite the efforts to increase the use of clean energy.

6. EVALUATION OF RESPONSIBLE GROWTH WITH ENVIRONMENTAL STABILITY IN NORTH AMERICA

North America faces great challenges to move towards an adequate degree of environmental sustainability. In particular,

Graph 15: Response to economic growth due to a shock on the independent variables
Note: The estimator is obtained from *Bootstrapping*.



Source: Own elaboration with data from the World Bank, British Petroleum (2020), and R.project

Mexico, unlike the US and Canada, is a developing country that must undertake a profound cultural change to reverse the growing environmental deterioration. To do this, the Mexican government has launched several programs: Green seal; Rain harvest; Climate change; Solid waste, Cyclotron; Barter market; Polluting vehicles; Inventory of green areas; Green infrastructure; Today does not circulate, Reforest; Rescue of rivers and bodies of water; Sustainable water management; Integrated and sustainable mobility; and Solar city, among others. However, really substantial and high-impact improvements should be made immediately, for example, the generation of electricity from renewable resources, the use of less polluting fuels in the production of cement with and, in the transport sector, with incentives taxes on the purchase of electric and hybrid vehicles, to mention some areas of opportunity that require prompt attention.

At the international level, an accelerated use of fossil fuel reserves can be distinguished, which leads to encourage the use of renewable energies and the search for an increase in energy efficiency in all productive sectors so that in the future they can be sustainable. Predominantly, the efforts are directed to developed countries, and in particular to Mexico, since this country does not have sufficient capital, or the necessary technology, to promote scientific research and technological innovation for the development of renewable energy sources.

According to the results of the research, the use of non-renewable energy remains an important factor for economic development. In the case of Canada, it is observed that there is an important effort in the use of renewable energy but still maintains important CO_2 emissions. Canada is remarkable for its geographical location, the magnitude of its territory, and the small size of its population compared to the other members of North America. On the other hand, US shows a positive relationship between economic growth and CO_2 emissions, which implies that industry requires energy sources in a constant, renewable or non-renewable way, and this negatively impacts ecological sustainability. Therefore, for US it is necessary that in the future the efforts continue to be aimed at technological development with more intensive employment of renewable energies to significantly reduce CO_2 emissions and more quickly reduce the negative effect on the environment. Mexico for its part has negative effects between economic growth and CO_2 emissions, which clearly shows that excessive consumption of non-renewable energy prevails. Of course, legislative and governmental initiatives are expected to quickly achieve sustainable development and a significant impact in favor of growth while caring for the environment.

7. CONCLUSION

This research examined the relationships between economic growth and various independent variables, among which are the consumption of renewable and non-renewable energy, as well as CO_2 emissions, for the countries of North America, Canada, the US and Mexico, The first two are developed countries and the last one, Mexico, is developing. The analysis considered annual data from 1966 to 2020.

For Canada, economic growth is explained with a lag from the previous year with a small positive effect. Likewise, non-renewable and renewable energy consumption affects economic growth in a slightly negative. Finally, CO_2 emissions are not significant to explain economic activity. The US and Canada share a similar dynamics regarding the consumption of non-renewable and renewable energy but CO_2 emissions, that accompany the industry, affect positively growth. Mexico differs from Canada and US in that the consumption of non-renewable energy has a positive effect on economic growth, although it is not significant. Likewise CO_2 emissions negatively affect the EG. This is due to a timeless, and of course very expensive, change in industrial development that the US and Canada went through earlier in their process of industrialization and technological modernization.

According to the impulse analysis of economic growth in the face of a shock in independent variables with a confidence estimator from bootstrapping, it is observed in the three countries, which statistically significant was the response to a shock in the growth rates of the renewable energies, in Canada during the second period in a positive way, US in the second period in the negative sense and Mexico from the first period in a positive sense. In the case of US, it turned out that a CO_2 emissions shock impacts, given the multiple strategies to reduce pollutants and a green culture that has grown in recent years.

According to the impulse response analysis of economic growth to a shock in the independent variables with a confidence estimator based on Bootstrapping, it can be seen in the three countries that the response was statistically significant to a in the growth rates of the renewable energies: in Canada during the second period in a positive sense, in the US in the second period in a negative sense and in Mexico from the first period in a positive sense. Only in the case of the US did it turn out that economic growth is affected by a shock of CO_2 emissions. This is due to multiple strategies to reduce pollutants and a green culture that has grown in recent years in the US.

It is concluded that economic growth is affected by the consumption of renewable and non-renewable energies, although in a small and different way for the developed and developing countries that make up North America. On the other hand, a reduction of CO_2 emissions play a fundamental role in the ecological sustainability of the world, but it is clear that sustainable development is that it allows drastically reducing this factor, in addition to a culture popular ecological and a high purchasing power for acquisition and use of renewable and green technology.

Regarding the recommendations in public policies for North America to promote the use of renewable energy in all sectors of production respecting the environment in the long term that emerges from the present research there are: (1) energy consumption is vital for the economic development of North America, in recent decades the region has had accelerated population growth and it is necessary to satisfy demand paying more attention to clean energy; (2) technological innovation among the three countries is different, with Mexico being the furthest behind, more attention should be paid to promoting technological modernization to meet the demand of the transportation, construction, and energy sector; (3) if energy is generated from non-renewable sources, the environment degrades, which is why the generation of energy from renewable sources must be encouraged from the government. In particular, Mexico has an excellent location to exploit solar, wind, and geothermal resources.

Public policies should provide incentives for the operation of renewable energies through: (1) direct incentives for the use of non-conventional renewable energies (solar, geothermal, wind, biomass, tidal, hydroelectric, etc.); (2) exemption for the transmission of renewable energy, mainly from the electricity sector; (3) stabilize market prices for the benefit of small producers for the use of renewable energy; (4) promote the use of renewable energy for those industries that use large amounts of energy; (5) facilitate public and private bidding for renewable energy producing companies; and (6) promote certifications of companies responsible with the environment before the auditing agencies.

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