Impact of renewable energies on greenhouse gas emissions in Mexico

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Date received: March 30, 2020. Date accepted: September 16, 2020.

Abstract

This article seeks to analyze the relationship between greenhouse gas (GHG) emissions, income level (GDP), and consumption of renewable and non-renewable energy in Mexico for the period 1990-2015. The Autoregressive Distributed Lags (ARDL) approach demonstrates that income and non-renewable energies are the main variables that explain the trajectory of GHG emissions. The consumption of renewable energies has a marginal long-term impact, with an elasticity of -0.021. This situation is a significant obstacle to the objective of effecting change in Mexico's energy matrix towards a sustainable development path that includes a lower carbon intensity.

Keywords: greenhouse gas emissions; environmental impact; GDP; renewable energies; consumption; ARDL model; cointegration equation.

1. INTRODUCTION

The intensive use of energy obtained by burning fossil fuels -such as oil, coal, and gas- has been one of the main inputs for economic growth across several decades, in both developed and developing countries. However, the negative externality associated with the consumption of these fuels is greenhouse gas (GHG) emissions (International Energy Agency [IEA], 2018). Scientific evidence demonstrates that there is a positive association between increased emissions of various GHGs and an increase in the average global temperature. Estimates suggest that the global average combined surface and ocean temperature showed an increase in the range of 0.8 to 1.2°C during the period 1880-2012, when compared to the pre-industrial era (Intergovernmental Panel on Climate Change [IPCC], 2018). This increase in temperature effects serious changes in the global climate, such as modifications in precipitation patterns, changes in the intensity or frequency of extreme weather events, reduction of the cryosphere, and rising sea levels (IPCC, 2018).

Stabilizing the planet's average temperature involves reducing global carbon dioxide equivalent (CO2e) emissions levels. Some of the policies suggested to mitigate climate change mitigation policies include: improving energy efficiency and streamlining energy use; implementing CO2 capture processes; and, one of the central policy recommendations, replacing fossil energy sources with renewable energies without affecting economic growth (Cai *et al*., 2018; Amri, 2017). Indeed, climate change is a global problem, as it requires a general consensus on the future trajectories of GHG emissions. However, it also implies an externality for the global economy, since the main source of GHG emissions is associated with the consumption of fossil fuels, which represent the main input in the production of goods and services through energy consumption.

While it must be acknowledged that the trajectory of GHG emissions over time is a function of a complex relationship between various factors, these emissions are clearly related to certain specific variables, such as the evolution and composition of output (Stern *et al*., 1996; Dinda, 2004), the extent of financial development and trade openness (Dogan and Turkekul, 2016), foreign direct investment (Pao and Tsai, 2011), and the level of urbanization (Raggad, 2018). However, energy consumption is undoubtedly a significant variable in this picture (Muhammad, 2019; Cai *et al*., 2018), in particular when understood in relation to the hypothesis that clean energy consumption should reduce emission levels in the long term.

Empirical research yields mixed results regarding the long-term relationship between emissions and renewable energies. For example, Appiah *et al*. (2019), Bekhet and Othman (2018), Cherni and Essaber Jouini (2017), and Dogan and Ozturk (2017) find that renewable energies have a negative elasticity with respect to CO2 emissions. In contrast, Amri (2017), Ben Jebli and Ben Youssef (2017), and Bulut (2017) estimated a positive elasticity, suggesting that the consumption of clean energies does not contribute to the reduction of CO2 emissions in the long term.

In light of the above, when seeking to understand the Mexican case, the long-term relationship between GHG emissions and the consumption of clean or renewable energies needs to be estimated, as well as their potential impact on emissions reduction. However, the research differentiates prospective scenarios of potential reduction of CO2 and other GHG emissions, according to various criteria, such as; using different types of renewable energies (Alemán-Nava *et al*., 2014); considering policies in the energy sector in relation to governments' financial limitations (Bauer and Quintanilla, 2000), and; cost optimization models that evaluate alternatives between carbon pricing and the application of a carbon tax with an emissions trading scheme (Barragán-Beaud *et al*., 2018). These are partial equilibrium models that assess different sectors from a bottom-up perspective, one requiring the calibration of certain parameters.

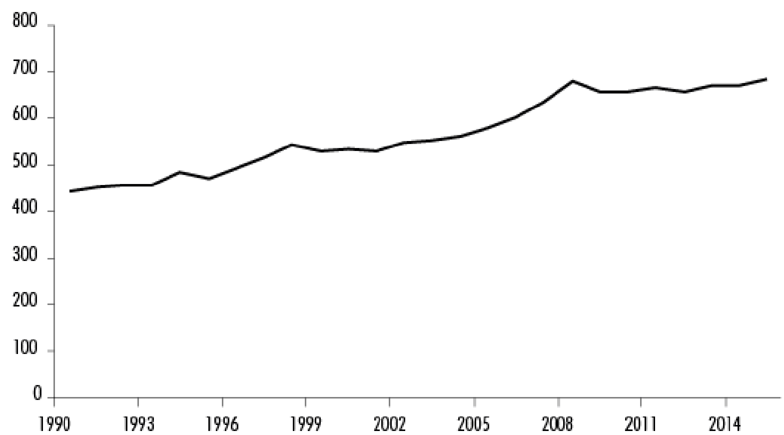
This article sets out to estimate a cointegration relationship between GHG emissions, the level of Gross Domestic Product (GDP), and the consumption of renewable and fossil fuel energies, in order to quantify the long-term impact and verify whether these can contribute to reducing GHG emissions. If so, this would suggest that developing clean energies could have environmental, economic, and competitiveness co-benefits in the Mexican economy. The long-term elasticities estimated by the cointegration equation could be used as a simpler policy instrument to establish short- and long-term goals.

The long-term relationship is estimated using the Autoregressive Distributed Lag (ARDL) method, developed by Pesaran *et al*. (2001). This model has certain advantages over others, as it can be applied to small samples, and also allows the use of both I(0) and I(1) integration order variables. This article is divided into five sections, including this introduction. The second section analyzes the GHG emissions trajectory in Mexico; the third section describes the equation to be estimated, as well as the methodology to do so; the fourth section presents the empirical evidence, with some conclusions offered in the final section.

2. CARBON DIOXIDE EQUIVALENT EMISSIONS, GDP AND ENERGY CONSUMPTION IN MEXICO

In 1992, Mexico signed the United Nations Framework Convention on Climate Change (UNFCCC), thereby committing to comply with the guidelines established in the instrument. One such guideline is to develop and update a national GHG inventory, based on the methodology put forth by the Intergovernmental Panel on Climate Change (Instituto Nacional de Ecología y Cambio Climático [INECC], 2018). For this purpose, historical data is available on the evolution of anthropogenic GHG emissions by their different sources for the period 1990-2015, expressed in metric tons of CO2e.[1] Figure 1 shows the trajectory of total emissions (without factoring in absorption), measured in tons of CO2e. This trajectory maintained an upward trend during the period 1990-2015, going from a level of 444.7 million tons of CO2e in 1990 to 683 million in 2015, i.e., an increase of 53.6% with an average annual growth rate of 1.7%.

Figure 1. Evolution of total CO2e emissions in Mexico

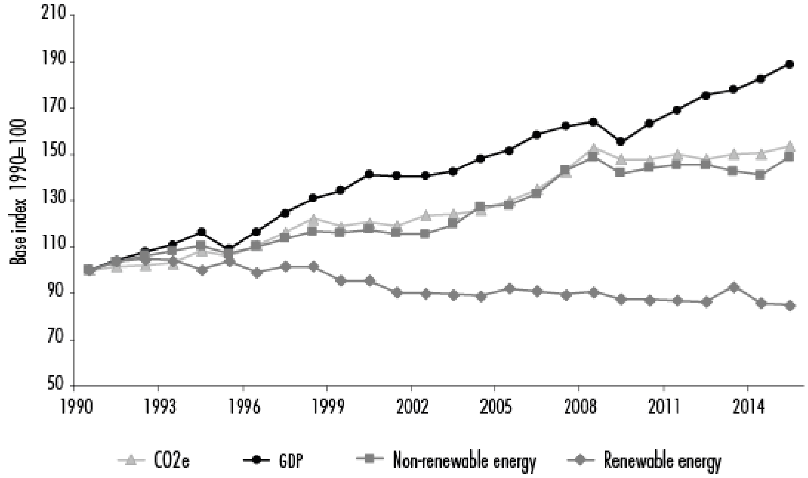


Source: based on data from the National Inventory of Greenhouse Gas and Compound Emissions (INECC, 2018).

As of 2008, there is a change in the series' trend with emissions levels stabilizing, reporting an annual growth of 0.6%. This indicates a possible phase of decarbonization in the Mexican economy. On the other hand, the burning of fossil fuels plays an important role in the evolution of GHGs - in 2015 they contributed 64% of total emissions. In fact, a widely used indicator for international comparisons is to assess per capita emissions derived from fuel consumption, which in 2015 stood at 3.7 tons of CO2 per inhabitant.

Theoretically, the trajectory of CO2e emissions is associated with the evolution of the economy's output level, as well as energy consumption (Dogan and Seker, 2016, Tol *et al*., 2009). Figure 2 presents the trajectory of the variables' total CO2e emissions, GDP,[2] renewable and non-renewable energy consumption,[3] with values expressed in a base index 1990=100, in order to observe values on a common scale in response to each variable's distinct unit of measurement.

Figure 2. Trend of CO2 emissions, GDP, renewable and non-renewable energy



Source: based on data from the National Inventory of Greenhouse Gas and Compound Emissions, INECC, SENER, and INEGI.

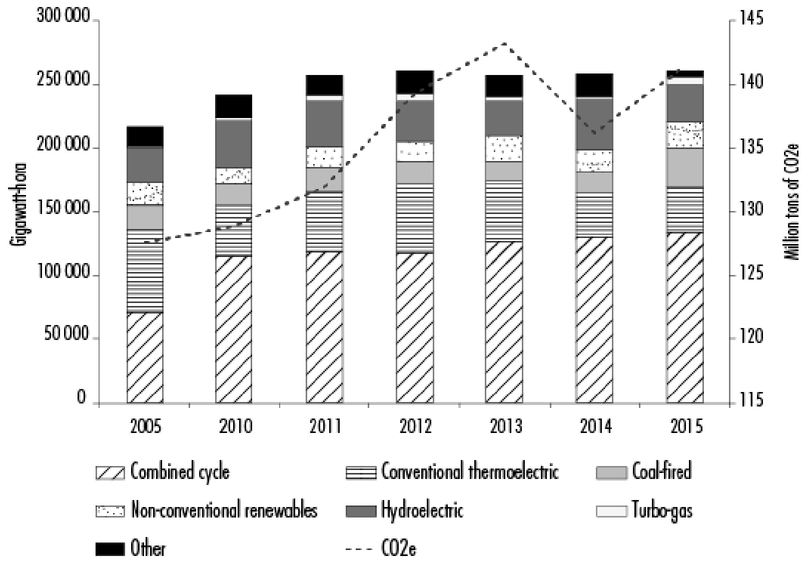
It can be observed that between 1990 and 2008, total CO2e emissions had an upward trend very similar to GDP and non-renewable energy consumption, thus confirming the strong association between economic activity, fossil fuel consumption, and emissions. Furthermore, between 1990 and 2008, CO2e grew at a rate of 2.4% per year, similar to the rate of economic growth (2.8%), while non-renewable energy consumption increased by 2.2% annually. During this period, the evolution of energy consumption from fossil fuel sources followed an upward trajectory with a certain lag with respect to changes in the trajectory of output. In contrast, the consumption of renewable energies showed a slight downward trend, with an average annual growth rate of -0.6% for the entire study period; in other words, the use of this kind of energy decreased.

Indeed, the renewable energies' share of final energy consumption decreased from 11% in 1990 to 6% in 2015. However, during the 1990s, reforms were carried out in the energy sector with the aim of promoting private investment in developing renewable energies, mainly in electricity generation (Lokey, 2009). However, the state-owned company *Comisión Federal de Electricidad* (CFE) has remained the main producer and distributor of electricity, and various barriers to entry have been imposed on new companies, such as costly transmission tariffs and company size restrictions (Lokey, 2009). Similarly, the most recent reforms have not improved the entry and development prospects of new energy production companies (Ibarra-Yunez, 2015).

After the 2008 international crisis, there was an important change in the trends of the three variables. Between 2009 and 2015, GDP growth averaged 3.3% annually, while non-renewable energy consumption and CO2e reported growth of 0.8% and 0.6%, respectively. This result could indicate that, after the 2008 crisis, there has been a degree of decoupling between the level of output and emissions, yet without decoupling the evolution of non-renewable energy from the trajectory of GHG emissions, as energy generation is still largely based on burning fuels.

Regarding the electricity sector, the last 15 years have seen a shift in the technologies used in energy production. For example, in 2004, 39.6% of the supply came from conventional thermoelectric power plants whose main fuel was fuel oil; combined cycle technology (which uses natural gas) contributed 22%; non-conventional renewable energies (solar, wind, geothermal, and nuclear) 7.6%; while coalfired power accounted for 8%. In 2015, the main technology used was combined cycle, accounting for 51.5%, with a decrease in conventional thermoelectric plants to 13.7%. Non-conventional renewable sources have remained unchanged, while coal-fired plants recorded a slight increase in their share to 11.5% (see Figure 3). This increase in natural gas consumption has allowed for the stabilization of GHG emissions derived from electricity generation, especially since 2013, with an annual average of 140 million tons (see Figure 3); however, an increase in energy demand could generate a rebound in emissions, as 79% of electric energy is obtained via burning fossil fuels.[4]

Figure 3. Gross electricity generation by technology and associated emissions in CO2e



Source: based on the National Inventory of Greenhouse Gas and Compound Emissions (INECC) and the Energy Information System (SENER, http://sie.energia.gob.mx/)

Meanwhile, transportation activities (air, land, and maritime), which mainly consume gasoline and diesel, registered an annual growth rate of 2.45% during 1990-2015, emitting 171.3 million tons of CO2e in 2015 alone, representing 24.5% of total emissions (INECC, 2018). The energy and transport industries clearly account for huge amounts of GHG emissions. The variables' trajectories indicate a high correlation between the trend of non-renewable energy consumption and emissions, while renewable energies show a slight decrease. Thus, the energy sector has a crucial role to play in the design of mitigation policies that should significantly alter the transportation and electricity sectors.

3. MODEL SPECIFICATION AND ECONOMETRIC METHODOLOGY

GHG emissions and their relationship with their various sources are the result of a complex dynamic system, with significant lags and adjustment costs, a system that is also subject to different types of random shocks. However, climate change models associate emissions with economic factors such as the evolution and composition of GDP, population growth, available technology and its forms of innovation, and even social and cultural elements (Appiah *et al*., 2019; Muhammad, 2019; Cai *et al*., 2018). The specification of the long-term equation to be estimated works from the assumption that CO2e emissions are a function of economic activity (Dogan and Seker, 2016), approximated by Gross Domestic Product (GDP_t), of fossil-based energy (ENG_t) (Cai *et al*., 2018). One strand in recent empirical research incorporates into the estimation the impact of renewable or clean energy consumption ($ENGR_t$), which is expected to stabilize or reduce emissions levels (Appiah *et al*., 2019; Raggad, 2018; Dogan and Aslan, 2017; Katircioglu, 2014). The long-term relationship is defined as a double logarithmic linear equation for the purpose of estimating response elasticities[5] (Dogan and Ozturk, 2017; Ben Jebli and Ben Youssef, 2017):

$$lnCO2_t = \beta_0 + \beta_1 lnGDP_t + \beta_2 lnENG_t + \beta_3 lnENGR_t + u_t \qquad (1)$$

Where the elasticities of CO2e emissions with respect to GDP $(\beta_1 > 0)$ and with respect to fossil energy consumption $(\beta_2 > 0)$ are expected to report a positive sign, renewable energy consumption is expected to report a positive sign, while the elasticity of renewable energy consumption is expected to be negative $(\beta_3 < 0)$, consistent with the hypothesis that higher consumption of this type of energy will reduce the level of emissions in the long term. Finally, *ut* represents the stochastic error term.

The empirical test of equation (2) is performed following the econometric methodology of cointegration (Engle and Granger, 1987). The ARDL method employed here, developed by Pesaran *et al*. (2001), has several advantages over others, such as the fact that the estimators are consistent when all variables are I(1) or of order I(0), even from a combination of both orders of integration; binary structural change variables can also be included, and the critical values of the cointegration F-statistic are not affected. Furthermore, it can be applied in small samples using ordinary least squares (Pesaran *et al*., 2001).

The ARDL procedure is based on Engle and Granger's (1987) representation theorem, which posits that if cointegration exists, it is possible to specify a model in its error correction form (ECM) using a dynamic specification of the variables in first differences and the lagged errors of the cointegrating equation. Pesaran *et al*. (2001) propose specifying an ECM model that leaves free the estimation of the cointegrating vector parameters, including the variables of the equation in levels with a lag. Within the framework of equation (1), the ARDL model can be specified as:

(2)

$$\Delta lnCO2_t = \sum_{k=1}^{n_1} \phi_k \Delta lnCO2_{t-k} + \sum_{k=0}^{n_2} \varphi_k \Delta lnGDP_{t-k} + \sum_{k=0}^{n_3} \gamma_k \Delta lnENG_{t-k} + \sum_{k=0}^{n_4} \theta_k \Delta lnENGR_{t-k} + \delta_1 lnCO2_{t-1} + \delta_2 lnGDP_{t-1} + \delta_3 lnENG_{t-1} + \delta_4 lnENGR_{t-1} + \alpha_0 + \varepsilon_t$$

Equation (2) represents an unrestricted error correction model that combines the short-term dynamics with the equilibrium relationship between the variables, without losing long-term data. Where Δ is the operator difference; $t-i$ is the number of lags associated with each variable and *et* is the error term. The coefficients δ_i associated with the variables in levels with one lag represent the long-term multipliers, which allow us to estimate the cointegration equation by normalizing with respect to δ_1, that is, the coefficient of the emission level. Understood in this way, the cointegration test consists of verifying the joint significance of the long-run multipliers by means of an F-test, i.e., the coefficient of the level of emissions:

$$H_0: \delta_1 = \delta_2 = \delta_3 = \delta_4 = 0$$

$$H_1: \delta_1 \neq \delta_2 \neq \delta_3 \neq \delta_4 \neq 0$$

The null hypothesis of no cointegration (H_0) assumes that the coefficients are not statistically significant and, therefore, do not yield data which explains the short-term dynamics of the exchange rate. Meanwhile the alternative hypothesis (H_1) indicates that the coefficients are different from 0 and there is an equilibrium relationship between the variables in the model. The test statistic is based on the F distribution, defining a lower limit based on the assumption that the regressors are I(0), that is, they are stationary in level, while the upper limit assumes that all variables are I(1), i.e., stationary in first difference.

If the F statistic is higher than the upper critical value, the null hypothesis can be rejected, indicating that cointegration exists, independently of the series integration. On the other hand, if the F statistic is lower than the lower critical value, the null hypothesis of no cointegration cannot be rejected. Finally, if the calculated F-statistic is between the two upper and lower bound values, the result is inconclusive and undetermined. The ADRL cointegration procedure has certain advantages over other methods: the estimators of the long-term coefficients converge faster than the estimators of the short-term parameters, and they are asymptotically normally distributed so that statistical inference is valid; additionally, it can be applied to small samples.

4. EMPIRICAL EVIDENCE

The database used[6] is annual data for the period 1990-2015. Total emissions are obtained from emission inventories and are measured in metric tons of CO2e; income level is measured by GDP in millions of pesos at 2013 prices; fossil energy consumption (ENG_t) corresponds to final energy consumption whose source is petroleum fuels; and final renewable energy consumption ($ENGR_t$), which consists of hydro, geothermal, wind, solar, and biomass energy. Table 1 presents the results of the Augmented Dickey-Fuller[7] (ADF) (Dickey and Fuller, 1981) and KPSS (Kwiatkowski *et al*., 1992) unit root tests. The ADF test uses the null hypothesis as the series has a unit root, while the KPSS test uses the null hypothesis as, here, the series is stationary.

Table 1. Unit root tests

Variable	ADF		KPSS	
	Constant	Constant and trend	Constant	Constant and trend
$lnCO2_t$	-0.875(0)	-2.148(0)	0.735(3)*	0.073(0)
$\Delta lnCO2_t$	-5.105(0)*	-5.041(0)*	0.077(0)	0.061(1)
$lnGDP_t$	-0.978(0)	-2.724(0)	0.753(3)*	0.159(2)*
$\Delta lnGDP_t$	-5.406(0)*	-4.699(4)*	0.157(4)	0.138(5)
$lnENG_t$	-0.939(0)	-3.375(4)	0.728(3)*	0.076(3)
$\Delta lnENG_t$	-4.113(0)*	-3.953(0)*	0.088(3)	0.075(3)
$lnENGR_t$	-0.717(1)	-3.447(0)	0.681(3)*	0.121(2)
$\Delta lnENGR_t$	-7.493(0)*	-7.304(0)*	0.096(3)	0.089(3)

Note: * indicates rejection of the null hypothesis at 5% significance. The number of lags is between parentheses. Critical values at 5% ADF (T=100), -2.89 including constant and -3.45 constant and trend (Maddala and Kim, 1998, p. 64). Critical values at 5% for KPSS for the model including exclusively the constant is 0.463 for the constant model and 0.146 for the trend model (Kwiatkowski et al., 1992, p. 166).

Source: compiled by the author.

The CO2 emissions series can be considered as a non-stationary series of integration order I(1), and the deterministic components are not relevant when seeking to characterize the series' stochastic process. GDP can also be characterized as a series of order I(1). The ADF test concludes that both the variables which measure energy consumption, from fossil and renewable sources respectively, are both series of order I(1). However, the KPSS test reports that both variables could be stationary around a trend and a constant. It can be concluded, therefore, that the variables are non-stationary series, and so a cointegration method must be applied must be employed to identify the long-term relationship Engle and Granger, 1987).

Applying the ordinary least squares method, the ARDL model (Pesaran and Shin, 1999; Pesaran *et al*., 2001) was estimated based on the specification of equation (3), including the variables in first differences and the variables in levels with a lag. At first, equations with a maximum of three lags were specified, with the final estimation selected based on the Akaike Information Criterion (AIC), which is considered an efficient estimator for small samples (see Table 2). With the exception of renewable energies, the remaining variables specified in levels with one lag are statistically significant. In order to test for the presence of a cointegration relationship between the variables, an F-test was applied on the coefficients associated with the variables in levels with one lag. Table 3 presents the F statistic, as well as the critical values for both the lower bound (I(0) series) and the upper bound (I(1) series).

Table 2. ADRL (2,3,3,2) model estimate for CO2 emissions

Variable	*Coefficient*	*Error Std.*	*t-student*
$\Delta lnCO2_{t-1}$	2.523	0.764	3.303*
$\Delta lnCO2_{t-2}$	1.602	0.596	2.688*
$\Delta lnGDP_t$	1.829	0.425	4.300*
$\Delta lnGDP_{t-1}$	-0.812	0.334	-2.431
$\Delta lnGDP_{t-2}$	-0.200	0.203	-0.988
$\Delta lnGDP_{t-3}$	-0.470	0.204	-2.304
$\Delta lnENG_t$	-1.221	0.551	-2.218
$\Delta lnENG_{t-1}$	-0.696	0.476	-1.462
$\Delta lnENG_{t-2}$	-1.543	0.595	-2.594*
$\Delta lnENG_{t-3}$	0.517	0.317	1.631
$\Delta lnENGR_t$	-0.042	0.227	-0.185
$\Delta lnENGR_{t-1}$	-0.631	0.191	-3.301*
$\Delta lnENGR_{t-2}$	-0.568	0.162	-3.518*
$lnCO2_{t-1}$	-3.050	0.797	-3.825*
$lnGDP_{t-1}$	1.291	0.303	4.257*
$lnENG_{t-1}$	1.716	0.488	3.516*
$lnENGR_{t-1}$	-0.065	0.452	-0.144
C	-11.656	7.004	-1.664
AIC = -6.02958	R^2 = 0.966		
SIC = -5.13691	$\underline{R}^2$ = 0.821		
F = 6.657 (0.039)	DW = 2.856		

Note: * rejection of the null hypothesis at 5% significance. AIC = Akaike Information Criterion
SIC = Schwarz Criterion. R^2 = R-squared. R^2 = adjusted R-squared.
DW = Durbin-Watson statistic.
Source: Compiled by the author.

Table 3. Co-integration analysis ADRL procedure

Statistic	*Level of Significance*	*I(0)*	*I(1)*
F = 6.4336**	1%	4.614	5.966
k=3	5%	3.272	4.306
T = 30	10%	2.676	3.585

Notes: *; ** rejection of the null hypothesis at 1 and 5% significance level, respectively. Narayan critical values (2004, pp. 26 and 27).
Source: compiled by the author.

The long-term elasticities can be obtained, as expressed in the following equation, by normalizing the cointegration vector with respect to $lnCO2_t$:

$$lnCO2_t = -3.822 + 0.423 lnGDP_t + 0.563 lnENG_t - 0.021 lnENGR_t \quad (3)$$

The coefficients in equation (3) can be interpreted as long-term elasticities, given that the variables form a natural logarithm. Thus, CO2e emissions increase with the level of output and the consumption of fossil fuel-based energy. For example, a 3% increase in economic activity causes emissions to increase by 1.27%, while a 3% increase in fossil fuel energy consumption would cause total emissions to increase by 1.69%, assuming other factors remain constant. Although the elasticities have a positive sign, they are inelastic (less than unitary), i.e., the emission variable's response to these two variables is less than proportional. Nevertheless, there is a strong relationship between the emissions, output, and energy variables, which should be taken into account when designing energy and mitigation policies.

Galindo and Sanchez (2005) based their research on data pertaining to the Mexican economy,[8] and found evidence of a bidirectional causal relationship between energy and output, indicating that both variables form a complementary process, i.e., the expansion of GDP is accompanied by an increase in energy demand. This relationship is explained by the fact that energy consumption is a demand function with high income elasticity and low price elasticity (Caballero and Galindo, 2007; Galindo, 2005). The elasticity of renewable energy consumption reports a negative sign, so emissions decrease when this type of energy consumption increases. However, it is crucial to note that the magnitude of the elasticity is very low (-0.021). A 3% increase in renewable energy consumption would imply a decrease of only 0.063% in the level of total emissions, which can be considered a marginal effect.

This result is consistent with other international research that reports a negative elasticity in renewable energies. One example is Appiah *et al.* (2019), who used annual data from 1971 to 2013 for the BRICS group of countries to perform a panel data estimation, with findings showing an elasticity of -0.158 between emissions and non-renewable energies. Bekhet and Othman (2018), applying the ARDL procedure with data from Malaysia for the period 1971-2015, calculated the value of long-term elasticity as -0.38. The ARDL method was also applied in the article by Cherni and Essaber Jouini (2017), with data for Tunisia and an elasticity of -0.427. In the case of the U.S. economy, Dogan and Ozturk (2017) used annual data from 1980 to 2014 to estimate a negative elasticity for renewable energy consumption of -0.09. Finally, Rasoulinezhad and Saboori (2018), who used annual information for the set of countries of the Commonwealth of Independent States[9] and applied cointegration techniques for panel data, estimated a negative elasticity, but one very close to 0.

Based on the results of the cointegration equation, and following Engle and Granger's representation theorem (1987), the next stage of the methodology consisted of specifying an error correction model to model the short-term dynamics of the variations of total CO2e emissions, including the variables in first difference and the deviations of the cointegration equation. Table 4 presents the estimation results, which indicate that the variation in CO2e emissions responds to an autoregressive pattern, as they depend on the variation of emissions from a previous period. There, GDP growth rate has a significant positive impact,[10] confirming that economic activity influences variations in emissions. The growth rate of renewable energy consumption from a previous period reports a negative sign; however, this is only significant at 10%. There is only weak evidence regarding the short-term impact of renewables and CO2e emissions, i.e., it does not have a relevant contribution to change the trajectory of total GHG emissions.

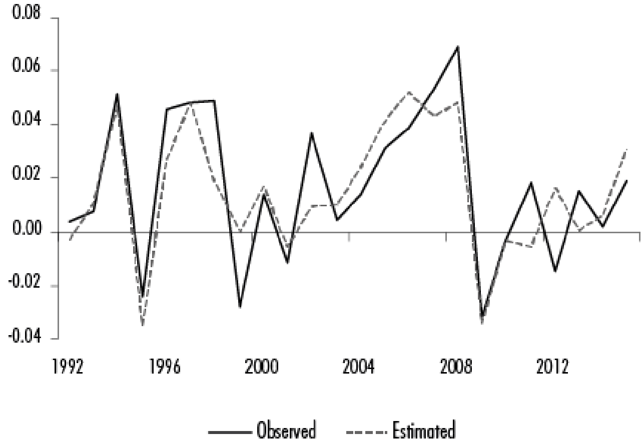
Table 4. Error correction model estimation for $\Delta lnCO2_t$

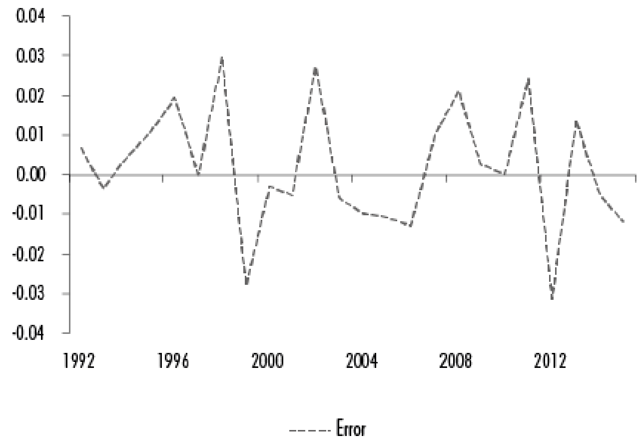
Variable	*Coefficient*	*Error Std.*	*t-student*
$\Delta lnCO2_{t-1}$	0.699	0.186	3.766*
$\Delta lnGDP_t$	0.843	0.117	7.211*
$\Delta lnGDP_{t-1}$	-0.323	0.147	-2.191*
$\Delta lnENG_{t-1}$	-0.196	0.110	-1.775
ECM_{t-1}	-0.878	0.193	-4.547*
R^2-*ajustada* = 0.603		Autocorrelation LM(2): $F(2,17)$=2.108(0.152)	
RSS = 0.006		Heteros ARCH(4): $F(2,19)$=1.583(0.231)	
SIC = -5.0597		Normality JB: χ^2 (2)=0.202(0.903)	
AIC = -4.8143		Linearity: RESET(1): $F(1,18)$=0.837(0.372)	
DW = 2.505			

Note: * rejection of the null hypothesis at 5% significance. RSS = sum of squared errors. SIC = Schwarz Information Criterion. AIC = Akaike's Information Criterion. DW = Durbin-Watson statistic.
Source: Compiled by the author.

On the other hand, the errors from the final model do not report problems of normality, heteroscedasticity, and autocorrelation. In other words, there is no systematic information that can be incorporated into the model. Additionally, the short-term equation shows a good fit. This can be seen in Figure 4, which shows the observed and estimated values of CO2e emission variations. The estimation results show that, in the long term, emissions respond to the trend in the level of output and the consumption of non-renewable energies, while in the short term they follow an autoregressive process with GDP growth rate as the most important variable. The consumption of clean energies is not significant in the long term; although this variable shows a negative sign in elasticity, its impact is marginal, while in the short term, variations report a negative coefficient, but one that is not statistically significant.

Figure 4. Observed and estimated values of CO2 variation





Source: compiled by the author using data from INECC (2018).

This result can be attributed to the energy policy in place in Mexico since the mid-1970s. Mexico's energy policy has been informed by an awareness that the country possessed enormous reserves of crude oil and gas, a situation that was reinforced by a policy of restricting the share of both domestic and foreign private investment in the energy sector. This approach discouraged and limited the development of renewable energy sources. In fact, more than two-thirds of Mexico's electricity is currently obtained through thermal power plants that burn gas or petroleum derivatives; in other words, electricity production in Mexico is highly dependent on fossil fuels (Bauer and Quintanilla, 2000). The reforms implemented in the energy sector since the 1990s have not translated into a growth in the supply of renewable energies; on the contrary, the use of renewable energies has slightly decreased.

The 2013 energy reform was aimed at increasing the supply of various fuels at competitive prices. This was to be achieved via the development of the oil and natural gas exploration and extraction industry, with the participation of private initiative in different phases of the hydrocarbon value chain, by means of contracts and prohibiting granting concessions. However, natural gas production contracted by 5.6% annually between 2014 and 2019, from 6 531 million cubic feet per day in 2014 to 4 894 million cubic feet per day in 2019. Oil production also fell from 2.4 million barrels per day in 2014 to 1.7 million in 2019.

Renewables are concentrated in electric power generation[11] and report modest annual growth, averaging 1.9% between 2014 and 2017. In the case of non-conventional renewable energies (geothermal, nuclear, wind, and photovoltaic), their relative weight as an energy source has remained constant, standing at 7.3% as of 2017. Meanwhile, the energy generated by hydroelectric plants accounts for 11.7% (see Table 5). Almost 20% of electricity is generated by clean sources, the remaining 80% being obtained from fuel oil, coal, and natural gas. Therefore, it is clear that the energy reform has not generated a significant change in the energy matrix.

Table 5. Electric power generation. Percentage structure by type of technology

Type of technology	*2013*	*2014*	*2015*	*2016*	*2017*
Combined cycle	49.2	50.6	51.5	51.8	49.9
Fuel oil	18.3	13.0	13.7	14.0	16.2
Coal	6.2	6.8	11.5	13.0	11.9
Renewable	7.6	6.9	7.8	7.2	7.3
Hydroelectric	10.6	14.8	11.5	11.1	11.7
Turbogas	1.5	1.1	2.0	2.2	2.3
Other	6.6	6.8	2.0	0.7	0.7
Sum	100.0	100.0	100.0	100.0	100.0

Notes: * renewables refers to geothermal, nuclear, wind, and photovoltaic.
Source: Energy Information System (SENER, http://sie.energia.gob.mx).

The new administration has not proposed a clear strategy on the role of renewable energies; on the contrary, tenders for the acquisition of clean energies have been canceled. The main objective of the new energy policy is achieving and maintaining energy self-sufficiency to meet national demand, both in the hydrocarbon and electricity value chains. Given the structure of the energy matrix, actions will focus on increasing investment in oil and gas exploitation and extraction activities, rehabilitation and reconfiguration of six refineries system, the construction of a new refinery at a cost of 8 billion dollars, and, finally, increasing electricity generation through the modernization of hydroelectric plants.

There is no renewable energy investment program; it has merely been stated that investment criteria will be sought based on demand, costs, and environmental impacts. Likewise, energy efficiency will be promoted across various sectors. What has been observed so far is that the priority will be to increase the supply of fossil fuels through the operation and management of state companies: PEMEX[12] and CFE. Within this configuration, renewable energies will continue to play a marginal role in the reduction of GHG emission levels, as energy production will continue to depend on the burning of fossil fuels.

5. CONCLUSIONS

The empirical evidence presented here shows that there is an equilibrium relationship between total GHG emissions, GDP, and non-renewable energy consumption. These two variables continue to be relevant in explaining the evolution of emissions in the long term; they report positive elasticities, but less than unitary, with non-renewable energy having a greater impact (0.563). The contribution of clean energy consumption to the trajectory of emissions can be considered marginal, both in the long term and in the short term. In fact, as the long-term elasticity is only -0.021, its impact on the decrease in the level of GHG emissions is practically null.

Here, it should be pointed out that Mexico is committed to meeting the mitigation goals established in the Law for the Use of Renewable Energies and the Financing of the Energy Transition (LAERFTE), which states that, by 2024, the electricity sector must be transformed so that a maximum of 65% of electricity comes from fossil fuels. This goal is ratified in the General Law on Climate Change, which stipulates that 35% of electricity generation should come from clean energies by 2024. Achieving these goals is not feasible under the current conditions of the energy matrix, especially considering that the share of renewable energies in the supply of electricity has remained constant at 20% since 2013. In other words, in order to achieve the climate change goals, it would be necessary to double the energy supply from clean sources, from 51,292 GWh to 111,000 GWh.

The country's energy policy has historically favored energy production based on burning fossil fuels. Until 2001, 52% of the total gross energy supply was generated using crude oil, with renewable energies accounting for 8.7% in the same year; the previous administration's energy reform generated a change in favor of natural gas, which, as of 2018, is the main energy source and accounts for 47% of the country's energy. Clean energies, however, have not increased their share; on the contrary, they now only contribute 7.3% of the energy supply. The current administration aims to promote the production of fossil fuels, relying mainly on PEMEX and CFE, while state investment plans do not prioritize renewable energies; the aim is to support projects related to the reactivation of CFE's power plants, and to promote the development and use of technologies based on clean energies in different sectors of the country.

Greater consumption of non-renewable energy, therefore, leads to an increase in emissions, especially in sectors such as electricity generation, transportation, industry, and agriculture. This reality represents a major constraint to the medium-term objective of generating a change in the country's energy matrix towards a sustainable development path that includes a lower carbon intensity. On the other hand, the shift towards renewable energies would reduce the impact of fuel price volatility on domestic prices.

It is important to develop strategies that transform energy demand in favor of renewable energies, for example, by means of pricing policies, regulations associated with greater efficiency, promotion of private sector participation, and incentives for technological innovation. This should be done within a general framework that establishes targets for decarbonization by sector and leaves free those sectors that obtain these results at the lowest possible cost; it should also contribute to accelerating the dissemination of technical progress and setting appropriate prices.

APPENDIX: VARIABLES USED

- CO2e = Carbon dioxide equivalent emissions of greenhouse gases. Source: https://www.gob.mx/inecc/acciones-y-programas/inventa national-government-gas-emissions-and-greenhouse-gas-compounds-emissions-register.
- CNE = Total final energy consumption of petroleum products measured in peta-joules. Source: Secretaría de Energía Balance Nacional de Energía. http:// sie.energia.gob.mx/bdiController.do?action=temas&fromCuadros=true.
- CNER = Final consumption of renewable energy measured in petajoules. Source: Ministry of Energy National Energy Balance Sheet.
- GDP = Gross Domestic Product in millions of pesos at 2013 prices. Source: INEGI.

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[1] When the sun's energy penetrates the atmosphere, this energy must be released back into space, as if it were stored, the planet would overheat. The radiation received is returned as terrestrial radiation producing the so-called heat balance. GHGs mix with the atmosphere and heat the surface by retaining energy and reducing the rate at which the energy escapes into space. Measurements of these gases are made by converting the emission of each GHG into units of CO2e using the global warming potential of each gas. This potential is defined as the factor describing the impact of the radiative forcing (the ability to retain energy) of one unit of a given gas relative to one unit of carbon dioxide.

[2] GDP measured in millions of pesos (MXN) at 2013 prices.

[3] Energy is measured in petajoules and factors in the total final energy consumption. Non-renewable energies include: Liquefied Petroleum Gas (LPG), gasoline and naphtha, kerosene, diesel, and fuel oil. Renewable energies: hydroelectric, wind, geothermal, photovoltaic, bagasse, firewood, and biogas.

[4] The natural gas used in combined cycle thermoelectric plants generates minimal amounts of sulfur, mercury, and other particles, which is why it is classified as the fossil fuel with the lowest environmental impact, when compared with fuel oil and coal. However, it has been proven that some pollutants can be released during the extraction phase, such as methane, which has a greater greenhouse gas potency than CO2.

[5] The concept of response elasticity is used in economics to measure or evaluate the response of the dependent variable, in this case GHG emissions, to a change in one of the explanatory variables. That is, the percentage change in emissions in response to a 1% percentage change in, for example, GDP or energy consumption.

[6] The description of the variables and their statistical source can be found in the Appendix. The estimation period corresponds to the available information on total GHG emissions.

[7] The number of lags in the ADF test was determined according to the statistical significance of the last lag (t-sig). In the case of the KPSS test, the Newey-West function is used and the lag selection is by means of the Bartlett function.

[8] They use annual data from 1965 to 2001, employing a VAR methodology and the Johansen cointegration procedure, and apply non-causality tests in the Granger sense.

[9] The following countries are considered: Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyzstan, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, and Uzbekistan.

[10] The short-term impact of GDP is obtained by adding together all of this variable's coefficients in the error correction model.

[11] Electricity accounts for 18.9% of final energy consumption.

[12] State-owned companies: Petróleos Mexicanos and Comisión Federal de Electricida, the latter a state-owned company operating in the electricity sector.