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The relation of GDP per capita with energy and CO_2 emissions in Colombia

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Abstract

We analyze the relation of CO_2 emissions per capita and primary energy per capita with GDP per capita and other relevant variables, for the period 1971–2011. Two dynamic econometric partial adjustment models are estimated using data from the International Energy Agency. The results suggest a relation that is compatible with the hypothesis of the environmental Kuznets curve, and whose turning points are within the range of the sample, reflecting a change in the relations between both indicators and GDP per capita. Several factors explain this change, the policies applied during the period being crucial. We compute the trajectory of the elasticities of these environmental pressures with respect to GDP, which decline significantly over time. We develop a new method, better fitted for asymmetric distributions, to compute the confidence intervals of these elasticities. Some determinants of the reduction of these environmental pressures are the change in the composition of primary energy sources, which entailed both primary energy savings and a reduction in CO_2 emissions, as well as the favorable impact of the regulations imposed by the government aimed at controlling CO_2 emissions from the transport and industrial sectors. The results provide important insights for the design of environmental and energy policies in developing countries to allow economic and social improvement without further growth in energy use and emissions.

Keywords: CO_2 emissions; environmental Kuznets curve; partial adjustment model; primary energy.

1. Introduction

The share of developing countries and emerging economies on total emissions has steadily increased in last decades. Moreover, even though some developed countries have managed to limit emissions growth, the increase experienced in developing countries has led to a constant increase in global greenhouse gas emissions. Consequently, the analysis of the determinants of emissions in developing countries and of the energy and environmental policies that may lead to curb fossil fuel consumption and emissions growth in these countries is crucial in the challenge of mitigating global greenhouse gas emissions. Of special interest is to study how these countries could decouple their economic development and social welfare from the consumption of fossil fuels and associated emissions. In this paper, we study whether this was the case for Colombia and which were the determinants and/or policies allowing this, which could then provide important insights on the measures allowing a more sustainable growth in developing countries.

The Colombian economy was much affected by a strong energy crisis during 1992–1993, caused by the El Niño phenomenon. This led the government to develop an Energy Emergency Plan and periodically formulate energy supply and diversification strategies, using alternatives compatible with a more sustainable development, such as natural gas, hydroelectric power plants and biofuels (Law 693 of 2001 and Law 939 of 2004). Together with this situation, at the end of 1992 the new Public and Electric Utilities laws of the Political Constitution of 1991 were introduced (UPME, 2007). This impulse to the development of the energy sector continues at present. The Development Plan 2015–2018 has among its purposes to move towards low-carbon sustainable growth, through the use of clean and unconventional sources of energy, within the framework of green growth (DNP, 2015).

The trajectory of the use of primary energy in Colombia between 1971 and 2011 shows a significant decrease after 1996. During this period the generation of electricity from natural gas and hydroelectric plants increased, with growth rates of 5.1% and 4.9%, respectively, and the use of petroleum products for the generation of electricity decreased, with a growth rate of -5.1%. These elements contributed together to a decrease of the total primary energy consumption. The use of coal and other fossil fuels and their derivatives was also reduced. The greater weight of natural gas, to the detriment of the most polluting fossil fuels, would largely explain the behavior of carbon dioxide (CO_2) emissions, which went from 1.67 t CO_2 per capita in 1997 to 1.42 t CO_2 per capita in 2011, compared to values for Latin America as a whole of 1.84 t CO_2 per capita and 2.46 t CO_2 per capita, respectively (IEA, 2012). In the same period there was significant economic growth in Colombia, with an average annual rate of 3.8% in the period 1971–2011; only in 1999 was there a negative rate of growth of -4.3%. According to Ocampo (1998) and Esguerra-Roa et al. (2005) the Colombian economy has experienced changes in its productive structure, towards a tertiarization. It would then be interesting to analyze the relation between the decrease in the consumption of some energy sources (and associated emissions) and the behavior of economic activity.

The interest in analyzing the relation between economy and energy increased at the beginning of the 1970's, due to the oil crisis and its impact on the world economy. Later, at the beginning of the 1990s, several studies suggested that for some polluting substances there was a delinking with economic growth from a certain level of income per capita (Grossman and Krueger, 1995; Panayotou, 1993), a relation that is known as the environmental Kuznets curve (EKC) hypothesis. This finding led some authors to argue hurriedly that the solution to environmental problems was just to promote growth (Beckerman, 1992), although most subsequent studies dismissed this option and highlighted the need for environmental policies, as well as the role played by these in the cases in which such delinking occurred (Ekins, 1997; Panayotou, 1993; Dasgupta et al., 2002). The results in the literature are varied, finding evidence for and against the EKC hypothesis, the pollutants with long-term effects, such as CO_2, being pollutants for which it is less clear that the hypothesis is fulfilled (Cole et al., 1997; Roca et al., 2001). Moreover, most studies finding evidence in favor of the hypothesis obtained turning points that are above the average income level of most countries, and especially of the average income level of developing countries.

Most of the first papers analyzed the hypothesis for groups of countries with panel or cross-sectional data. However, several authors suggest that it is more appropriate to conduct studies at the country level in order to develop a more in-depth analysis of the relation that occurs in each case (De Bruyn et al., 1998; Roca et al., 2001; Dijkgraaf and Vollebergh, 2005; Piaggio and Padilla, 2012). Individual analyses would also be more appropriate given the empirical evidence that the relation between environmental degradation and per capita income may be different for different countries in aspects such as functional form, parameters, and turning points (Dijkgraaf and Vollebergh, 2005; Piaggio and Padilla, 2012).

The present work aims to improve the knowledge of the relations between energy, CO_2 emissions, and economic activity, so as to contribute to a better planning of energy use and emissions control without harming economic development (a requirement expressed in the National Energy Plan 2006–2025 and in the Plan Visión Colombia 2019). In short, we are going to investigate: the relations of GDP per capita with per capita energy consumption and CO_2 emissions in Colombia, during the period 1971–2011, testing the EKC hypothesis (and whether there was a turning point within the sample), as well as the significance of other variables for these environmental pressures; and the elasticities of these relations and their change over time.

To address these objectives, two partial adjustment models (PAM) are estimated. Unlike previous studies done for Colombia that used static equations (Correa-Restrepo et al., 2005), a dynamic equation is used, and different variables are considered besides income. In addition, to deal with the relatively small size of our available sample, we have developed an alternative to the asymptotic distribution method to estimate the confidence intervals of the long-run elasticities. The new proposed approach relies on simulation techniques and enables us to take into account the sample size as well as the asymmetries of the distributions.

The rest of this paper is organized as follows. Section 2 provides a brief conceptual and empirical reference framework for the relations between the level of economic activity and environmental pressures. Section 3 explains the data sources, the methods, and the specification of the model. Section 4 presents and discusses the results. Section 5 presents the conclusions.

2. Conceptual and empirical reference framework

The EKC hypothesis posits the existence of an inverted U-shaped relation between environmental degradation and per capita income (Bilgili et al., 2016; Stern, 1998)[1]. Among the pioneering works, Grossman and Krueger (1995) and Panayotou (1993) found some evidence of an inverted U-shaped relation between economic growth and some polluting substances, while the World Bank (1992) presented various graphs showing this type of relation for some indicators of environmental quality.

According to this hypothesis, the initial phase of economic development of a country is characterized by the development of industry and polluting extractive activities, so that emissions increase as production increases. In the second phase, a certain threshold (turning point) is reached, from which economic growth allows the adoption of new, less polluting technologies and, in addition, increases the share of the services sector (supposedly less polluting)[2] and information-intensive industries. Moreover, the higher per capita income could translate into a greater preference for environmental quality (Ayres, 2008; Dinda, 2004; Grossman and Krueger, 1995; Nadal, 2007).

Even though in some cases there is a delinking between environmental pressure and economic growth, as suggested by the EKC, this could be a temporary situation, as De Bruyn and Opschoor (1997) state, so there could be a later re-linking (due to the possible exhaustion of mitigation opportunities), converting additional growth into environmental degradation. These authors also distinguish two forms of de-linking or dematerialization in a growing economy: weak (relative) dematerialization and strong (absolute) dematerialization. The first is characterized by decreasing the intensity of use of materials or waste per unit of production. The second means that the total environmental pressure decreases over time. In terms of environmental impact, the important thing is to analyze whether or not a strong dematerialization occurs.

In the literature, multiple determinants of emissions have been analyzed in addition to income, such as, for example, the inequality of power and wealth (Boyce, 1994; Ravallion et al., 2000; Torras and Boyce, 1998), the structure of the energy supply (Roca et al.,

[1] The EKC owes its name to its analogy with the Kuznets curve, which reflects the relation found by Kuznets (1955) between the level of per capita income and inequality (Stern, 1998).
2 However, some service activities are highly polluting (Roca and Padilla, 2003), as is the case of transport, or require inputs from highly polluting activities, so that they would be indirectly responsible for their emissions (Alcántara and Padilla, 2009; Piaggio et al., 2014). Hence, it cannot be conclusively stated that the tertiarization of an economy necessarily implies a lower environmental impact.

2001), the degree of urbanization (Jiang and Hardee, 2011), the composition of production (Piaggio et al., 2017), openness to foreign trade (Copeland and Taylor, 1994; Piaggio et al., 2017), or even less “conventional” determinants, such as the degree of confidence (Carattini et al., 2015), among others. However, given the number of possible determining factors and their possible correlations, authors often decide to directly relate the environmental pressure with the GDP per capita, so that the whole of the (apparent) direct and indirect relations established between both variables through different channels is taken into account (Piaggio and Padilla, 2012). In any case, most studies emphasize that a fundamental element that influences the relation between economic growth and environmental degradation are the public policies enforced (Bernauer and Koubi, 2009; Carson et al., 1997; De Bruyn and Opschoor, 1997; Dasgupta et al., 2002; Dinda, 2004, Panayotou, 1997; World Bank, 1992). The importance of the quality of policies and institutions for reducing environmental degradation at low income levels and accelerating improvements at high income levels is highlighted in Dasgupta et al. (2002) and Panayotou (1997).

Several studies have found that the relation between economic growth and environmental degradation can take different forms, depending on the type of pollutant, the database, the period analyzed, the model specifications, and the methods used, so that, although the EKC hypothesis could reflect what happens in some cases, the empirical evidence would not be too favorable to it as a general explanation of the relation between economic growth and environmental degradation.

There are varied results in the literature. Some studies find that some countries during certain periods fulfill the EKC for some pollutants (Cole et al., 1997; Galeotti et al., 2006; Grossman and Krueger, 1995; List and Gallet, 1999). In other studies there is contradictory evidence for the same pollutants (Gergel et al., 2004; List and Gallet, 1999), depending on the region analyzed and the estimated model. Other studies have found evidence contrary to the EKC hypothesis (De Bruyn, 1997; Friedl and Getzner, 2003; Galeotti et al., 2006; Halkos and Tsionas, 2001; Lindbeck, 2000; Panayotou, 1997; Roca and Alcántara, 2001) for the environmental pressure indicators studied. The studies employ different econometric methods. In contrast to the first studies, in many post-1995 studies the problems of autocorrelation and heteroskedasticity are corrected for and consistency and simultaneity tests are carried out to avoid errors of bias depending on the estimation technique used. Specifically, in the case of time series models, the hypothesis of non-cointegration between GDP and emissions is tested (Friedl and Getzner, 2003).

Much of the literature that finds evidence favorable to the EKC hypothesis is carried out with cross-sectional data, where the models estimated assume homogeneity in the form of the relation between emissions and GDP for the different countries and in its parameters and, therefore, the turning point in the relation. However, this assumption of homogeneity was rejected when empirically tested (Dijkgraaf and Vollebergh, 2005; Piaggio and Padilla, 2012). It seems, therefore, that studies of individual countries that go into more depth about the relation that occurs in each case, would make more sense. This would be the case of, for example, the studies for Austria (Friedl and Getzner, 2003), China (Jalil and Feridun, 2011), Sweden (Kriström and Lundgren, 2005), Malaysia (Vincent, 1997), Spain (Roca and Alcántara, 2001; Roca and Padilla, 2003; Roca et al., 2001), and Uruguay (Piaggio et al., 2017), among others.

The patterns of the relation between income and environmental degradation depend on the economic structure, access to technology, public policies and trade, as well as environmental regulation, among other possible factors. Hence, the way the region has faced the oil crises and the policy measures that have been adopted to improve energy efficiency become highly relevant, issues that we consider in our research.

3. Data, methods, and model specification

3.1. Data

The data used for the estimates come from the International Energy Agency (IEA, 2012). CO_2 emissions are measured in billions of tons, population in millions of inhabitants, gross domestic product (GDP) in trillions of 2005 dollars in purchasing power parity (PPP) values, and the total supply of primary energy and of some types of energy (natural gas, coal, crude oil, and renewable energy) are measured in millions of tons of oil equivalent.

3.2. Methods

We first graphically analyze the behavior of the data, studying whether the data apparently shows weak (emissions or energy per unit of GDP) or strong (CO_2 emissions or per capita energy) decoupling from GDP per capita. To do this, we produce various scatter plots, showing a smoothed least squares line for the analysis period, which allows observing the pattern of behavior of the data and identifying possible linearities in the relations between the variables over time (StataCorp, 2007).

We then proceed to the estimation of a PAM that allows observing in a more interactive way the trajectory of the variables over time, taking into account different determinants, as well as identifying the functional form of the relation and, in the case of finding evidence in favor of the EKC, determining the income level of the turning point.

Previous studies have used the PAM to analyze flows of materials, total energy, and sectoral energy (Dilaver and Hunt, 2011), as well as different polluting emissions (Agras and Chapman, 1999; De Bruyn et al., 1998). Our study is the first to apply this method to the analysis of environmental pressures in the Colombian case.

The use of the PAM allows us to analyze the relations between the variables: i) identifying if there has been a change in the parameters of the model and estimating the equilibrium equations; ii) directly estimating the influence of income and some socioeconomic variables on the environmental pressure indicator; iii) explicitly considering the past evolution of environmental pressure as a possible influence on the present (the reason may be technological, psychological, or institutional); iv) examining the speed with which the changes take place. This is achieved by calculating the elasticities. The short-run ones capture the change in the rates of use of the existing flow and the long-run ones capture both changes in the rate of use as well as changes in the economic structure.

3.3. Specification of the model

According to the model, the dependent variable, Y_t (CO_2 emissions per capita or primary energy per capita in a given year) depends on X_t, a vector of different socioeconomic factors or other variables (GDP per capita, regulation, and energy structure) that influence Y_t, α is the intercept, the βs of the vector X_t are the coefficients of the explanatory variables, and u_t -is the error term:

(1) $$Y_t^* = \alpha + \beta X_t + u_t$$

The adjustment process can be represented as:

$$\underbrace{Y_t - Y_{t-1}}_{\text{Observed change}} = \lambda \underbrace{\left(Y_t^* - Y_{t-1}\right)}_{\substack{\text{Desired change=} \\ \text{=long run change}}} \qquad (2)$$

The equation specifies that the change observed in the environmental pressure indicator at any time *t*, is a fraction λ of the long-run change, where λ is the adjustment coefficient. It is assumed that the coefficient is between 1 and 0. The closer to 1 is the coefficient, the higher is the speed of the adjustment.

Two models are estimated, one for the use of energy and the other for CO_2 emissions. We take the series in logarithms, so that the coefficients are interpreted as elasticities.

In model 1, the equation estimated for energy is

$$(3) \qquad \ln\left(\frac{PE_t}{POP_t}\right) = \beta_0 + \beta_1 \ln\left(\frac{GDP_t}{POP_t}\right) + \beta_2 \left[\ln\left(\frac{GDP_t}{POP_t}\right)\right]^2 + \beta_3 \left[\ln\left(\frac{PE\_NG_t + PE\_HIDRO_t}{EP\_TOTAL_t}\right)\right] + (1-\lambda)\ln\left(\frac{PE_{t-1}}{POP_{t-1}}\right)$$

where the lagged dependent variable measures the relation that energy consumption has with the one in previous period and makes the model dynamic. The GDP per capita coefficient measures the impact of the scale of production, while, according to its usual interpretation in the EKC literature, the squared variable shows the endogenous change in the relation as the income level increases due to changes in the productive structure, consumption patterns, and technology, among other determinants. The EKC hypothesis is met if the variable in levels has a positive value and the squared variable has a negative one (Grossman and Krueger, 1995). The coefficient of the proportion of natural gas plus hydroelectric energy in total primary energy $\left(\frac{PE_{NG_t} + PE_{HIDRO_t}}{PE_{TOTAL_t}}\right)$ reflects the impact of a change in the composition of energy sources towards sources that are more efficient in their transformation into final energy. These are the two main primary sources of electricity generation in the country. Both contribute to a lower energy consumption due to their high efficiency in the transformation of primary energy to final energy. In addition, generation occurs in the same place where it is consumed, avoiding transformation and distribution losses (UPME, 2014).

In model 2, the equation estimated for CO_2 emissions is

(4) $$\ln\left(\frac{CO_{2t}}{POP_t}\right)=\beta_0+\beta_1\ln\left(\frac{GDP_t}{POP_t}\right)+\beta_2\left[\ln\left(\frac{GDP_t}{POP_t}\right)\right]^2+\beta_3\left[\ln\left(\frac{PE\_RENO_t}{EP\_TOTAL_t}\right)\right]+\beta_4 G_t+(1-\lambda)\ln\left(\frac{CO_{2t-1}}{POP_{t-1}}\right)$$

As in the previous model, the lagged dependent variable makes the model dynamic and shows the relation between the current generation of emissions and that in the previous period. The proportion of renewable energy in total primary energy, $\left(\frac{PE_{RENO_t}}{EP_{TOTAL_t}}\right)$, made up mainly of hydroelectricity, biofuels, solar, and wind, are clean energies that would contribute to a lower generation of CO_2 emissions per capita. For example, in Colombia, sugarcane ethanol is associated with a 71% reduction in emissions (IPCC, 2011). The variable G_t is a proxy variable for regulation, since factors related to changes in legislation can affect environmental quality (Apergis and Ozturk, 2015). It is a dichotomous variable that takes the value zero before 1998 and one after 1998. Some Colombian government regulations related to the control of environmental pollution include: a) Decree 948 of 1995 that establishes standards for air quality control and establishes different progressive quotas especially from 1998. b) Decree 1228 of 1997 that determines emission regulations for automotive vehicles. c) Resolution 619 of 1997 that establishes atmospheric emission permits for certain industries and activities with fixed emission sources. d) Laws 693 and 697 of 2001: the first promotes the rational use of energy and the second creates incentives to use biofuels to reduce emissions.

The estimation of the short-run elasticity of CO_2 emissions per capita (or the use of primary energy per capita) with respect to GDP per capita is calculated using the following expression:

(5) $$\eta_{sr}=\frac{\partial Y_t}{\partial X_t}=\beta_0+2\beta_1 X_t$$

If $\eta > 1$, there is a high response capacity of CO_2 emissions per capita (or use of primary energy per capita) to changes in income. CO_2 emissions (or the use of energy) would behave like a luxury good.

If $0 < \eta < 1$, higher revenues lead to a proportionally lower increase in CO_2 emissions (or energy use) per capita. There would be changes that would reduce the impact of GDP on emissions with respect to what the scale effect would suggest.

Si $\eta < 0$, there is a negative relation between CO_2 emissions per capita (or energy use) and real GDP per capita. This result would be consistent with the EKC hypothesis.

In the long term, the elasticities of the indicator of environmental pressure with respect to GDP per capita are estimated applying the following equation:

$$\eta_{lr} = \frac{\partial \overline{Y}}{\partial \overline{X}} = \frac{\beta_0}{1-\lambda} + 2\frac{\beta_1}{1-\lambda}\overline{X} \tag{6}$$

Under the hypothesis of normality, a 70% confidence interval of the elasticity around the mean can be obtained by adding and subtracting from the mean the standard deviation of the elasticity. However, if the distribution is asymmetric, two points must be highlighted. First, the mode of the distribution can be more representative than the mean to the extent that the mode and the mean differ (the mode is the most probable value). Second, the mode and the confidence interval must be obtained by simulation methods, as explained in Annex 1. In fact, in an asymmetric distribution, the width of a 70% confidence interval is smaller if this interval is built around the mode of the distribution than when it is built around the mean.

Finally, to estimate the turning point of income $Y(TP)$ where the environmental pressure indicator reaches its maximum, the following expression is used:

$$Y(TP) = \exp\left(\frac{-\beta_1}{(2\beta_2)}\right) \tag{7}$$

where β_1 is the coefficient for the income variable in levels and β_2 the coefficient for the squared income term.

4. Results

4.1. Graphical analysis of the relations between energy or CO_2 emissions and GDP in Colombia

We carry out a graphical analysis of the relations between energy consumption, emission generation, and GDP per capita. This allows observing whether there is any type of (weak/relative or strong/absolute) delinking with respect to energy consumption and CO_2 emissions. Figure 1 shows the relation between energy per unit of product and GDP per capita. This shows a negative correlation between the variables, indicating that, as GDP per capita increases, there has been a decrease in energy per unit of output. That is to say, there is an apparent relative delinking (weak dematerialization) between energy and economic growth. Figure 2 shows a relatively similar behavior when analyzing the relation between CO_2 emissions per unit of product and GDP per capita.

Figure 1.
Relative delinking of energy.

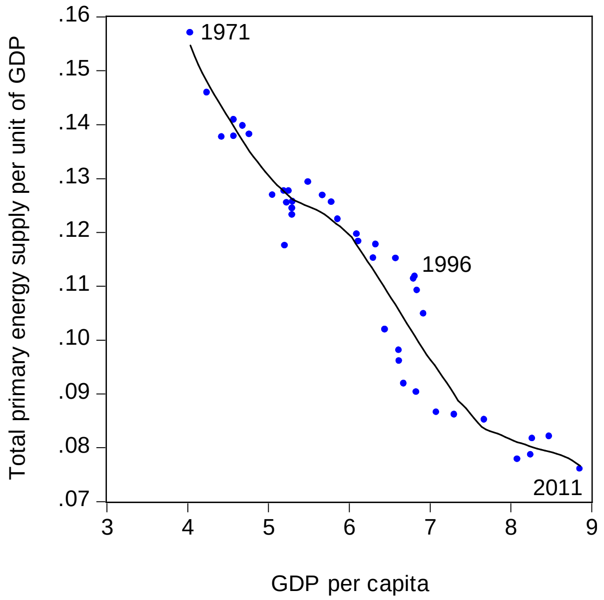
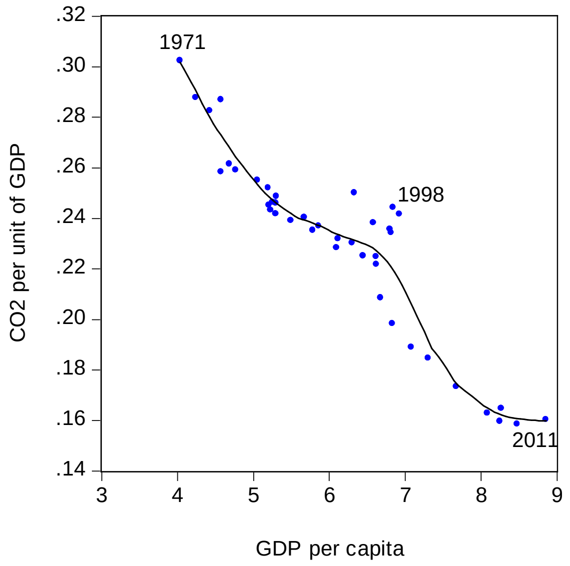


Figure 2.
Relative delinking of CO_2 emissions.



Source: Produced by the authors with IEA (2012) data.

As shown by Figure 3, there are two changes in the relation between primary energy per capita and GDP per capita. First, the relation between energy per capita and GDP per capita changes from a strongly positive correlation during the period 1971–1996 to a negative correlation during 1996–2006, whereas after 2007, the correlation is again positive until 2011. Figure 4 shows a similar behavior for the relation between CO_2 emissions per capita and GDP per capita, with the difference that, in this case, the changes occur later, so that the first change occurs in 1998 and the second in 2007.

Figure 3.
Absolute delinking of energy.

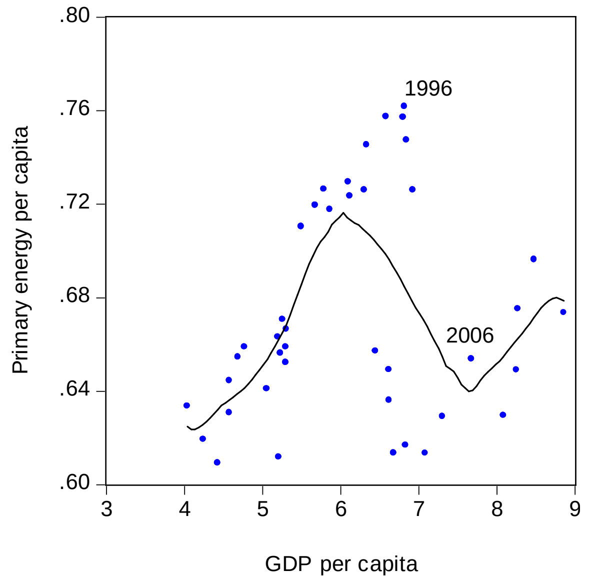
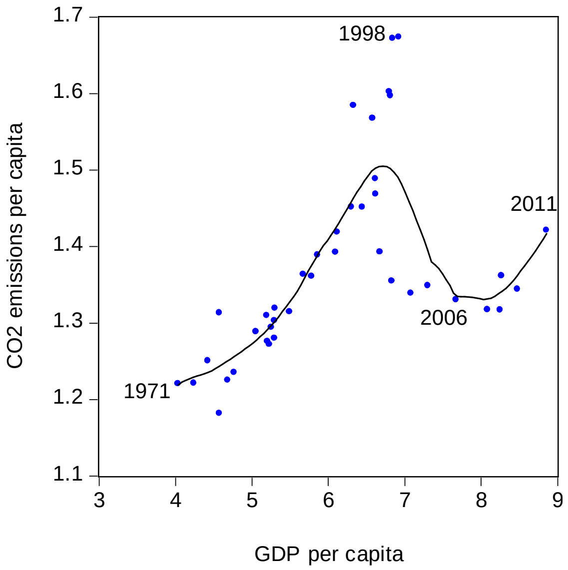


Figure 4.
Absolute delinking of CO_2 emissions.



Source: Produced by the authors with IEA (2012) data.

Both in Figure 3 and Figure 4, during the first transition, the formation of an inverted U is observed, similar to that described by the EKC hypothesis. This means that, as of 1996 and 1998, the consumption of energy and the generation of emissions, respectively, present an apparently absolute disconnection with economic growth (dematerialization), since the increase in GDP does not seem to entail greater emissions of CO_2, nor higher energy consumption. The same figures show a possible re-association in 2006 and 2007 of the ratio of GDP to primary energy consumption and CO_2 emissions, respectively, though there are not enough years in the sample to indicate that this was clearly the case.

According to the literature on the EKC, the reasons most commonly used to justify a decoupling such as that observed are technological changes and structural changes (Grossman and Krueger, 1992; De Bruyn et al., 1997), in addition to (or as a result of) the enforced policies. In the case of Colombia, these changes could have occurred and interacted with other factors, generating modifications in the composition of the energy sources and the intensity of the use of the materials. Next, we estimate a PAM to analyze in greater detail the relations between the variables and the influential factors.

4.2. Results of the econometric estimations

Models 1 (Equation (3)) and 2 (Equation (4)) are estimated for energy consumption per capita and CO_2 emissions per capita, respectively. In the emissions model, an autocorrelation problem is identified and corrected. Thus, the estimated models do not present problems of autocorrelation or heteroscedasticity. Likewise, the joint explanatory capacity of the variables included in the models is high since they have a high goodness of fit. When applying the stationarity test, the individual variables are non-stationary, but their linear combination seems stationary according to a cointegration test applied to the residuals $\hat{u}_t$.

The models were estimated with OLS using a dynamic structure, following the PAM, where the lagged dependent variable was very significant in all cases. As expected in this type of model, the long-run elasticities are greater than the short-run elasticities and have a similar interpretation (see Tables 1 and 2).

Tables 1 and 2 show that all the coefficients of the explanatory variables are significant at 1%, except those of the linear and quadratic GDP per capita, which in both models are significant at 5%. The coefficients or elasticities estimated for both models of the different variables related to energy structure and regulation are analyzed below, commenting later on those relative to GDP per capita and the squared variable, where we will carry out a more detailed analysis studying their evolution.

In the case of the energy model, the coefficient related to the composition of the primary sources of energy most used in the country in the generation of electricity is -0.17. In other words, if the proportion of energy production from natural gas and hydroelectric plants increases by 1%, primary energy consumption decreases by 0.17% in the short run and 0.47% in the long run, ceteris paribus (see Tables 1 and 2). The decrease in energy consumption would be due to the greater efficiency of these energy sources in their transformation processes, which, among other things, may be associated with cogeneration, higher R&D, better performance of new technologies, and the decentralization in the generation of energy with its consequent reduction of losses (UPME, 2014).

Regarding the model of CO_2 emissions, the elasticity of renewable energy consumption with respect to CO_2 emissions is -0.31 in the short run and -0.93 in the long run, involving a favorable impact for the environment. In the long run, this means that a 1% increase in the proportion of renewable energy use contributes to a decrease in the generation of per capita emissions of -0.93%. The estimates obtained are slightly high compared to the literature. Bilgili et al. (2016) found negative elasticities for renewable energies with respect to CO_2 emissions in five countries (Austria, Belgium, Greece, Portugal, and Turkey) for the period 1977–2010. In Colombia, two elements that may have favored the reduction of emissions are the promotion of the national biofuels policy promoted in Law 693 of 2001, based on Laws 142 and 143 of 1994; and Program for rational and efficient use of energy and other forms of non-conventional energy (UPME, 2015).

The dichotomous variable G_t of the CO_2 emission model, related to regulatory instruments, turns out to be negative and significant at 1%, indicating that the measures taken by the government (with effect after 1998) related to the control of emissions and air quality (Decree 948, 1995; Decree 1228, 1997; Resolution 619, 1997) had a favorable impact on the conservation of the environment. The coefficient of the variable is -0.12 in the short run and -0.37 in the long run (see tables 1 and 2). In the latter case this means that, keeping the other factors fixed, CO_2 emissions per capita decrease during the period of the regulation (with respect to a no-regulation situation). That is, when control instruments were established on the CO_2 emissions of the industry and the transport sector, per capita emissions decreased by 0.37% after 1998. Apergis and Ozturk (2015) also obtained negative coefficients (-0.186 to -0.168) in Asian countries for a variable of this type in the long run.

Table 1. Short-run estimates of models 1 and 2.

	Short-run coefficient	Standard error	Statistical value	P-value
Model 1 (dependent variable *ln(PE$_t$/POP$_t$)*)				
Intercept	-2.14	0.74	-2.90	0.0064 ***
ln(GDP$_t$/POP$_t$)	1.70	0.67	2.52	0.0166 **
(ln(GDP$_t$/POP$_t$))^2	-0.39	0.17	-2.30	0.0278 **
ln((PE_GN$_t$+PE_HIDRO$_t$)/PE_TOTAL$_t$)	-0.17	0.05	-3.29	0.0023 ***
ln(PE$_{t-1}$/POP$_{t-1}$)	0.64	0.10	6.23	0.0000 ***
Model 2 (dependent variable *ln(CO$_{2t}$/POP$_t$)*)				
Intercept	-1.44	0.43	-3.31	0.0023 ***
ln(GDP$_t$/POP$_t$)	1.20	0.44	2.72	0.0104 **
(ln(GDP$_t$/POP$_t$))^2	-0.29	0.12	-2.44	0.0206 **
ln(EP_RENOV$_t$/EP_TOTAL$_t$)	-0.31	0.06	-4.88	0.0000 ***
G$_t$	-0.12	0.02	-7.97	0.0000 ***
ln(CO$_{2t-1}$/POP$_{t-1}$)	0.67	0.06	10.42	0.0000 ***
AR(1)	-0.51	0.17	-3.06	0.0044 ***
	Model 1		**Model 2**	
R^2 adjusted	0.80		0.92	
DW	1.8		1.95	
F joint significance	40.29 ***		73.97 ***	
White Test	1.2		1.5	
P-Valor White	0.32		0.20	
Lagrange Multiplier test	2.5		0.4	
P-Valor ML	0.9		0.67	
Turning point (Thousands U$ 2000)	8573		7713	
N	40		39	

Note: ***,** denote the level of significance at 1% and 5%, respectively.

Source: Produced by the authors with IEA (2012) data.

Table 2. Long-run estimates of models 1 and 2.

	Long-run coefficient	Standard error	Statistical value	P-value
Model 1 (dependent variable *ln(PE$_t$/POP$_t$)*)				
Intercept	-5.95	1.41	-4.23	0.0002 ***
ln(GDP$_t$/POP$_t$)	4.72	1.38	3.43	0.0016 ***
(ln(GDP$_t$/POP$_t$))^2	-1.10	0.36	-3.02	0.0046 ***
ln((PE_GN$_t$+PE_HIDRO$_t$)/PE_TOTAL$_t$)	-0.47	0.12	-3.79	0.0006 ***
Model 2 (dependent variable *ln(CO$_{2t}$/POP$_t$)*)				
Intercept	-4.35	0.80	-5.45	0.0000 ***
ln(GDP$_t$/POP$_t$)	3.64	0.89	4.09	0.0003 ***
(ln(GDP$_t$/POP$_t$))^2	-0.89	0.26	-3.48	0.0015 ***
ln(PE_RENOV$_t$/PE_TOTAL$_t$)	-0.93	0.15	-6.43	0.0000 ***
G$_t$	-0.37	0.06	-6.32	0.0000 ***

Note: ***,** denote the level of significance at 1% and 5%, respectively.

Source: Produced by the authors with IEA (2012) data.

The positive coefficient of the GDP per capita in levels indicates that the increase in the scale of the economy increases environmental pressures. The coefficient of the squared GDP per capita in both models, in the short and long run, is negative and significant. This suggests that, after a particular level of GDP per capita, there is a possible delinking. This is observed for both energy and CO_2 emissions. The difference in the value of the elasticity of the indicator of environmental pressure (CO_2 emissions or energy) with respect to GDP in the short and long run can be a reflection of the structural and technological change of the country in the productive sectors, and the mix of energy sources. In this regard, Stern (2004) points out that the relation between per capita energy consumption and GDP per capita is affected by the substitution between energy and other inputs, technological change, the change in the mix of energy sources and the change in the composition of production. Given the strong connection between energy and CO_2 emissions, these factors also affect the trajectory of the emissions.

Some circumstances that may have promoted this change are: i) the beginning of the process to liberalize oil prices, according to Resolution 8-2439 (1998) of the Ministry of Mines and Energy; ii) the impulse for the change in the composition of energy sources, through the Natural Gas Massification Plan, since although this process began in 1986, it was only at the end of the 1990's that the infrastructure that connected the production centers with the largest markets was ready (UPME, 2010); and iii) the establishment of a full fuel substitution policy as of 1999, especially with regard to natural gas as a vehicular fuel (UPME, 2015).

Next, we analyze in more detail the relation between environmental pressures and per capita income and its evolution over the period. In the energy model, the estimates of the elasticity of primary energy consumption per capita with respect to GDP per capita in the period analyzed show a downward trend to zero (see Figures 5 and 6 and Annex 2A). In the short run, the elasticities have positive signs and oscillate between 0.59 and 0, with a confidence interval between 0.80 and -0.13 (see Figure 5). The values are relatively similar to those of previous studies done for Colombia for different energy variables (Espinoza-Acuña et al., 2013; Medina and Morales, 2007; Mendoza-Gutiérrez, 2010; Ramírez, 1991; Vélez et al., 1991) and those made for other countries (Agras and Chapman, 1999; Bentzen and Engsted, 1993; Dahl, 1991; Narayan and Smyth, 2005; Pourazarm and Cooray, 2013; Sene, 2012; Taghvaee and Hajiani, 2014). The long-run elasticity during the same period is between 1.5 and 0 with a confidence interval that varies between 3.2 and -0.9 (see Figure 6). According to the table in Annex A3, the long-run elasticity would also be in the ranges of other studies for different energy variables for Colombia (APEX, 1985; Espinoza-Acuña et al., 2013) and other countries (Bentzen and Engsted, 1993; Dahl, 1991; Kumar-Narayan et al., 2010; Narayan and Smyth, 2005; Pourazarm and Cooray, 2013; Sene, 2012; Taghvaee and Hajiani, 2014).

Figure 5. Short-run income elasticity of energy.

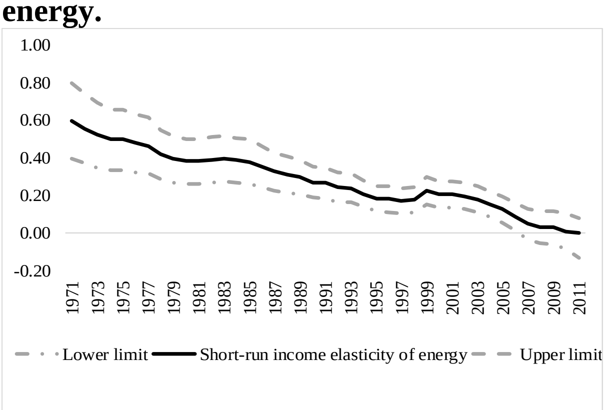
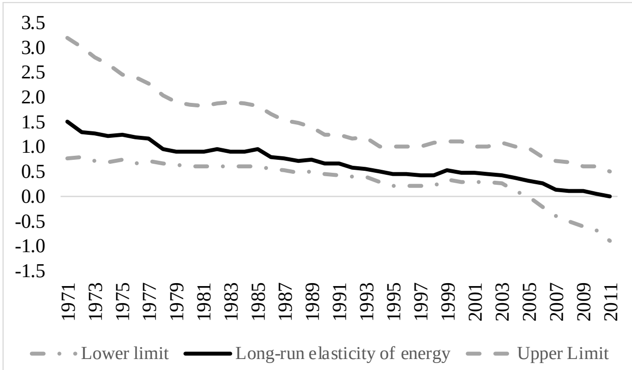


Figure 6. Long-run income elasticity of energy.



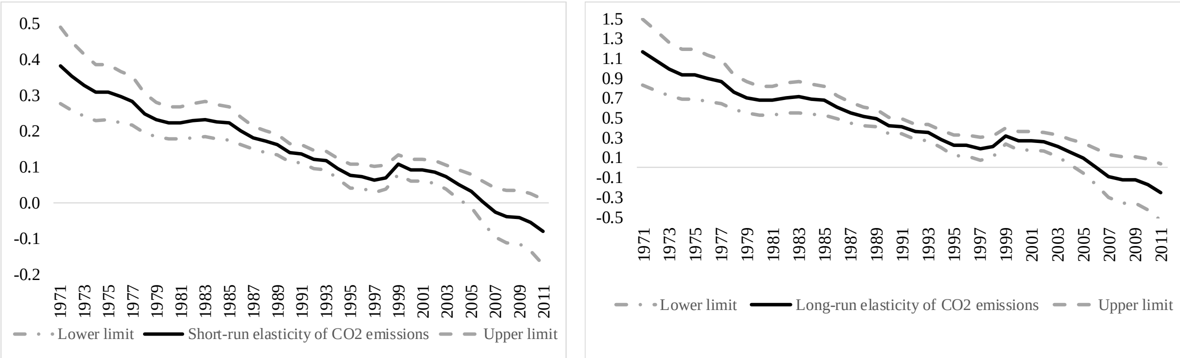
Source: Produced by the authors with IEA (2012) data.

In the model of CO_2 emissions, the elasticity of emissions per capita with respect to GDP per capita during the period 1971–2011 presents a positive relation in the first years that decreases with time, until becoming negative (see Figures 7 and 8 and Annex 2A).

Particularly, in the short run, the income elasticity of CO_2 emissions per capita ranges between 0.38 and -0.08, with a confidence interval between 0.49 and -0.17 (see Figure 7). The long-run elasticities are in a range between 1.16 and -0.25 with a confidence interval of 1.49 and -0.54 (see Figure 8). This means that the country has decreased its CO_2 emissions per capita with the increase in GDP per capita over the years (see Annex 2). According to the table in Annex 3, some studies find similar short- and long-run elasticities for other countries, such as Agras and Chapman (1999) and Jaunki (2011). Negative elasticities appear after 2007, varying between -0.09 and -0.25. In this sense, Jaunki (2011) also finds negative elasticities for the period 1980–2005 that range between -5.14 and -0.13 for five countries: Malta, Oman, Portugal, the United Kingdom, and Greece.

Figure 7. Short-run income elasticity of CO_2 emissions.

Figure 8. Long-run income elasticity of CO_2 emissions.



Source: Produced by the authors with IEA (2012) data.

4.3. Discussion

In the econometric models presented in Tables 1 and 2, in the short and long run, the coefficients of GDP per capita in levels are positive, while those of squared GDP per capita are negative, showing an inverted-U shaped relation between CO_2 emissions per capita and GDP per capita, and between primary energy per capita and GDP per capita. Other studies have also found favorable evidence for the EKC hypothesis for CO_2 for other countries or groups of countries (Apergis and Ozturk, 2015; Cole, 2004; Cole et al., 1997; Saboori et al., 2012), while many others have found evidence against it (Friedl and Getzner, 2003; Roca and Padilla, 2003; Roca et al., 2001).

In the case of Colombia, the turning point estimated with Equation (7) occurs in 2007 for per capita emissions and in 2011 for per capita energy consumption. This finding is similar to results found by different authors (Apergis and Ozturk, 2015; Cole, 2004; Cole et al., 1997; Saboori et al., 2012) in different regions that report a turning point of the EKC within the period of the observed sample. In our study, the turning point for Colombia is estimated at approximately \$ 8,573 per capita (in PPP of US\$ of 2000) for the energy model and \$ 7,713 per capita (in PPP of US\$ of 2000) for the model of CO_2 emissions. This is an interesting result, as for most developing countries there is no evidence of a turning point for CO_2 emissions within the sample. There are few exceptions, such as Saboori and Sulaiman (2013), who found a turning point in Malaysia for a similar value, 8,267 (US\$ of 2005), although in each case, these turning points would result from relations between income and environmental pressure conditioned by different determinants and economic structures.

In general, although the studies reviewed found relatively similar elasticities, they differ in method, time analyzed, regional or sectoral coverage, type of energy considered, etc. (APEX, 1985; Espinoza-Acuña et al., 2013; Laverde-Gaviria and Ruíz-Guzmán, 2014; Medina and Morales, 2007; Mendoza-Gutiérrez, 2010; Ramírez, 1991; Vélez et al., 1991) (See Annex 3). In addition, the literature that tests the EKC hypothesis for energy is scarce, and no studies were found at the country or regional level for Colombia. In contrast, the literature related to the models that analyze CO_2 emissions is abundant. These studies usually use different estimation techniques (such as GLS, fixed effects, random effects, error correction model, cointegration, etc., time series, panel data or cross-sectional data), have different time spans and different regional or sector coverages (Acaravci and Ozturk, 2010; Agras and Chapman, 1999; Apergis and Ozturk, 2015; Bilgili et al., 2016; Cole, 2004; Cole et al., 1997; Halicioglu, 2009; Piaggio and Padilla, 2012; Roca et al., 2001, Saboori and Sulaiman, 2013; Saboori et al., 2012).

The speed of adjustment is very similar for energy consumption and CO_2 emissions. In the case of energy, an adjustment speed of 0.64 implies that 64% of the energy consumption adjustment occurs during the first year. For CO_2 emissions, this speed is 0.67, that is, 67% of the adjustment occurs during the first year. Therefore, emissions would require only slightly less time than energy to reach the long-run equilibrium.

Tests were carried out with different variables related to the composition of GDP per capita, but these variables were not significant for any of the models. This could suggest that technology, changes in energy structure, and policies may have had a greater influence on the reduction of the environmental pressures considered.

5. Conclusions

The study allows a better understanding of the relations between GDP per capita and CO_2 emissions per capita and between GDP per capita and energy consumption per capita in Colombia during the period 1971–2011. The results indicate that at first the increase in GDP per capita increases emissions and energy consumption, while the estimated negative coefficient for squared GDP per capita shows that after a particular level of income the environmental pressure would tend to decrease, which would be compatible with the EKC hypothesis. Moreover, he turning point was found to be within the sample range, so

Colombia apparently shows a decoupling between economic activity and per capita emissions and per capita energy consumption, as of 2007 and 2011, respectively. This does not mean that the environmental pressures analyzed tended to disappear thanks to economic growth, since an increase in income does not automatically lead to lower environmental pressure if it is not accompanied by structural and technological changes conducted with appropriate policies. In order for the desired decoupling to take place, the existing environmental regulations must be complied with, as well as implementing additional energy and pollution control policies at the national and local levels that make economic development compatible with the reduction of environmental pressures. Otherwise, the signs of a possible re-association between environmental pressure and economic growth, that according to the graphical analysis seemed to occur in the last years of the period, could be confirmed. In addition, it is necessary to promote awareness-raising policies aimed at sensitizing the population and improving the environment, regardless of the level of income per capita.

Colombia was able to change the relationship between economic growth and CO_2 emissions during the period analyzed and our analysis indicates the type of policies that allowed this. This is a novel result for the case of a developing country, as there are just few studies finding a turning point for a developed country within the observed sample. Our results provide evidence that developing countries do not need to achieve the level of income per capita of developed economies in order to start controlling their emissions with appropriate policies. Our main contribution to existing literature is thus showing the type of energy and environmental policies that in this case allowed an apparent decoupling between greenhouse gas emissions and economic growth, which provides insights on the type of measures required in a developing economy to achieve these goals. The second major contribution of the paper is of methodological nature. We developed an alternative method to the asymptotic distribution methodology to estimate the confidence intervals of the long-run elasticities between GDP per capita and energy and emissions. The new proposed approach relies on simulation techniques and enables us to take into account the sample size as well as the asymmetries of the distributions.

The study finds that there is a clear relation between CO_2 emissions and the composition of energy sources: CO_2 emissions are reduced when the proportion of renewable energy consumption in the total of primary energy increases, and its impact is greater in the long run. This relation between renewable energies and CO_2 emissions does not seem to depend on GDP per capita, but rather on technological changes (for example, improvements associated with the energy production process, the composition of energy sources, fuel substitution, energy efficiency, etc.). Therefore, regulatory policies and incentives are required to support clean technological development and innovations aimed at sustainable development, especially in relation to non-conventional renewable energies.

The estimations suggest important changes in the generation of CO_2 emissions since 1998, due in large part to the incorporation of diverse regulatory mechanisms, which highlights the importance of environmental and energy policies in achieving the objective of reducing environmental pressures.

It can also be inferred that natural gas and renewable energies played an important role in the behavior of energy, favoring the decrease in energy consumption, due in part to the technical change and the comparative advantage of the country with these energy sources during the period 1971–2011.

The findings of our work are useful to evaluate and orient the appropriate policies for achieving a development compatible with the environmental goals of Colombia, and provide useful insights as regards the energy and environmental policies that may allow a similar transformation in other developing countries.

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6. References

Acaravci, A., Ozturk, I. (2010). On the relationship between energy consumption, CO_2 emissions and economic growth in Europe. *Energy*, 35(12), 5412–5420.

Agras, J., Chapman, D. (1999). A dynamic approach to the Environmental Kuznets Curve hypothesis. *Ecological Economics*, 28(2), 267–277.

Alcántara, V., Padilla, E. (2009). Input–output subsystems and pollution: An application to the service sector and CO2 emissions in Spain. *Ecological Economics*, 68, 905–914.

Apergis, N., Ozturk, I. (2015). Testing Environmental Kuznets Curve hypothesis in Asian countries. Ecological Indicators, 52, 16–22.

APEX Consultores. (1985). *Estudio de Proyección de Demanda de Energía Eléctrica*. Bogotá.

Ayres, R. U. (2008). Sustainability economics: Where do we stand? *Ecological Economics,* 67(2), 281–310.

Beckerman, W. (1992). Economic growth and the environment: Whose growth? Whose environment? *World Develop*ment, 20, 481–496.

Bentzen, J., Engsted, T. (1993). Short- and long-run elasticities in energy demand: A cointegration approach. *Energy Economics*, 15(1), 9–16.

Bernauer, T., Koubi, V. (2009). Effects of political institutions on air quality. *Ecological Economics*, 68(5), 1355–1365.

Bilgili, F., Koçak, E., Bulut, Ü. (2016). The dynamic impact of renewable energy consumption on CO_2 emissions: A revisited Environmental Kuznets Curve approach. *Renewable and Sustainable Energy Reviews,* 54, 838–845.

Boyce, J. K. (1994). Inequality as a cause of environmental degradation. *Ecological Economics*, 11(3), 169–178.

Carattini, S., Baranzini, A., Roca, J. (2015) Unconventional Determinants of Greenhouse Gas Emissions: The role of trust. *Environmental Policy and Governance* 25 (4), 243–257

Carson, R. T., Jeon, Y., McCubbin, D. R. (1997). The relationship between air pollution emissions and income: US Data. *Environment and Development Economics*, 2(04), 433–450.

Cole, M. A. (2004). Trade, the pollution haven hypothesis and the environmental Kuznets curve: Examining the linkages. *Ecological Economics*, 48(1), 71–81.

Cole, M. A., Rayner, A. J., Bates, J. M. (1997). The environmental Kuznets curve: An empirical analysis. *Environment and Development Econom*ics, 2(04), 401–416.

Copeland, B. R., Taylor, M. S. (1994). North–South trade and the environment. *The Quarterly Journal of Economics,* 109(3), 755–787.

Correa-Restrepo, F., Vasco-Ramírez, A. F., Pérez-Montoya, C. (2005). La curva medioambiental de Kuznets: Evidencia empírica para Colombia. *Semestre Económico,* 8(15), 13–30.

Dahl, C. (1991). A survey of oil demand elasticities for developing countries. *OPEC Energy Review*, 17(4), 399–420.

Dasgupta, S., Laplante, B., Wang, H., Wheeler, D. (1992). Confronting the Environmental Kuznets curve. *Journal of Economic Perspectives*, 16(1), 147–168.

De Bruyn, S. M. (1997). Explaining the environmental Kuznets curve: Structural change and international agreements in reducing sulphur emissions. *Environment and Development Economics*, 2(04), 485-503.

De Bruyn, S. M., Opschoor, J. B. (1997). Developments in the throughput–income relationship: Theoretical and empirical observations. *Ecological Economics*, 20(3), 255–268.

De Bruyn, S. M., van den Bergh, J. C. J. M., Opschoor, J. B. (1998). Economic growth and emissions: reconsidering the empirical basis of environmental Kuznets curves. *Ecological Economics*, 25(2), 161–175.

Decreto 948. (1995). Diario Oficial No. 41876 de la Republica de Colombia. Bogota, Colombia, June 5th, 1995. Available at: http://www.alcaldiabogota.gov.co/sisjur/normas/Norma1.jsp?i=1479

Decreto 1228. (1997). Diario Oficial Ministerio del Interior de la Republica de Colombia. Bogota, Colombia, May 6th, 1997. Available at: https://www.minambiente.gov.co/images/BosquesBiodiversidadyServiciosEcosistemicos/pdf/Normativa/Decretos/dec_1228_060597.pdf

Dijkgraaf, E., Vollebergh, H. J. (2005). A Test for parameter homogeneity in CO_2 panel EKC estimations. *Environmental and Resource Economics*, 32(2), 229–239.

Dilaver, Z., Hunt, L. C. (2011). Industrial electricity demand for Turkey: A structural time series analysis. *Energy Economics*, 33(3), 426–436.

Dinda, S. (2004). Environmental Kuznets curve hypothesis: A survey. *Ecological Economics*, 49(4), 431–455.

Departamento Nacional de Planeación (DNP). (2015). *Bases del Plan Nacional de Desarrollo 2014–2018. Todos por un Nuevo País*. Bogotá, D.C.: DNP.

Doyle, A. (2015). Carbon emissions fall in 11 of G20 members, in turning point. Environment. Available at: http://uk.reuters.com/article/us-climatechange-g-idUKKCN0SZ1G720151110

Ekins, P. (1997). The Kuznets curve for the environment and economic growth: Examining the evidence. *Environment and Planning A*, 29(5), 805–830.

Esguerra Roa, C., Castro Fernández, J. C., González Quintero, N. I. (2005). Cambio estructural y competitividad: el caso colombiano. Bogotá: DANE.

Espinoza-Acuña, O. A., Vaca Gonzalez, P. A., Ávila Forero, R. A. (2013). Elasticidades de demanda por electricidad e impactos macroeconómicos del precio de la energía eléctrica en Colombia. *Revista de métodos cuantitativos para la economía y la empresa*, 16, 216–249.

Friedl, B., Getzner, M. (2003). Determinants of CO2 emissions in a small open economy. *Ecological Economics*, 45(1), 133–148.

Galeotti, M., Lanza, A., Pauli, F. (2006). Reassessing the environmental Kuznets curve for CO"2 emissions: A robustness exercise. *Ecological Economics*, 57(1), 152–163.

Gergel, S. E., Bennett, E. M., Greenfield, B. K., King, S., Overdevest, C. A., Stumborg, B. (2004). A Test of the Environmental Kuznets Curve Using Long-Term Watershed Inputs. *Ecological Applications*, 14(2), 555–570.

Grossman, G. M., Krueger, A. B. (1995). Economic Growth and the Environment. The *Quarterly Journal of Economics*, 110(2), 353–377.

Halicioglu, F. (2009). An econometric study of CO2 emissions, energy consumption, income and foreign trade in Turkey. *Energy Policy*, 37(3), 1156–1164.

Halkos, G. E., Tsionas, E. G. (2001). Environmental Kuznets curves: Bayesian evidence from switching regime models. *Energy Economics*, 23(2), 191–210.

International Energy Agency (IEA). (2012). *CO_2 Emissions from Fuel Combustion 1971–2010*. Paris: OCDE/IEA.

IPCC. (2011). *Informe Especial sobre Fuentes de Energía Renovables y Mitigación del Cambio Climático*. Abu Dhabi: Organización Meteorológica Mundial y el Programa de las Naciones Unidas para el Medio Ambiente.

Jalil, A., Feridun, M. (2011). The impact of growth, energy and financial development on the environment in China: A cointegration analysis. *Energy Economics*, 33(2), 284–291.

Jaunky, V. C. (2011). The CO_2 emissions-income nexus: Evidence from rich countries. *Energy Policy*, 39(3), 1228–1240.

Jiang, L., Hardee, K. (2011) How do recent population trends matter to climate change. *Population Research and Policy Review* 30(2), 287–312

Kriström, B., Lundgren, T. (2005). Swedish CO_2 emissions 1900–2010: an exploratory note. *Energy Policy*, 33(9), 1223–1230.

Kumar-Narayan, P., Narayan, S., Popp, S. (2010). A note on the long-run elasticities from the energy consumption–GDP relationship. *Applied Energy*, 87, 1054–1057.

Kuznets, S. (1955). Economic Growth and Income Inequality. *The American Economic Review*, 45(1), 1–28.

Laverde-Gaviria, N., Ruíz-Guzmán, J. C. (2014). Elasticidades de la demanda residencial de energía eléctrica del estrato dos en el valle de Aburrá: un caso de estudio 2003–2013. Master dissertation, Maestría en Economía, Universidad EAFIT, Medellín.

Ley 693. (2001). Diario Oficial No. 44.564 de la República de Colombia. Bogotá, Colombia, September 27th, 2001. Available at: http://www1.upme.gov.co/sgic/sites/default/files/Ley%20693%20de%202001.pdf

Ley 697. (2001). Diario Oficial No. 44.573 de la República de Colombia. Bogotá, Colombia, October 5th, 2001. Available at: https://www.minminas.gov.co/documents/10180//23517//20858-3677.pdf

Lindbeck. (2000). The Sveriges Riksbank (Bank of Sweden) Prize in Economic Sciences in Memory of Alfred Nobel 1969–1998. Stockholm: The Nobel Foundation.

List, J. A., Gallet, C. A. (1999). The environmental Kuznets curve: does one size fit all? *Ecological Economics*, 31(3), 409–423.

Medina, C., Morales, L. F. (2007). Demanda por servicios públicos domiciliarios en Colombia y subsidios: Implicaciones sobre el bienestar. Borradores de Economía, Banco de la República (467), 350-354. Available at: http://www.banrep.gov.co/sites/default/files/publicaciones/pdfs/borra467.pdf

Mendoza-Gutiérrez, J. F. (2010). Estimación de la demanda de energía eléctrica de la empresa Electricaribe S.A. de la ciudad de Santa Marta, durante el periodo comprendido entre 1998–2006. Master dissertation. Maestria en Ciencias Económicas, Universidad Nacional de Colombia, Colombia. Available at: http://www.bdigital.unal.edu.co/6801/1/08407398.2010.pdf

Nadal, A. (2007). *De los Límites del Crecimiento al Desarrollo Sustentable. Programa sobre Ciencia, Tecnología y Desarrollo*. México: El Colegio de México.

Narayan, P. K., Smyth, R. (2005). The residential demand for electricity in Australia: An application of the bounds testing approach to cointegration. *Energy Policy*, 33(4), 467–474.

Ocampo, J. A. (1998). El desarrollo Económico. In E. Lora, J. A. Ocampo & R. Steiner (Eds.), *Introducción a la Macroeconomía Colombiana* (pp. 347–436). Bogotá: FEDESARROLLO.

Panayotou, T. (1993). Empirical tests and policy analysis of environmental degradation at different stages of economic development. Working Paper WP238. Geneva: Technology and Employment Program, International Labor Office.

Panayotou, T. (1997). Demystifying the environmental Kuznets curve: Turning a black box into a policy tool. *Environment and Development Economics*, 2(4), 465–484.

Piaggio, M., Padilla, E. (2012). CO_2 emissions and economic activity: Heterogeneity across countries and non-stationary series. *Energy Policy*, 46(0), 370–381.

Piaggio, M., Padilla, E., Román, C. (2017) The long-term relationship between CO2 emissions and economic activity in a small open economy: Uruguay 1882–2010, *Energy Economics*, 65, 271–282.

Pourazarm, E., Cooray, A. (2013). Estimating and forecasting residential electricity demand in Iran. *Economic Modelling*, 35, 546–558.

Ramírez, G. A. (1991). La demanda de energía eléctrica en la industria Colombiana. *Desarrollo y Sociedad*, 27, 121–139.

Ravallion, M., Heil, M., Jalan, J. (2000). Carbon Emissions and Income Inequality. *Oxford Economic Papers*, 52(4), 651–669.

Resolucion 8-2438. (1998). Diario oficial No.43.463 de la República de Colombia. Bogotá, Colombia, December 23rd, 1998. Available at: http://www.esu.com.co/esu/images/Descargables/PDF/Resolucion%2082438%20de%20diciembre%2023%20de%201998.pdf

Resolucion 619. (1997). Diario de la República de Colombia. Bogotá, Colombia, July 7th, 1997. Available at: https://www.minambiente.gov.co/index.php/normativa/resoluciones

Roca, J., Alcántara, V. (2001). Energy intensity, CO2 emissions and the environmental Kuznets curve. The Spanish case. *Energy Policy*, 29(7), 553–556.

Roca, J., Padilla, E. (2003). Emisiones atmosféricas y crecimiento económico en España. La curva de Kuznets Ambiental y el protocolo de Kyoto. *Economía Industrial* 351, 73–86.

Roca, J., Padilla, E., Farre, M., Galletto, V. (2001). Economic growth and atmospheric pollution in Spain: Discussing the environmental Kuznets curve hypothesis. *Ecological Economics*, 39(1), 85–99.

Saboori, B., Sulaiman, J. (2013). Environmental degradation, economic growth and energy consumption: Evidence of the environmental Kuznets curve in Malaysia. Energy Policy, 60, 892–905.

Saboori, B., Sulaiman, J., Mohd, S. (2012). Economic growth and CO_2 emissions in Malaysia: A cointegration analysis of the Environmental Kuznets Curve. *Energy Policy*, 51(0), 184–191.

Sene, S. O. (2012). Estimating the demand for gasoline in developing countries: Senegal. *Energy Economics*, 34(1), 189–194.

StataCorp. (2007). Stata Statistical Software: Release 10 Graphics. College Station, Texas: StataCorp LP.

Stern, D. I. (1998). Progress on the environmental Kuznets curve? *Environment and Development Economics*, 3 (2), 173–196.

Stern, D. I. (2004). Economic Growth and Energy. In C. J. Cleveland (Ed.), *Encyclopedia of Energy* (pp. 35–51). New York: Elsevier.

Taghvaee, V. M., Ajiani, P. (2014). Price and Income Elasticities of Gasoline Demand in Iran: Using Static, ECM, and Dynamic Models in Short, Intermediate, and Long Run. *Modern Economy*, 5, 939–950.

Torras, M., Boyce, J. K. (1998). Income, inequality, and pollution: A reassessment of the environmental Kuznets Curve. *Ecological Economics*, 25(2), 147–160.

Unidad de Planeación Minero Energética (UPME). (2007). Plan Energético Nacional 2006–2025. Bogotá, D.C.: MINMINAS-UPME.

Unidad de Planeación Minero Energética (UPME). (2010). Plan de Abastecimiento para el Suministro y Transporte de Gas Natural - Versión 2010. Bogotá: MINMINAS-UPME.
Unidad de Planeación Minero Energética (UPME). (2014). Capacidad instalada de autogeneración y cogeneración en sector de industria, petróleo, comercio y público del país. Bogotá: Consorcio Hart - Re.
Unidad de Planeación Minero Energética (UPME). (2015). Programa de uso racional y eficiente de energìa y fuentes no convencionales-PROURE. Available at: http://www1.upme.gov.co/DemandaEnergetica/MarcoNormatividad/plan.pdf
Vélez, C. E., Botero, J. A., Yánez, S. (1991). La demanda de energía de electricidad: Un caso colombiano. 1970–1983. *Lecturas de Economía*, 34, 149–189.
Verbeek, M. (2004). *A Guide to Modern Econometrics*. West Sussex: John Wiley & Sons.
Vincent, J. (1997). Testing for environmental Kuznets curves within a developing country. *Environment and Development Economics*, 2(4), 417–431.
World Bank. (1992). *Development and the Environment: World Development Report*. New York: Oxford University Press.

Annex 1. Methodological approach for estimating long-run elasticities

Consider an equililibrium relation between the dependent variable and the explanatory variables of the following type:

(A.1) $$Y_t^* = \alpha + \beta_0 X_t + \beta_1 X_t^2 + \varepsilon_t$$

and a partial adjustment process towards this equilibrium

(A.2) $$\Delta Y_t = \lambda\left(Y_t^* - Y_{t-1}\right)$$

The equation to be estimated and the short- and long-run elasticities would be

(A.3) $$Y_t = \alpha + \beta_0 X_t + \beta_1 X_t^2 + \underbrace{(1-\lambda)}_{\gamma} Y_{t-1} + \varepsilon_t$$

(A.4) Short-run elasticity: $$\eta_{sr} = \frac{\partial Y_t}{\partial X_t} = \beta_0 + 2\beta_1 X_t$$

(A.5) Long-run elasticity: $$\eta_{lr} = \frac{\partial \overline{Y}}{\partial \overline{X}} = \frac{\beta_0}{1-\lambda} + 2\frac{\beta_1}{1-\lambda}\overline{X}$$

In our context, relying on the asymptotic theory to derive the corresponding distributions faces two problems:

- The reduced size of our sample.
- The long-run elasticity implies nonlinear expressions of normal variables, and this must be manifested in the lack of symmetry of the corresponding distribution.

To obtain the corresponding distributions of the elasticity by simulation, the starting point is the estimation of the PAM by OLS. This enables to us to get the following distribution:

(A.6) $$\hat{\delta} = \begin{bmatrix} \hat{\beta}_0 \\ \hat{\beta}_1 \\ \hat{\gamma} \end{bmatrix} : \ N\left\{ \begin{bmatrix} \beta_0 \\ \beta_1 \\ \gamma \end{bmatrix}, \begin{bmatrix} V(\hat{\beta}_0) & V(\hat{\beta}_0\hat{\beta}_1) & V(\hat{\beta}_0\hat{\gamma}) \\ V(\hat{\beta}_0\hat{\beta}_1) & V(\hat{\beta}_1) & V(\hat{\beta}_1\hat{\gamma}) \\ V(\hat{\beta}_0\hat{\gamma}) & V(\hat{\beta}_1\hat{\gamma}) & V(\hat{\gamma}) \end{bmatrix} \right\}$$

Now, we build one hundred thousand realizations of the estimated $\hat{\delta}$ coefficients to empirically construct $\hat{\eta}$ and its distribution.

Since the estimated covariance matrix is given by the estimation of the model, the Cholesky decomposition is used, in order to obtain

(A.7) $\operatorname{cov}\left(\hat{\delta}\right) = \mathbf{PP'}$

Assuming that the random variable ε follows an independent normal distribution of the type (0,1), we obtain

(A.8)
$$\hat{\delta} = \mathbf{P\varepsilon}$$
$$\operatorname{cov}\left(\hat{\delta}\right) = \mathbf{P}\left[\mathbf{E}\left(\boldsymbol{\varepsilon\varepsilon'}\right)\right]\mathbf{P'} = \mathbf{PP'}$$

The matrix $\mathbf{P}$ is given by

(A.9)
$$\mathbf{P} = \begin{bmatrix} p_{11} & 0 & 0 \\ p_{21} & p_{22} & 0 \\ p_{31} & p_{32} & p_{33} \end{bmatrix}$$

Therefore, we generate 100,000 realizations of

(A.10)
$$\tilde{\beta}_0 = \hat{\beta}_0 + \underbrace{p_{11}\varepsilon_1}_{w_1},\ \tilde{\beta}_1 = \hat{\beta}_1 + \underbrace{\left(p_{21}\cdot\varepsilon_1 + p_{22}\cdot\varepsilon_2\right)}_{w_2},\ \tilde{\gamma} = \hat{\gamma} + \underbrace{\left(p_{31}\,\varepsilon_1 + p_{32}\,\varepsilon_2 + p_{33}\,\varepsilon_3\right)}_{w_3}$$

In this way, the generated coefficients

$$\tilde{\delta} = \begin{bmatrix} \tilde{\beta}_0 \\ \tilde{\beta}_1 \\ \tilde{\gamma} \end{bmatrix} = \begin{bmatrix} \hat{\beta}_0 \\ \hat{\beta}_1 \\ \hat{\gamma} \end{bmatrix} + \begin{bmatrix} p_{11} & 0 & 0 \\ p_{21} & p_{22} & 0 \\ p_{31} & p_{32} & p_{33} \end{bmatrix} \begin{bmatrix} \varepsilon_1 \\ \varepsilon_2 \\ \varepsilon_3 \end{bmatrix}$$
(A.11)

follow the same distribution as the original estimated coefficients by OLS,

$$\hat{\delta} = \begin{bmatrix} \hat{\beta}_0 \\ \hat{\beta}_1 \\ \hat{\gamma} \end{bmatrix}$$
(A.12)

That is to say,

$$E\left(\tilde{\delta}\right) = E\left(\hat{\delta}\right) = \delta$$
$$\operatorname{cov}\left(\tilde{\delta}, \hat{\delta}\right) = \operatorname{cov}\left(\hat{\delta}\right)$$
(A.13)

From the simulated $\tilde{\delta}$ coefficients, the distribution of the short- and long-run coefficients is derived using the expressions

$$\tilde{\eta}_{sr} = \frac{\partial Y_t}{\partial X_t} = \tilde{\beta}_0 + 2\tilde{\beta}_1 X_t$$
(A14)

$$\tilde{\eta}_{lr} = \frac{\partial \overline{Y}_t}{\partial \overline{X}} = \frac{\tilde{\beta}_0}{1-\tilde{\lambda}} + 2\frac{\tilde{\beta}_1}{1-\tilde{\lambda}}\overline{X} \qquad \text{(A.15)}$$

Given the asymmetric form of the function, the mode is considered more representative of the value of the elasticity than the mean. After sorting the simulated values in increasing order, using the mode of the distribution as the point estimation, a 70% confidence interval is obtained counting 35,000 observations below the mode and 35,000 observations over the mode. In this way, the number of observations included within the confidence interval is 70,000, and the tails to the left and to the right included 15,000 observations each.

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