System dynamics modelling and the Environmental Kuznets Curve in Ecuador (1980-2025)

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Abstract

Is it possible for a country in the process of development to comply with the Environmental Kuznets Curve (EKC) hypothesis in the medium term? This is question that inspired this study. This paper is an extension of a previous study focused on economic development and CO_2 emissions in the coming years in Ecuador (Robalino-López et al., 2013). The main goal of this paper is to analyze whether the EKC hypothesis holds within the period 1980-2025 under four different scenarios. This paper uses co-integration techniques (Stock and Watson, 1993) to test the existence of the EKC hypothesis in Ecuador in the medium term using the Jaunky's specification (Jaunky, 2011). Our proposal goes a step further than previous contributions, and intends to see under which conditions a country could approach the fulfilment of this hypothesis in the medium term. Results do not support the fulfilment of the EKC, nevertheless, our estimations show that Ecuador could be on the way to achieving environmental stabilization in the near future if economic growth is combined with an increase in the use of renewable energies, an improvement of the productive sectoral structure, and the use of a more efficient fossil fuel technology.

Keywords: CO_2 emissions, System Dynamics, Environmental Kuznets Curve, Ecuador

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1. Introduction

Ecuador has a relatively low level of CO_2 emissions (2.1 metric tons per capita) while Quatar, the world's largest CO_2 polluter per capita in 2009, emitted 44 metric tons per capita. At the same time Venezuela, the largest CO_2 polluter of Latin America (LA), emitted 6.5 metric tons per capita (World Bank, 2013), but it is expected that the social and economic development in the coming years will significantly increase the country's emissions. Several international organizations, notably, the Intergovernmental Panel on Climate Change (IPCC), are warning about the need to stabilize CO_2 and other anthropogenic greenhouse gas (GHG) emissions in order to avoid a catastrophic warming of the climatic system during this century (IPCC, 2007). To estimate GHG emissions, the IPCC has developed several methods, such as the *Reference Method* (IPCC, 2006), which is a top-down technique that uses data from the country's energy supply to calculate CO_2 emissions, mainly from the burning of fossil fuels. It is a straightforward method that can be applied on the basis of the available energy supply statistics (IPCC, 2006). However, the problem arises when data is not available or is not sufficiently disaggregated for use with this method.

A general question that arises when studying the relationship between the GDP and the CO_2 emissions is whether this relationship will be always linear, *i.e.* that a growth in GDP will produce an increase of the CO_2 emissions (that assumption is somehow implicit in the Kaya identity (Kaya and Yokobori, 1993)). In the early 1990s it was suggested, almost simultaneously, by (Shafik and Bandyopadhyay, 1992; Panayotou, 1993; Grossman and Krueger, 1995) that this behaviour can be modified and they proposed an "inverted-U" shape for the relationship between the per capita GDP and the per capita CO_2 emissions (see Fig. 1). They coined the term Environmental Kuznets Curve (EKC) in analogy to the inverted U-shaped relationship between the level of economic development and the degree of income inequality posit by Kuznets[1](1955). According to the EKC hypothesis the relationship between income per capita and some types of pollution is approximately an inverted U. This behavior states that as the per capita GDP growths, environmental damage increases, reaches a maximum, and then declines. The reason for this behaviour is that when GDP reaches

[1] For an exhaustive survey see Stern (2004) and (Dinda, 2004), or more recently (Pasten and Figueroa , 2012).

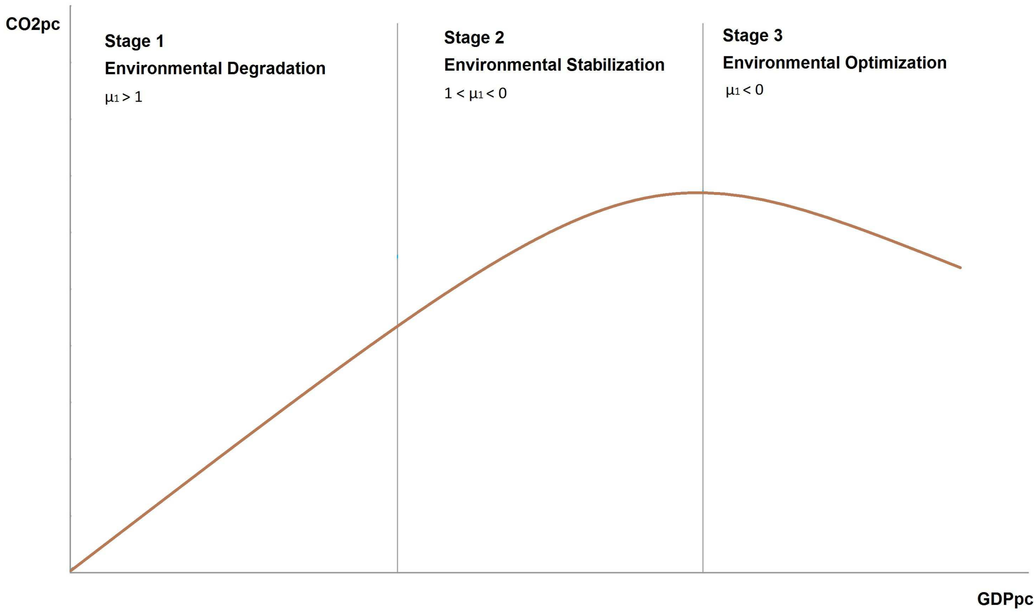

Figure 1: Schematic plot of the relationship between the per capita income and the per capita polution: 1) linear growth of the polution with the GDP, 2) stabilization, and 3) reduction of the emissions with the increase of the income. Figure adapted from (Iglesias et al., 2013).

a certain threshold the economy moves into a different regime, where the rate of emissions with respect to income can be reduced with respect to the initial regime. In the initial stage, as in the developing countries, CO_2 emissions scale with the *size* of the economy because the industries are relatively rudimentary, unproductive, and polluting. In the second stage, the impact of the economy in environmental degradation is reduced through the *structure and composition effect*, because the economy growth induces structural changes. In particular, that happens as an agricultural based economy shifts into a manufacturing services based economy. Finally, the third stage appears when nations invest intensively in research and development and the dirty and obsolete technologies are replaced by clean ones. At this point the pollution starts to decrease as a function the GDP. The different phases of the EKC are depicted schematically in Fig. 1.

The inverted U shaped relationship between CO_2 emissions and GDP is an empirical observation. In this respect there are many studies where quadratic and cubic models are used to fit the emissions to income (Canas and Ferrao, 2003; Shen and Hashimoto, 2004; Cole, 2005; Galeotti et al., 2006; Esteve and Tamarit, 2012a). However, in many cases the evidences of the ECK hypothesis is weak. Another way to test the validity of the ECK assumption is to compare the long and the short run impact of income on emissions (Narayan and Narayan, 2010; Jaunky, 2011). Whatever approach is used or set of countries studied, analysis always uses past data and there are no studies where the ECK hypothesis has been tested in a forthcoming period. To do this, a detailed model of the connection between GDP and CO_2 emissions is needed, as well as a set of plausible scenarios that could describe a possible evolution (GDP, energy matrix, and sectoral structure) of a given country.

As the theory predicts a long-run relationship linking emissions and economic growth, there is a wide stream of recent research that has assessed this relationship employing co-integration techniques. The empirical evidence suggests that pollution levels and GDP may be jointly determined, so that any constraint put on energy consumption, to help in reducing emissions will have effects on economic growth. Some authors, (Soytas et al., 2001; Soytas and Sari., 2003; Lee, 2005; Lise, 2006; Chontanawat et al., 2008; Halicioglu, 2009; Ozturk and Acaravci, 2010; Esteve and Tamarit, 2012a,b; Fosten et al., 2012) among others, use cointegration procedures to examine the CO_2 and GDP nexus, however these studies analyze past evidence. Our proposal goes a step further, and intends to see under what conditions a country could approach the fulfilment of the EKC hypothesis in the medium term.

To this end, we will use a model recently proposed by Robalino-López et al (2013), extending it for the period 1980-2025. The model is based on a variation of the Kaya identity (Kaya and Yokobori, 1993), and on a GDP formation approach which includes a contribution from renewable energy (Taichen et al., 2008). The model has been implemented using the system dynamics technique (Forrester, 1961) on a Vensim platform (Vensim, 2011). System dynamics is a method for modelling, simulating and analyzing complex systems and its main goal is to understand how a given system evolves, and even more importantly, to understand the causes that govern its evolution (Radzicki and Tauheed, 2009; Tan et al., 2010; García , 2011). To fix the unknown parameters of the model we have considered data from $1980-2010$ which was extracted from the official data set of Ecuador[2].

[2]Data is from the Ecuadorian Institute of Statistics and Census (INEC, 2012), Banco

Once the parameters of the model were fixed, four different scenarios were defined and this allowed us to perform the prediction of CO_2 emissions in a medium term period.

The present study is an effort to fill the gap in the literature of studies on the relationship between emissions and GDP in LA countries in general, and in Ecuador in particular. In addition, studies of a single country help policy makers improve comprehensive policies to control environmental degradation. Moreover, it represents a step forward in the study of the ECK hypothesis following Jaunky's specification (Jaunky, 2011), due to the inclusion of a forthcoming and not a past period of time.

The paper is organized as follows: section 2 summarizes the main data indexes of Ecuador and outlines the method used for the case study; section 3 presents and discusses the main results of this paper and lastly, section 4 provides the summary, conclusions and policy implication.

2. Study area and methodology

2.1. Overview of the study area

Ecuador is a medium-income country with a Human Development Index score of 0.724 (UNDP, 2013) and about 35.1% of its population lives below the poverty threshold (Index Mundi, 2012). Its economy is the eighth largest in LA and experienced an average annual growth of 4.6% between 2000 and 2010.

The Ecuadorian GDP was increased by 2.3 times between 1980 and 2010, and the GDP reached a value of approximately 104 billion US dollars that year. Inflation in December 2012 was around 4.2%, according to the BCE. The monthly unemployment rate remained between 9% to 5% from December 2009 until December 2012. Today, approximately 9 million Ecuadorians have an economic occupation and approximately 1 million people are inactive (INEC, 2012). The economy of the country expanded 7.8% in 2011, twice as much as in previous years.

Because of expected economic growth, CO_2 emissions will increase notably in coming years. Fig. 2 depicts the evolution of the CO_2 emissions for

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Central de Ecuador (BCE) (BCE, 2012), World Bank (World Bank, 2013), and International Energy Agency (IEA, 2013). Economic official data set used is given in constant 2005 *PPP* international dollars (World Bank, 2013). In the rest of this paper GDP-PPP will be referred to only as GDP, for brevity.

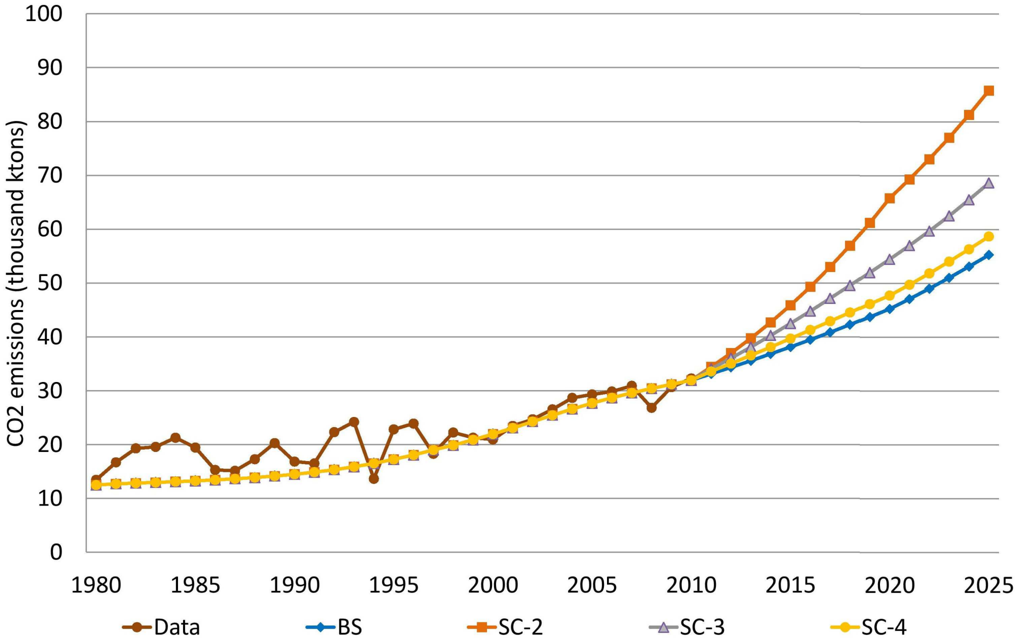

Figure 2: Ecuador CO_2 emissions for the period 1980−2025. Brown line-dots corresponds to official data, blue line-diamond to the *BS* scenario, orange line-square to the *SC-2* scenario, gray line-triangle to the *SC-3* scenario, and yellow line-dots to the *SC-4* scenario. CO_2 in thousand of ktons.

the period 1980-2025. The data record is plotted until the year 2010, moreover the results from the model (Robalino-López et al., 2013) are depicted for the whole period (see Section 2.2 for the details of the calculations). The four different curves correspond to four different scenarios (see section 2.6).

2.2. Formulation of model

In this section we present the summary of the model[3] that relates to GDP, the sectoral structure and the energy mix with the CO_2 emissions. The model uses a variation of the Kaya identity, where the amount of CO_2 emissions from industry and from other energy uses may be studied quantifying the contributions of five different factors: global industrial activity, industry activity mix, sectoral energy intensity, sectoral energy mix, and

[3]For a complete description of the model see (Robalino-López et al., 2013).

CO_2 emission factors. Moreover, we consider different sub-categories concerning the industrial sectors and the fuel type. The CO_2 emissions can be written as,

$$C = \sum_{ij} C_{ij} = \sum_{ij} Q \frac{Q_i}{Q} \frac{E_i}{Q_i} \frac{E_{ij}}{E_i} \frac{C_{ij}}{E_{ij}} = \sum_{ij} Q \cdot S_i \cdot EI_i \cdot M_{ij} \cdot U_{ij}, \qquad (1)$$

where C is the total CO_2 emissions and C_{ij} is the CO_2 emissions arising from fuel type j in the productive sector i; E_{ij} is the consumption of fuel j in the industrial sector i; where $E = \sum_{ij} E_{ij}$; the energy matrix[4] is given by M_{ij} $(\frac{E_{ij}}{E_i})$ and the CO_2 emission factor by U_{ij} $(\frac{C_{ij}}{E_{ij}})$.

The system dynamics simulation was performed through the Vensim-PLE for Windows V5.1e software. The simulation period extends from 1980 to 2025, although $1980 - 2010$ is used to fix the parameters of the model and $2011 - 2025$ corresponds to the forecast period of the model, under the assumption of different scenarios concerning the evolution of the GDP, the evolution of the energy mix, and the efficiency of the technology used in to minimize CO_2 emissions. The geometric-growth rate (Rowland, 2003; Jin et al., 2009) is used to extrapolate the trends into the forecast period.

2.3. Economic submodel

This paper uses a perspective of environmental economics to include the influence of renewable energy usage directly contributing to the formation of the GDP (Domac et al., 2005). We assume that renewable energy can increase GDP and the import substitution of energy has direct and indirect effects on increasing the GDP and the trade balance (Taichen et al., 2008).

Closely following to Taichen et al. (2008), we use the expenditure approach to form GDP,

$$GDP = C_a + I + G + X - M, \qquad (2)$$

where C_a is the final household consumption expenditure, I is the gross domestic capital formation, G is the general final government consumption expenditure, X is the export, and M the import. The deduction of imports from exports is the trade balance, TB.

[4]Note that the index i runs over five productive sectors and the index j over five type of energy sources.

Table 1: Estimated coefficients for the GDP formation equations (see Eqs. (3)-(7))[a].

Variable	GDP [b]	I	TB	C	E_{imp}
I [c]	1.16***			-6.07***	
	(5.11)			(-41.44)	
TB [d]	0.99***				
	(3.46)				
C [e]	1.21***	0.50***			
	(7.70)	(100.40)			
E_{imp} [f]	0.05***		0.01***	−0.27***	
	(2.66)		(4.14)	(-100.17)	
RN [g]	−0.50***	−0.84***	0.04		−36.79***
	(-4.44)	(-5.40)	(0.28)		(-5.47)

[a] *** represents significance at the 1% level and numbers in the parentheses are *t*-statistics. Estimation Method: Seemingly Unrelated Regression. Sample: 1980-2010. Included observations: 155.
[b] GDP = 2005 GDP/10^{10} (USD).
[c] I = 2005 I/10^{10} (USD).
[c] TB = 2005 TB/10^{10} (USD).
[d] C = 2005 C/10^{10} (USD).
[e] $E_{imp} = E_{imp}/10^3$ (ktoe).
[f] RN = RN /10^3 (ktoe).

On the other hand, according to (Taichen et al., 2008) the variable G is eliminated from the model estimation to avoid multicollinearity. Our goal is to establish a link between GDP, energy imports, and renewable energy. This relationship was proposed in (Taichen et al., 2008) and used in (Robalino-López et al., 2013) to build the economic sub-model for Ecuador and is summarized in the equations below,

$$GDP = a_1 \cdot I + a_2 \cdot TB + a_3 \cdot C_a + a_4 \cdot E_{imp} + a_5 \cdot RN + \epsilon_1 \quad (3)$$
$$I = b_1 \cdot RN + b_2 \cdot C_a + \epsilon_2 \quad (4)$$
$$TB = c_1 \cdot E_{imp} + c_2 \cdot RN + \epsilon_3 \quad (5)$$
$$E_{imp} = d_1 \cdot RN + \epsilon_4 \quad (6)$$
$$C_a = f_1 \cdot E_{imp} + f_2 \cdot TB + \epsilon_5 \quad (7)$$

where E_{imp} is the energy import, RN is the renewable energy and $\epsilon_1 ... \epsilon_5$ are residuals. In Eq. 3, GDP is influenced by capital formation, trade balance, consumption, energy import, and renewable energy. Those equations have been solved, taking into account the data set of the period 1980-2010, using the Seemingly Unrelated Regression (SUR) in STATA software platform (STATA, 2012), giving us the value of the coefficients $a_1, ..., a_5$. Table 1 summarizes their values (taken from (Robalino-López et al., 2013)) and they are considered as constant for the extrapolation period (2011-2025).

2.4. Energy consumption and productive sectoral structure submodel

Energy consumption refers to the use of primary energy before transformation into any other end-use energy, which is equal to the local production of energy plus imports and stock changes, minus the exports and the amount of fuel supplied to ships and aircraft engaged in international transport. It is given in kg of oil equivalent (ktoe). Energy intensity is defined as the ratio of energy consumption and GDP (World Bank, 2013).

In this paper we consider five sectors to define the productive sectoral structure: 1) agriculture, fishing and mining, 2) industry, 3) construction, 4) services, trade, and residential, and 5) transportation. These will be represented inside of model by its contribution to the country's economy (S_i), by its energy intensity[5] (EI_i) and by their energy mix (M_{ij}). Index i runs over each sector of the productive sectoral structure and index j runs over each kind of fuel: 1) natural gas, 2) coal, 3) petroleum, 4) renewable energy, and 5) alternative and nuclear energy.

2.5. CO_2 intensity and energy matrix submodel

CO_2 intensity (CO_{2int}) of a given country corresponds to the ratio of CO_2 emissions and the total consumed energy written in terms of mass of oil equivalent ($CO_{2int} = \sum_{ij} C_{ij} / \sum_i E_i$). The value of the CO_{2int} in a given year depends on the particular energy mix during that year. M_{ij} gives the energy matrix, but it is more convenient to sum over the different sectors and aggregate the fossil fuel contributions, therefore, we define $M_j = \sum_i M_{ij} / \sum_{ij} M_{ij}$.

[5]Note that the different economic sectors have different intensive use of energy (Cancelo and Díaz, 2002). Two factors explain the differences in energy intensity between each sector: i) differences in the efficiency of the energy used in each sector and ii) differences in the economic activity of each sector.

Finally, we define $ES_1 = M_1 + M_2 + M_3$ (share of fossil energy in the total consumption), $ES_2 = M_4$ (share of renewable energy), and $ES_3 = M_5$ (share of alternative and nuclear energy), we also introduce $ES_{11} = M_1$ (share of natural gas), $ES_{12} = M_2$ (share of coal), $ES_{13} = M_3$ (share of petroleum).

Therefore, $ES_1 = ES_{11} + ES_{12} + ES_{13}$ and $ES_1 + ES_2 + ES_3 = 100\%$. In order to simplify the description, in this paper we assume that ES_2 and ES_3 do not contribute to the CO_2 emissions. Following the methodology recommended by the IPCC, that is, the *Reference method* (IPCC, 2006), the approach of the first level for the fossil energy mix was used.

The emission factors, U_{ij}, are taken from the *IPCC* methodology to estimate the CO_2 emission of each fuel (IPCC, 2006).

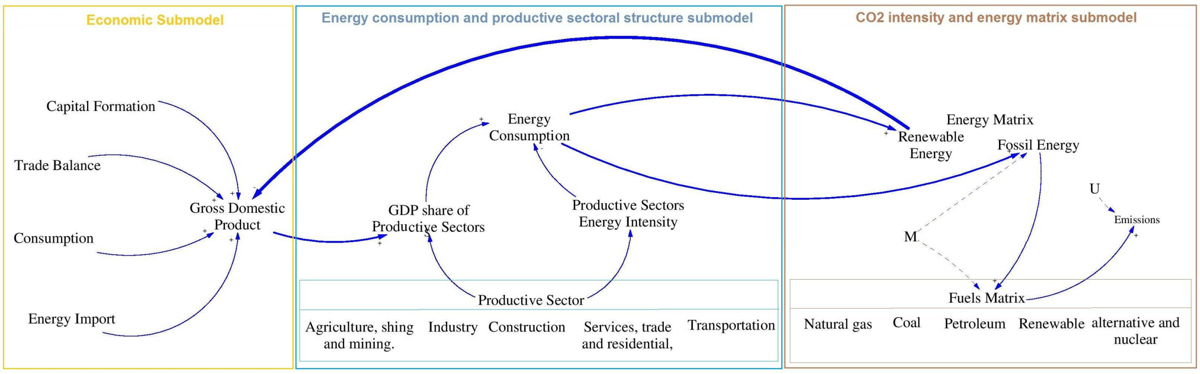

Figure 3: Causal diagram: continuous lines stand for the relationship between variables, while dashed ones correspond to control terms (S: *productive sectoral structure*, M: *energy matrix*, U: *emission factors*). Bold line represents a feedback mechanism.

In Fig. 3 we present the schematic view of the whole model. It is worth noting the feedback mechanism between renewable energy and GDP. This is one of the keys of the model, which allows us to generate a non-trivial evolution of the system. Here one can identify the economic submodel, the energy consumption and productive submodel, and the CO_2 intensity and energy matrix submodel.

2.6. Scenarios

We propose four scenarios concerning the growth of the GDP, the evolution of the energy matrix and of the productive sectoral structure for the period 2011-2025 (see (Robalino-López et al., 2013) for further details).

1. *Baseline scenario* (*BS*): the GDP, the energy matrix and the productive sectoral structure will evolve through the smooth trend of the period 1980-2010 extrapolated to 2011-2025 using the geometric growth rate method.

2. *Doubling of the GDP* (*SC-2* scenario): GDP will be approximately double the one of 2010 at the end of this period of study. To generate this scenario a constant annual growth of GDP formation components (I, TB, C, E_{imp}) of 7% per year between 2011 to 2025 will be assumed and a structural change in the productive sectoral structure will be implemented through a growth of 1% per year in the share (S_i) in the GDP of sectors with more profit to the country economy: industry sector (sector 2) and service, trade, and residential sector (sector 4). The rest of the variables will evolve as in the *BS* scenario. This scenario clearly corresponds to a situation where the economy is growing rapidly and no mitigation measurements to reduce the CO_2 emissions are carried out.

3. *Doubling of GDP and of the share of renewable energies* (*SC-3* scenario): the doubling of GDP and the change of the productive sectoral structure as in the *SC-2* scenario is considered, however the share of fossil energy, ES_1, will be reduced approximately one point per year, passing from a 88% in 2011 to 67% in 2025 due to a constant annual growth of the renewable and alternative energy share (ES_2 and ES_3). This scenario shows a first measure of environmental responsibility in order to try to reduce dependence of fossil energy.

4. *Doubling of GDP, doubling of renewable energy share and improvement in the efficiency of energy use* (*SC-4* scenario): the doubling of the GDP, the change in the productive sectoral structure and the change of the share of ES_1 is the same as in the *SC-3* scenario. Moreover, an improvement in the efficiency of energy use is implemented with a 1% reduction of the energy intensity in the industry sector (sector 2), in the trade, service and residential sector (sector 4) and in the transportation sector (sector 5). This scenario takes a step towards improving the country's environmental responsibility and sustainable development by supporting their energetic saving measures and energy efficiency. Both *SC-3* and *SC-4* goals are realistic considering the state of development and evolution of the energy technology and

of the various energy projects implemented by the Ecuadorian government, with the trends in the use of renewable energies in the country (Mosquera, 2008; Robalino-López et al., 2013).

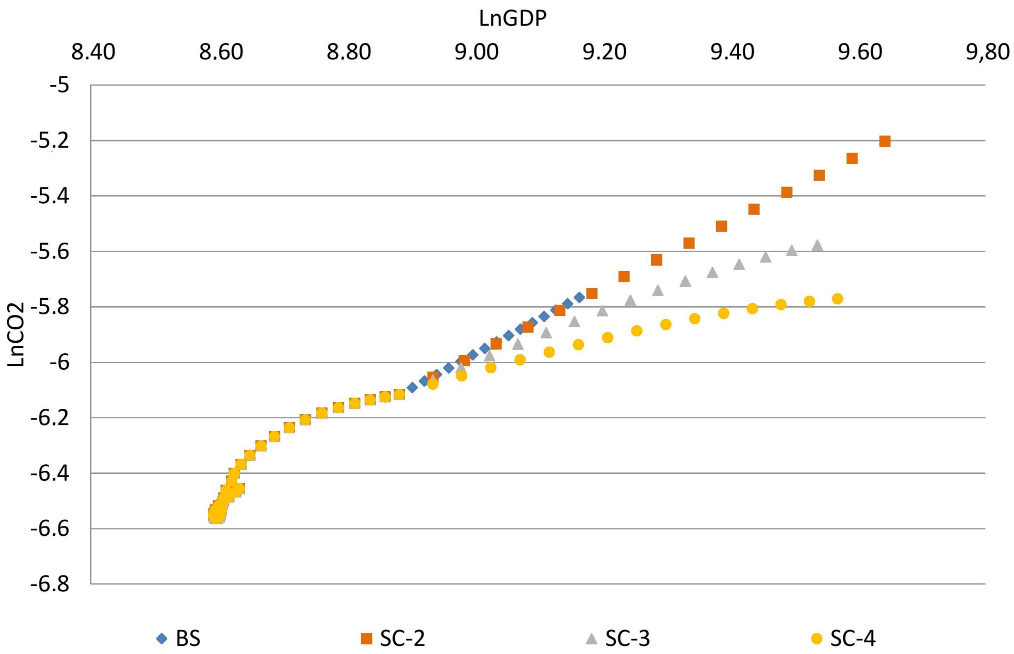

Figure 4: Ecuador natural logarithm of the per capita GDP *versus* natural logarithm of the per capita CO_2 emission for the period $1980-2025$. Blue dots correspond to the *BS* scenario, orange crosses to the *SC-2* scenario, gray asterisks to the *SC-3* scenario, and yellow marks to the *SC-4* scenario.

2.7. EKC hypothesis verification

The EKC hypothesis supposes that from a given moment onward the relationship between CO_2 emission and income is no longer proportional and that, even the first can be reduced as GDP increases. To get the first insight about the relationship between GDP and CO_2 we plot both variables in a logarithmic scale in Fig. 4, using the data set of the period 1980-2010 and the model calculation for the four considered scenarios (2011-2025). No conclusion is visible with naked eye, however it seems that the different scenarios generate different regimes and the environmental impact is somehow attenuated in some cases.

The paper follows the Jaunky's specification (Jaunky, 2011) for testing the EKC hypothesis in Ecuador. We assume the next reduced form equation for the relationship between the per capita income and the CO2 emission:

$$LCO2_t = \mu_0 + \mu_1 LGDP_t + \epsilon_t, \tag{8}$$

where $LCO2$ is the natural logarithm of the CO_2, $LGDP$ is the natural logarithm of the GDP, ϵ is the error term, μ_0 is the term constant, and μ_1 estimates the CO_2-GDP elasticity. In the first region of the simplified Kuznets curve (Fig. 1), as the elasticity $\mu_1 > 1$ there is a high responsiveness of GDP to changes in CO_2 emissions. Therefore a change in GDP generates a more than proportional increase in CO_2 emission. This phase involves little environmental responsibility and also implies that the country is in the early stage of environmental sustainability. If $0 < \mu_1 < 1$, then an income increase leads to a less than proportional increase in CO_2 emissions and, as a consequence, it implies that the country enters into the second stage of the EKC with environmental stabilization. Finally, for $\mu_1 < 0$ a negative relationship occurs between GDP and CO_2 emission. This is the final stage of the EKC and the country enters into a phase with intensive use of green technology and environmental optimization.

3. Empirical results and discussion

This section includes the main result of this paper, *i.e.* the ECK analysis in the four proposed scenarios. Prior to this study we present a simplified analysis of the relationship GDP-CO_2 using the logarithmic mean Divisia index (LMDI) (Ang, 2005).

3.1. Decomposition of the CO_2 emission in its conforming factors

In this section we will carry out a sensitivity analysis based on LMDI approach (Ang, 2005). This analysis will allow us to determine the relative importance of each term conforming to the nexus identity (1). Indeed, it is very enlightening to write down the increase of CO_2 emissions relative to the value of a given year, and to decompose it as the product of the factors corresponding to the different driving forces that conform the CO_2 emission. Therefore, we can write (Ang, 2005),

$$D_{tot} = D_{act} \times D_{str} \times D_{int} \times D_{mix} \times D_{emf}, \tag{9}$$

where D_{tot} is the times factor that CO_2 emission has increased (relative to 2010), D_{act} is the GDP term (*scale term*), D_{str} is the structure term (the share of the different sectors to the GDP), D_{int} is the energy intensity term, D_{mix} is the energy mixing term (*structure term*), and D_{emf} is the emission factor term[6](*intensity term*).

The LDMI analysis shows that by 2025 in the *BS* scenario the CO_2 emissions increase 1.7 times (relative to 2010), due to a 1.6 times increase in GDP. The *SC-2* scenario presents a CO_2 emission that is 3.0 times the one in 2010, this increase is due to a GDP growth 2.6 times greater in the same period. The *SC-3* scenario presents a CO_2 emission more than double the one in 2010 (2.1 times), while GDP corresponds to 2.3 times the one in 2010. Finally, in the *SC-4* scenario the emissions only reach 1.7 times and the GDP term is 2.4 times the one of 2010.

It is important to note that the reduction in the global CO_{2int} in the "cleaner" scenarios is twofold, on one hand, it is due to the use of a more efficient fossil fuel technology (lower CO_2 intensity) and, on the other, due to the reduction of the ES_1 share to the energy matrix. Both contributions are equally important. Note that the 2011-2025 period presents a reduction of the global CO_{2int} from 3.0 ktCO$_2$/ktoe in *BS* scenario to 2.4 ktCO$_2$/ktoe in *SC-4* scenario.

To see more clearly how the GDP-CO_2 relationship behaves as a function of time, it is very enlightening to depict the ratio D_{tot}/D_{act} as a function of the year (Fig. 5). The first striking thing is the very different behaviour for each scenario. On one hand, it is somehow surprising the almost flat curve corresponding to the *SC-1* scenario which implies a low-growth GDP scenario, however the CO_2 emission increases steadily because of the absence of attenuation measurements. A similar behaviour, although slightly sloping down, is observed for *SC-2*, where a rapid growth of the GDP is assumed without any attenuation action regarding CO_2 emission. It is worth noting a certain decrease of the ratio D_{tot}/D_{act} in the final part of the period under study. The other two scenarios, *SC-3* and *SC-4*, show a steady reduction of the ratio D_{tot}/D_{act} due to the changes in the sectoral structure and in the energy mix, which allows compensation of rapid GDP growth.

This preliminary analysis suggests that, with the appropriate changes in the energy mix, the sectoral structure, and the share of renewable energies, Ecuador can move into a more environmentally sustainable situation. All this encourages us to perform a more rigorous analysis of the ECK hypothesis and to study in which stage of the process Ecuador is currently in, and

[6]Note that because the emission factors, given by the IPCC, do not change over the time, $D_{emf} = 1$ all the time and therefore it will not be shown in the tables.

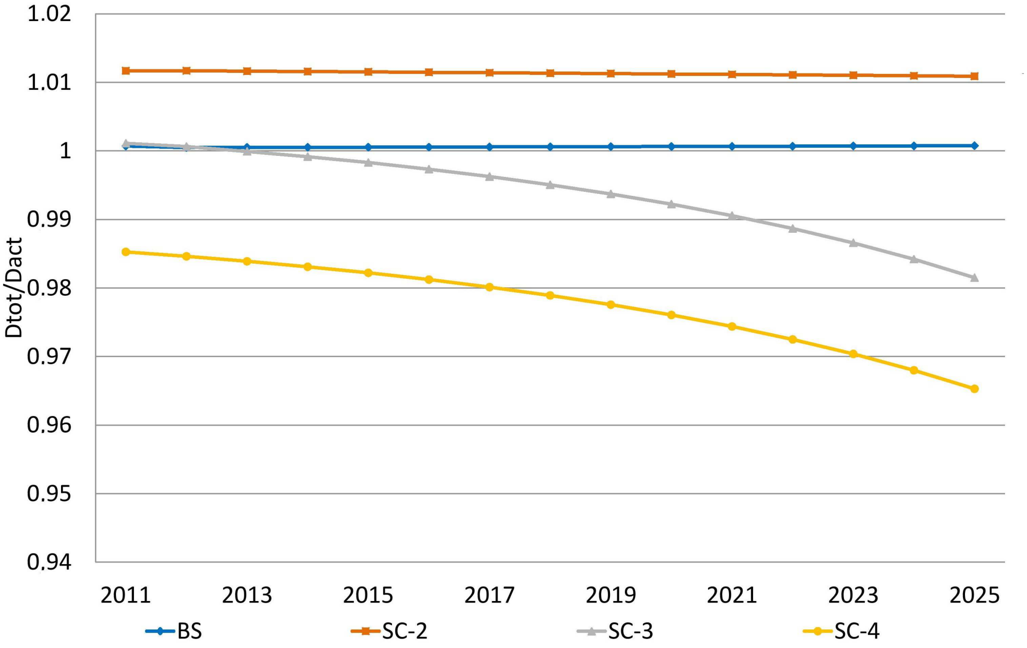

Figure 5: D_{tot}/D_{act} for the period $1980 - 2025$ (see text for definitions). Blue line with diamonds correspond to the *BS* scenario, orange line with squares to the *SC-2* scenario, gray line with triangles to the *SC-3* scenario, and yellow line with dots to the *SC-4* scenario.

will be in the coming future.

Table 2: Ng-Perron unit root test.

Variable	$\bar{M}Z_{\alpha}^{GLS}$	$\bar{M}Z_{t}^{GLS}$	$\bar{M}SB^{GLS}$	$\bar{M}PT^{GLS}$
$LGDP_t$	-3.488	-1.268	0.364	25.197
LCO_{2t}	-4.827	-1.532	0.317	18.750

3.2. EKC verification

We start the analysis testing the order of integration of both variables $LGDP_t$ and $LCO2_t$ using the tests of (Ng and Perron, 2001)[7]. The results

[7]These authors proposed using test statistics which are modified versions of Phillip-Perron and ADF tests. Such modifications improve the tests with regard to both size

are shown in Table 2, and according to them, the null hypothesis of no stationarity cannot be rejected, independently of the statistic used, for both series, $LDGP$ and $LCO2$. Accordingly, both series would be concluded to be I(1).

Once the order of integration of the series is analyzed, we will estimate the long-run regression model (Jaunky, 2011) using the Dynamic Ordinary Least Squares (DOLS)[8] estimation method of (Stock and Watson, 1993), following the methodology proposed by (Shin, 1994)[9]. This approach is similar to the KPSS[10] tests, which are implemented in two stages for the case of cointegration.

The first step in our estimation strategy would therefore consist of the estimation of the coefficients of a long-run dynamic equation (Jaunky, 2011) including leads and lags of the explanatory variables (GDP) in the long-run regression model, *i.e.* the so-called DOLS regression:

$$LCO2_t = \mu_0 + \mu_1 LGDP_t + \sum_{j=-q}^{q} \mu_j \Delta LGDP_{t-j} + \epsilon_j. \tag{10}$$

The second step is to use the statistic C_μ[11], a LM-type test designed by (Shin, 1994), to test the null hypothesis of cointegration against the alternative of no cointegration in a DOLS regression. In table 3 (Full sample column), we report the estimates from the DOLS regression and the results from Shin's test (Shin, 1994). Results show evidence of linear cointegration between CO_2 emissions and GDP, because we cannot reject the null hypothesis of cointegration, being the estimated value of the income elasticity of CO_2 emissions, $\mu_1 = 1.185$ which denotes little environmental responsibility, *i.e. Ecuador in 2010 is still in the first stage of the EKC.*

Our final aim is to verify whether the EKC applies to Ecuador in the medium term (up to 2025), or to know the ECK stage that the country

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distortions and power.

[8]Least squares estimation of equation might suffer two problems: endogeneity bias in the explanatory variables and nuisance parameter dependences due to serial correlation in the residuals.

[9]In order to overcome the problem of the low power of the classical cointegration tests in the presence of persistent roots in the residuals of the cointegration regression, (Shin, 1994) suggests a new test where the null hypothesis is that of cointegration.

[10]These tests are called the Kwiatkowski et al. (1992) tests, and assume the null hypothesis of stationarity.

[11]C_μ is the test statistic for deterministic cointegration, i.e., when no trend is present in the regression.

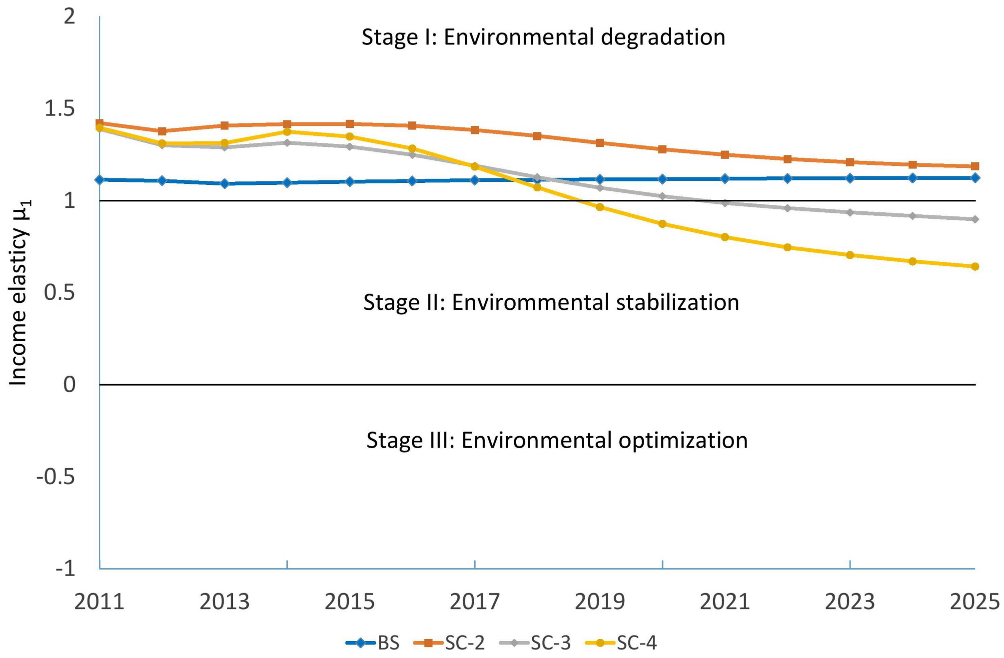

Figure 6: Evolution of CO_2-GDP elasticity for the period 2010 − 2025. Blue line with diamonds corresponds to the *BS* scenario, orange line with squares to the *SC-2* scenario, gray line with triangles to the *SC-3* scenario, and yellow line with dots to the *SC-4* scenario.

fulfils. To carry out this task, we perform the same process described above using the time series obtained in our model. The results are showed in Table 3. The resultd show that in any scenario, Ecuador exhibits the EKC. However, in *SC-3* and *SC-4* scenarios the income elasticity of CO_2 emissions is below 1, which means, that in these cases, Ecuador has reached a new stage of environmental responsibility. In particular, stage 2 of the EKC is closer in the 2020's decade than in first decade of the 21th century. Fig. 6 clearly illustrates this, where the μ_1 elasticity is plotted as a function of the year for the four scenarios under investigation. It is important to point out that Ecuador switches from the first to the second stage in 2019 and 2021 for scenarios *SC-4* and *SC-3*, respectively.

In conclusion, the changes introduced in the *SC-3* and *SC-4* scenarios, which suppose an increase in energy efficiency, changes in the energy matrix, the productive sectoral structure, and in the share of renewable energy to the total consumption, have induced a more environmentally sounding scenario.

Table 3: Stock -Watson-Shin's DOLS [a,b,c,d] estimation of linear cointegration.

Parameter estimates	Full sample 1980-2010	BS 1980-2025	SC-2 1980-2025	SC-3 1980-2025	SC-4 1980-2025
μ_0	-19.882***	-18.382***	-19.662**	-12.734	-6.454
	(1.692)	(0.212)	(2.500)	(2.386)	(3.455)
μ_1	1.185***	1.123***	1.185***	0.898***	0.641***
	(0.070)	(0.009)	(0.104)	(0.099)	(0.056)
R^2	0.998	0.999	0.995	0.989	0.982
Test: C_μ^c	0.132	0.071	0.113	0.131	0.152
σ^2	0.013	0.011	0.046	0.053	0.071

[a] Standard Errors (in brackets) are adjusted for long-run variance. The long-run variance of the cointegrating regression residual is estimated using the Barlett window which is approximately equal to INT($T^{1/2}$) as proposed in (Newey and West, 1987).
[b] We choose q=INT($T^{1/3}$) as proposed by (Stock and Watson, 1993).
[c] C_μ is a LM statistic for cointegration using the DOLS residuals from deterministic cointegration, as proposed Shin (1994). *, ** and *** denote significance at the 10%, 5% and 1% levels, respectively.
[d] The critical values are taken from table 1 and $m = 1$ of (Shin, 1994): C_μ 0.231 (10%) 0.314 (5%) 0.533 (1%)

The impact of GDP growth is somehow attenuated and the country moves towards a situation where the increase of the GDP will not lead to an unavoidable and uncontrolled increase of CO_2 emissions.

4. Summary, conclusions and policy implication

In this paper we have studied the EKC hypothesis for Ecuador in a forthcoming period, 2010-2025, using the model recently presented in Robalino-López et al. (2008) under four different scenarios. The model allows us to estimate the CO_2 emission as a function of global productive activity, the energy mix and industry sectoral structure, using the system dynamics methodology. In addition we use a GDP formation presented in Taichen et al. (2008) that depends on the renewable energy which creates a feedback mechanism that makes the model more reliable and allows us to obtain non-trivial conclusions in the analysis. The generated data under four different scenarios closely followed Jaunky's specification (Jaunky, 2011) to see whether the EKC is fulfilled, or not, in Ecuador and to calculate the elasticity between GDP and CO_2 emission.

First, a *BS* scenario (baseline scenario) was defined, in which the variables of the model were parameterized according to the observed tendency during the period 1980-2010. The second scenario, *SC-2*, is characterized by the doubling (relative to 2010) of GDP during the period 2011-2025. In the third scenario, *SC-3*, besides assuming the doubling of the GDP, we impose the decreasing of the fossil energy share up to 67%. Finally, in the fourth scenario, *SC-4*, we complement the *SC-3* scenario including changes in the productive sectoral structure to achieve a reduction of energy intensity, which supposes a lower CO_2 intensity.

We first performed a quantitative study of the CO_2-GDP relationship in four different scenarios using the LMDI (Ang, 2005). This technique allows us to factorize the CO_2 emission growth in its component factors. Understanding the driving forces of carbon emissions is essential to a robust policy-making process. In decomposition analysis, driving forces are specified as *scale*, *intensity*, and *structural* effects providing a useful tool to discuss policy levers to reduce emissions. In particular, we calculated the ratio D_{tot}/D_{act} as a function of the year and we have found that in the two first scenarios this ratio remains constant, while in the *SC-3* and *SC-4* scenarios this ratio steadily decreases as a function of the time. These results encouraged us to go a step further into a more rigorous study of the EKC hypothesis, in particular, using a long-run regression model.

In the analysis of the EKC hypothesis we conclude that in any case Ecuador exhibits the EKC, but the value of the CO_2-GDP elasticity allows us to separate the proposed scenarios in two families, on one hand *SC-1* and *SC-2*, and, on the other, *SC-3* and *SC-4*. In the first case, the elasticity is larger than one, while in the second case it is lower than one. Therefore, the first family implies little environmental respect, while the second family corresponds to a situation where the impact of the GDP growth is attenuated. Our estimates do indeed show that Ecuador will be able to enter the area of environmental stability (second stage of the ECK) in the medium term (2019-2021). Therefore, to achieve this goal it is essential to implement policies that allow the diversification of energy sources and to increase energy efficiency in the productive sectors in order to get more sustainable development.

This paper intended to fill the gap in the literature of studies on energy and CO_2 emissions in LA countries in general, and in Ecuador in particular.

On the other hand, this kind of study may help policymakers create more comprehensive and reliable policies for control of environmental degradation. Moreover this work contributes to the EKC literature with a case study of Ecuador using time series data for the period 1980-2010 and goes a step further with the study of a forthcoming period, up to 2025.

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