Economic growth, renewable energy and CO_2 emissions: the Kaya identity and the environmental Kuznets curve

García-Ramos, José-Enrique[1], Golpe, Antonio A.[2], Mena-Nieto, Ángel[3], and Robalino-López, Andrés[4]

1: Departamento de Física Aplicada, Universidad de Huelva, 21071 Huelva, Spain. e-mail: enrique.ramos@dfaie.uhu.es,

2: Departamento de Economía, Universidad de Huelva, 21071 Huelva, Spain. e-mail: antonio.golpe@dehie.uhu.es,

3: Departamento de Ingeniería de Diseño y Proyectos, Unversidad de Huelva, 21071 Huelva, Spain. e-mail: mena@uhu.es,

4: Escuela Politécnica Nacional, Quito, Ecuador. E-mail: andres.robalino@epn.edu.ec

Abstract. *This contribution presents a model for estimating CO_2 emissions in a given country for a near future. The model is based on a modification of the Kaya identity that allows to connect gross domestic product, productive sectoral structure, energy matrix, and energy intensity with CO_2 emissions. A key point in the model will be the introduction of a feedback mechanism involving the use of renewable energy. We will analyze the results on the light of the so-called environmental Kuznets curve. The model will be applied to the case of Ecuador and to the time period 2011-2015.*

Key words: CO_2 emissions, gross domestic product, Kaya identity, environmental Kuznets curve.

1. INTRODUCTION

It is a very complicated task to predict how much the economy of a given country will grow in the near future. This growth will strongly modulate CO_2 emissions of any country and therefore it will be crucial to make a realistic estimate of its emissions. On the other hand, the different feedback-mechanisms, both in the climatic and in the economic system make any prediction highly questionable beyond 5-10 years. However, it is critical to provide accurate information to policymakers in order to design appropriate energy policies for the near future.

This contribution presents a model that explores the relationship between economic growth, structure of the productive sectors, energy consumption, changes in the use of renewable energy, improvements in the efficiency of fossil energy, and CO_2 emissions. To illustrate the usefulness of the model we will apply it to Ecuador within the period 2011-2025. To estimate CO_2 emissions in the near future we will define different scenarios in both income and energy use.

The model is based on a variation of the Kaya identity (Kaya and Yokobori, (1990); Kaya, (1993)) and on an approach for the formation of gross domestic product (GDP) which includes a contribution from renewable energy (Chien and Hu, (2005)). The considered data for the application of the model to Ecuador corresponds to the period 1980-2010 and it has been extracted from official data sources such as: Ecuadorian Institute of Statistics and Census, Central Bank of Ecuador, World Bank, and International Energy Agency. The raw data has been processed using a Hodrick-Prescott filter (HP) (Hodrick and Prescott, (1997)) which allows to generate a smooth representation of a time series.

The Kaya identity is commonly used as an analytical tool to explore the main driving forces that control the amount of carbon dioxide emissions. The identity taken literally is almost a tautology, however it shows all its capabilities when used in the framework of scenario theory. According to this identity, CO_2 emissions of a given country could be broken down into the product of four factors: carbon intensity (defined as the CO_2 emitted per unit of energy consumed), energy intensity (defined as the consumed energy per unit of GDP), economic level (defined as GDP per capita), and population. Along this contribution we will present an extension of Kaya identity in which we will disaggregate in sectors and types of energy sources.

2. THE MODEL

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 CO_2 emission factors (model presented in Robalino et al (2014a) and Robalino et al. (2014b)). Moreover, we consider different sub-categories concerning the industrial sectors and the fuel type. The CO_2 emissions can be written as,

$$C = \sum_{ij} C_{ij} = \sum_{ij} Q \frac{Q_i}{Q} \frac{E_i}{Q_i} \frac{E_{ij}}{E_i} \frac{C_{ij}}{E_{ij}} = \sum_{ij} Q_i \times S_i \times EI_i \times M_{ij} \times U_{ij} \tag{1}$$

where C is the total CO_2 emissions (in a given year); C_{ij} is the CO_2 emission arising from fuel type j in the productive sector i (note that the index i runs over five productive sectors and the index j over five type of energy sources); Q is the total GDP of the country; Q_i is the GDP generated by the productive sector i; E_i is the energy consumption in the productive sector i; E_{ij} is the consumption of fuel j in the productive sector i, verifying that the total consumed energy, $E=\sum E_{ij}$; S_i (Q_i/Q) is the share of sector i in the total GDP; the energy intensity of sector i is given by EI_i (E_i/Q_i); the energy matrix is given by M_{ij} (E_{ij}/E_i) and the CO_2 emission factor by U_{ij} (C_{ij}/E_{ij}). Throughout this work, as a convention, we will always refer to the productive sector with the i index and to the type of energy source with the j index. This equation is an extension of the Kaya identity because we disaggregate in type of productive sector and kind of fuel used, while in the original formulation only aggregated terms are considered: C, Q, and E.

As will be shown later, the raw data to perform the model corresponds to the official available data as provided by international and national agencies. The subsequent data analysis and the preprocessing of the time series were performed using the Hodrick–Prescott (HP) filter (Hodrick and Prescott, (1997)), which allows isolation of outliers (economic crises, random behavior of markets, etc.) and to determine the trend of the time series under study. After that, it is possible to perform more adequate estimations. The smoothing parameter λ of the filter, which penalizes acceleration in the trend relative to cycle component, needs to be specified. Most of the business cycle literature use past data and a value of the smoothing parameter λ equal to 100 (Hodrick and Prescott, (1997)). Indeed, all time series used in this paper have been computed using the HP filter with a λ value of 100.

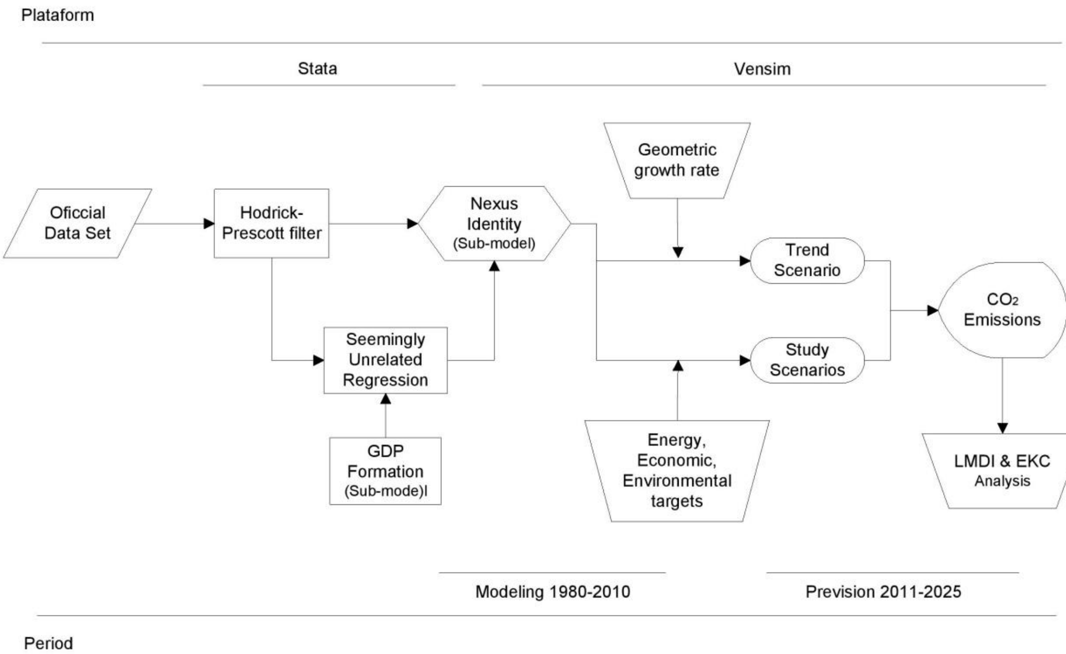

Figure 1: Schematic diagram of the methodology used to build the model.

The simulation period extends from 1980 to 2025, where 1980–2010 is used to fix the parameters of the model and 2011–2025 corresponds to the forecast period, under the assumption of different scenarios concerning the evolution of the GDP, the evolution of the energy mix, and the efficiency of the used technology in minimizing the CO_2 emissions. The geometric growth rate (Rowland, (2003); Jin et al., (2009)) has been used to extrapolate the trends into the forecast period and an ordinary linear regression has been implemented to fix the parameters of the GDP formation. Figure 1 shows, in a schematic way, how the calculations have been performed using the different techniques described in previous paragraphs.

2.1 Economic model

In this section we will review the work of Chien and Hu (2008) that broadens the perspective of environmental economics to include an analysis of renewable usage directly contributing to the important elements of economies or regional development. Domac et al. (2005) suggest that renewable energy increases the macroeconomic efficiency by the following process: i) the business expansion and new employment brought by renewable energy industries result in economic growth; ii) the import substitution of energy has direct and indirect effects in increasing income of the economy and trade balance.

Measured by expenditures, GDP is the sum of goods and services produced during a giving period. Total output comprises four groups' purchases of final goods and services: i) households purchase consumption goods; ii) businesses purchase investment goods (and retain unsold production as inventory increases); iii) governments purchase goods and services used in public administration and iv) welfare transfers; and foreigners purchase (net) exports.

The expenditure approach estimates GDP by the following equation:

$$GDP = C + I + G + X - M \quad (2)$$

where:

- C (consumption) is normally the largest GDP component in the economy, consisting of private (household final consumption expenditure) in the economy.
- I (investment) includes, for instance, business investment in equipment, but does not include exchanges of existing assets.
- G (government spending) is the sum of government expenditures on final goods and services.
- X (exports) represents gross exports. GDP captures the amount a country produces, including goods and services produced for other nations' consumption, therefore exports are added.
- M (imports) represents gross imports. Imports are subtracted since imported goods will be included in the terms G, I, or C, and must be deducted to avoid counting foreign supply as domestic.

Closely following Chien and Hu (2008), in Figure 2, the diagram shows that the use of renewables influences GDP through two paths: i) the emergence of renewable energy industries brings about business expansion, which results in increased capital formation; and ii) the import substitution of traditional energy by locally produced renewables has direct and indirect effects on increasing trade balance in an economy. The increases of capital formation and trade balance would lead to the increase of the GDP.

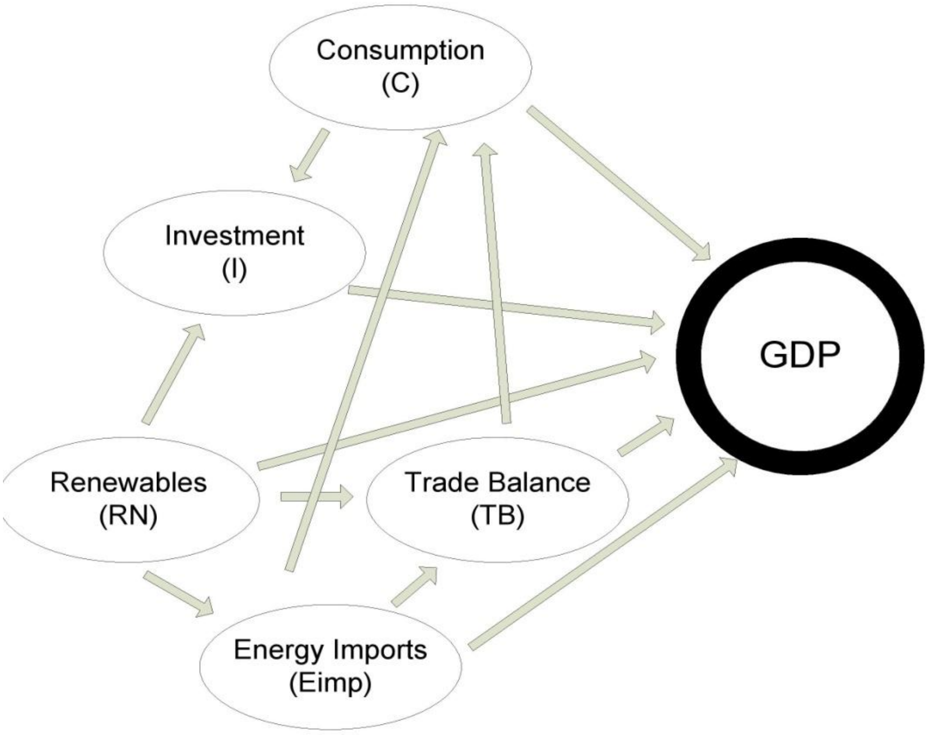

Figure 2: Schematic diagram of the methodology used to build the model.

The system of theoretical GDP formation model is made up by the following equation (see Figure 2):

$$Q = a_1 I + a_2 TB + a_3 C + a_4 Eimp + a_5 RN + \epsilon_1 \quad (3)$$

where Q refers to GDP of the country, *Eimp* is the energy import, *RN* is the renewable energy and ϵ_1 is a residual.

a_1	a_2	a_3	a_4	a_5 (10^4 USD/toe)
1.16	0.99	1.21	0.05	-0.50

Table 1: Coefficient appearing in Eq. 3. All coefficients with a significance at the 1% level.

In Equation (3), income Q is influenced by invest (*I*), trade balance (*TB*), and consumption (*C*). Chien and Hu (2007) suggested that energy imports may affect income. Coefficients of Eq. (3) should be fixed through a least squares fit to data of the reference period (1980-2010). In Table 1 we present the values of the coefficient obtained after the fit procedure. Note the negative value of coefficient a_5 in Table (1) for the case of Ecuador. Note that this coefficient can become positive in other countries as in the case of Venezuela (Robalino-López et al., (2015)).

2.2 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 kt of oil equivalent (ktoe). Energy intensity is defined as the ratio of energy consumption and GDP.

The usual standard division of productive sectors follows the ISIC specification (International Standard Industrial Classification of All Economic Activities, Rev.4), but taking in account the availability of data, we follow for Ecuador the division of the productive sectors given in Mosquera (2008): i) agriculture, fishing and mining (sec-1), ii) industry (sec-2), iii) construction (sec-3), iv) trade and public services (sec-4), and v) transportation (sec-5).

Sectors will be represented inside the model by their contribution to the country's economy (S_i), by their energy intensity (EI_i), and by their energy mix (M_{ij}). Energy intensity measures the amount of energy required per unit of consumption or product, expressed in terms of a value which is determined by the used sources which have different caloric powers and by the equipment used with different technologies and efficiency levels. Note that the different economic sectors have different intensive use of energy. 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. Index i runs over each sector of the productive sectoral structure and index j runs over each kind of fuel: natural gas (j=1), coal (j=2), petroleum (j=3), renewable (j=4), and alternative energy (j=5).

CO_2 intensity ($CO2_{int}$) 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.

$$CO2_{int} = \frac{\sum C_{ij}}{\sum E_{ij}} \tag{4}$$

The value of the $CO2_{int}$ in a given year depends on the particular energy mix during that year. M_{ij} gives the energy matrix, but we can also define the sum over the different sectors and aggregate the fossil fuel contributions, therefore, we have:

$$M_j = \frac{\sum E_{ij}}{\sum E_{ij}} \tag{5}$$

On one hand, M_1, M_2, and M_3 correspond to the energy consumption from natural gas, coal, and petroleum, respectively. Therefore, the share of fossil energy in the total consumption will be $M_1+M_2+M_3$. On the other hand, M_4 and M_5 stand for the energy consumption from renewable and alternative sources, respectively. Therefore:

$$M_1 + M_2 + M_3 + M_4 + M_5 = 100 \tag{6}$$

In order to simplify the description, we assume that M_4 and M_5 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).

2.3 Model equations

Below we summarize the difference equations that are used in each submodel:

$$\begin{gathered} Q_{(t)} = a_1 I_{(t)} + a_2 TB_{(t)} + a_3 C_{(t)} + a_4 Eimp_{(t)} + a_5 RN_{(t-1)}, \\ E_{j\,(t)} = \sum S_{i(t)}\, EI_{i(t)} M_{ij\,(t)} GDP_{(t)}, \\ RN_{(t)} = E_{4(t)} + E_{5(t)}, \\ y_{(t)} = y_{(t-1)}\left(1 + r_y\right), \end{gathered} \tag{7}$$

where $S_{i(t)}$, $EI_{i(t)}$, $M_{ij(t)}$, $I_{(t)}$, $TB_{(t)}$, $C_{(t)}$, and $Eimp_{(t)}$ evolve following last line of Equation (7) while the parameters a_i have constant values. Note that index *j* runs over the type of energy sources, while *i* on the industrial sectors; *j*=4 and *j*=5 corresponds to renewable and alternative energy, respectively. *t*=0 corresponds to the base year and *t* is given in number of years since 1980. The value of r_y is fixed through the definition of the used scenario. In the case of the BS scenario, to extrapolate the trend of the period 1980-2010, one should use a value of r_y that depends on the time,

$$r_{y(t)} = \left(\frac{y_{(t-1)}}{y_{(t-n)}}\right)^{1/n} - 1, \tag{8}$$

where *n* is the number of years of the dataset period, i.e., 31 in our case. The feedback mechanism is provided through the inclusion of $RN_{(t-1)}$ in the calculation of the income (Q) in Equation (7). This is one of the keys of the model, which allows us to generate a non-trivial evolution of the system. As $a_5<0$ (see Table (1)) the feedback mechanism is negative. This fact induces a decrease of the GDP for the SC-3 and SC-4 scenarios with respect to SC-2 (see section 3) for increasing of renewable energy use. In general, any increase of the terms $\sum S_{i(t)}\, EI_{i(t)} M_{ij\,(t)}$ for *j*=4 and *j*=5 will induce a reduction, though moderate, of the income.

3. SCENARIOS

Scenario analysis is used in a wide range of purposes in the literature. The primary function of the scenario approach in economy growth, energy consumption and emission in this research is to respond to uncertainty and potentially to develop strategic insights for policy.

Rather than prediction, scenario approach seeks to describe a *spectrum of possibilities*. This is a bounded package of probability that could cover the range of plausible outcomes. Economic and environmental scenarios are used in contexts where dynamic complex systems are subject to uncertainties.

The goals that will be considered to define the different scenarios that will be proposed, under the general purpose of *improve the quality of life of people with the least environmental impact* are:

- *Goal 1*, by 2025 the GDP per capita will reach the international average (approximately 15000 USD according to our estimates based on World Bank data) through a process of industrialization and improvement of the productive sectoral structure of the country;

- *Goal 2,* in regard to the *Goal 1*, the use of renewable energy will be increased up to almost 30% of the total energy consumption;

- *Goal 3*, in regard to *Goal 1* and *Goal 2*, the energy efficiency will be enlarged by a reduction of the energy intensity and by changes in the productive sectoral structure.

Taking into account the latter goals, we propose four scenarios concerning the growth of the income, the evolution of the energy matrix and of the productive sectoral structure for the period 2011-2025.

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. *Increasing GDP scenario (SC-2)*: GDP will increase approximately up to be double of reference GDP (2010) by 2025. To generate this scenario a constant annual growth of GDP formation components (I, TB, C, Eimp, see Section 2) 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 GDP share (S_i) in the sectors with more profit in the country economy: industry sector (sec-2) and trade and public service sector (sec-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. *Increasing GDP and share of renewable energies scenario (SC-3)*: increasing GDP and change in productive sectoral structure as in the *SC-2* scenario is considered, however the share of fossil energy, 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 share in renewable and alternative energy (M_4 and M_5). This scenario shows a first measure of environmental responsibility in order to try to reduce dependence of fossil energy.

4. *Increasing GDP and share of renewable energies and improvement in energy efficiency scenario (SC-4)*: increasing GDP, change in productive sectoral structure and change in share of fossil energy as in *SC-3* scenario is carried out. Moreover, an improvement in energy efficiency is implemented with a 1% reduction of energy

intensity in industry sector (sec-2), in trade and public services sector (sec-4) and in transportation sector (sec-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* scenarios goals are realistic considering the state of development and evolution of energy technology in various energy projects implemented by the Ecuadorian government, and the trends in the use of renewable energies in the country (Mosquera, (2008)).

4. RESULTS

This section includes the estimations and respective discussion for the period 2011-2025 in each studied scenarios of the main considerate variables, such as: income and income per capita, energy consumption and CO_2 emissions, among others.

GDP estimates for the two types of economic scenarios considered (on the one hand the *BS* and on the other hand *SC-2, SC-3* and *SC-4*) are presented in left panels of Figure 3, where one can see that the estimated GDP for the *SC-2* scenario will be around 271 billion USD (BUSD) in 2025 (61% higher than for *BS* scenario) and its average growth rate is 6.6% while in *BS* scenario is 3.2%. Note that the projected GDP is not a forecast but a consequence of the considered scenarios. Assuming an annual increase of the population of 1.2%, the population will pass from 14.5 million in 2010 to 17.6 million in 2025, thus GDP per capita in 2025 will be around 15000 USD (see left panels of Figure 3), which is roughly the prevision that has been considered as the international average of GDP per capita.

In *SC-3* and *SC-4* scenarios, GDP would be lower than in *SC-2* scenario with a reduction of 27 and 20 BUSD, reaching 244 and 251 billion BUSD in 2025, respectively, due to the promotion of renewable energy and energy efficiency (see left panels of Figure 3). The nexus between GDP and renewable energy is obtained through the feedback mechanism of the model (see Section 2). In *SC-4* scenario the reduction in GDP is slightly smaller (about 7 billion USD regarding the reduction in *SC-3*) because of the improvement in the energy intensity. Note that the tiny deviations between *SC-2*, *SC-3* and *SC-4* scenarios are due to the feedback mechanism between GDP and renewable energy.

Energy consumption is calculated through the product of the energy intensity of each productive sector (EI_i) and the corresponding share of the GDP (Q_i) of every sector. The values of the energy consumption for the period 2011-2025 are represented in mid panels of Figure 3. In 2025 the *BS* scenario generates a consumption of 20520 ktoe, the *SC-2* scenario about 36040 ktoe (76% higher than the *BS* scenario), and the *SC-3* scenario generates a consumption of 32425 ktoe (58 % higher than the *BS* scenario). These two last scenarios show the growth of the energy consumption due to the increase of GDP and to the changes of the productive sectoral structure. Finally, *SC-4* scenario generates a consumption of 26740 ktoe (only 30% higher than in the *BS* scenario). It clearly shows the benefits of the reduction of the energy intensity.

In mid panels of Figure 3, we can see that there are three pathways followed by the different proposed scenarios, the most energetically intensive is the path followed by *SC-2* and *SC-3* (indistinguishable in the used scale), due to its larger energy consumption and low energy efficiency goal. Indeed, in these scenarios the energy intensity increases more than 15% (period 2011-2025). The path taken by *SC-4* is clearly the most energetically efficient, with a reduction of 6 % in energy efficiency, while *BS* follows the trend path with an increase of 7 % in the whole period.

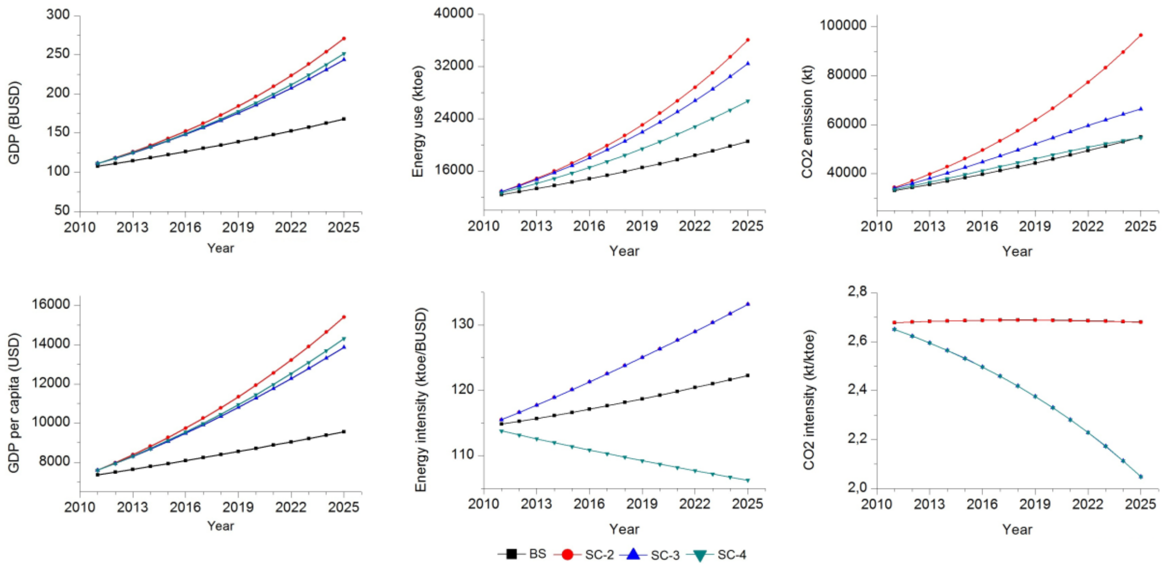

Figure 3: Left panels for estimation of the GDP and GDP per capita for the period 2011-2015 in Ecuador. Mid panels for estimation of the energy consumption and energy intensity. Right panels for estimation of CO_2 emissions and CO_2 intensity.

Regarding energy matrix, two types of evolution have been taken into account in the calculations, in particular, for the share of fossil energy inside of the energy matrix and its components (M_1, M_2, and M_3). In the first case (scenarios *BS* and *SC-2*), the evolution of fossil energy keeps the tendency of the period 1980-2010. In the second case (scenarios *SC-3* and *SC-4*), a continuous drop of the use of fuel energy down to 67% in 2025 due to an approximate increase of one point per year of renewable energy share (see mid panels of Figure 3).

A very important result is that the reduction of the global CO_2 intensity 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 hand, due to the reduction of the fossil energy share in the energy matrix. Both contributions are equally important. Note that the 2011-2025 period presents different evolution of the global CO_2 intensity. In both *BS* and *SC-2* scenarios the value CO_2 intensity was almost constant (2.7 kt/ktoe) and in *SC-3* and *SC-4* scenarios a decreasing trend was shown, going from 2.7 to 2.1 kt/ktoe between 2011 and 2025 (see right panels of Figure 3).

Right panels of Figure 3 show CO_2 emissions as a function of time for the period 2011-2025, under the four considered scenarios. In 2025, the highest CO_2 emission corresponds to the *SC-2* scenario, while the lowest corresponds to the *SC-4* scenario. The *SC-3* and *SC-4* scenarios, which imply the continuous growth of the GDP and the application of attenuation measures, with a reduction of the fossil energy contribution to the energy matrix and changes in the productive sectoral structure, present a clear reduction of CO_2 emissions with respect to the *SC-2* scenario. In particular, in 2025 CO_2 emissions would reach 97 thousand kt in *SC-2* scenario, and only 55 thousand kt in *BS* scenario. With the reduction of fossil energy, down to 67 % in *SC-3* scenario, without modifying the energy intensity, one reaches 66 thousand kt, while implementing energy efficiency measures in the productive sectoral structure (*SC-4* scenario) emissions are reduced down to 54 thousand kt.

The *BS* scenario presents CO*2* emissions in 2025, 1.7 times higher than in 2010, while the *SC-2* scenario gives rise to an increase of 2.8 times. This implies that the amount of CO_2 emissions in the *SC-2* scenario during the period 2011-2020 will be 260 thousand kt higher than in the *BS* scenario. Scenarios where renewable energy and efficiency goals are implemented show that it is possible to increase the GDP in a constant way, mitigating, at the same time, the CO_2 emissions, therefore reducing the rise of the emissions due to the higher economic activity. In particular, the most efficient scenario, *SC-4*, presents a remarkable reduction. In 2025 CO_2 emissions will be 43 % lower than in the *SC-2* scenario. Furthermore, the *SC-3* scenario generates 115 thousand kt more than *BS* scenario during the 2011-2025 period, which supposes a reduction of 30 thousand kt with respect to *SC-2* scenario. Finally, the *SC-4* scenario generates 300 kt less than *BS* scenario during the same period, which supposes a large reduction of 41 thousand kt with respect to the *SC-2* scenario.

5. THE ENVIRONMENTAL KUZNETS CURVE

Kuznets (1955) stated that the changing relationship between per capita income and income inequality is an *inverted-U-shaped* curve. As per capita income increases, income inequality also increases at first and then starts declining after a *turning point*. In other words, the distribution of income becomes more unequal in early stage of income growth and then the distribution moves towards greater equality as economic growth continues (Kuznets, (1955)). This observed empirical phenomenon is popularly known as the Kuznets curve.

In the 1990s and onwards, the Kuznets curve took a new existence. There were evidences that the level of environmental degradation and the per capita income follows the same inverted U-shaped relationship as does income inequality and per capita income in the original Kuznets curve. Now, Kuznets curve has become a tool for describing the relationship between measured levels of environmental quality (for example, emissions of CO_2) and per capita income. This inverted-U-shaped relationship between economic growth and measured pollution indicators (environmental quality) is known as the Environmental Kuznets curve (EKC).

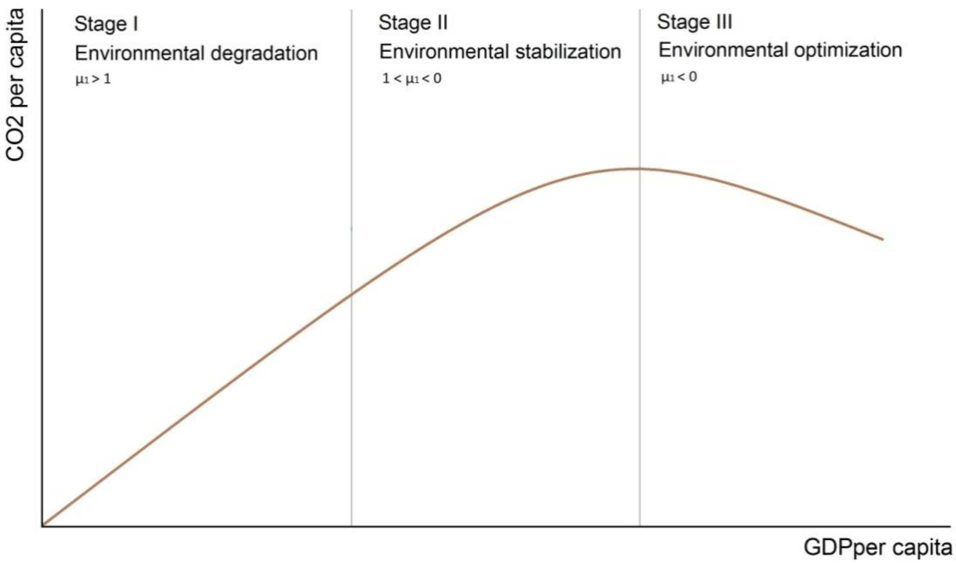

Figure 4: Schematic plot of the relationship between the per capita income and the CO2 emission: 1) linear growth of the pollution with the GDP, 2) stabilization, and 3) reduction of the emissions with the increase of the income.

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, (2003); Cole, (2005); Galeotti, (2006); Esteve, (2012)). However, in many cases the evidences of the EKC hypothesis is weak. Another way to test the validity of the EKC assumption is to compare the long and the short run impact of income on emissions (Jaunky (2011)). Whatever approach is used or set of countries studied, analysis always uses past data and there are no studies where the EKC 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 (income, 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. 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 of the income. The different phases of the EKC are depicted schematically in Figure 4.

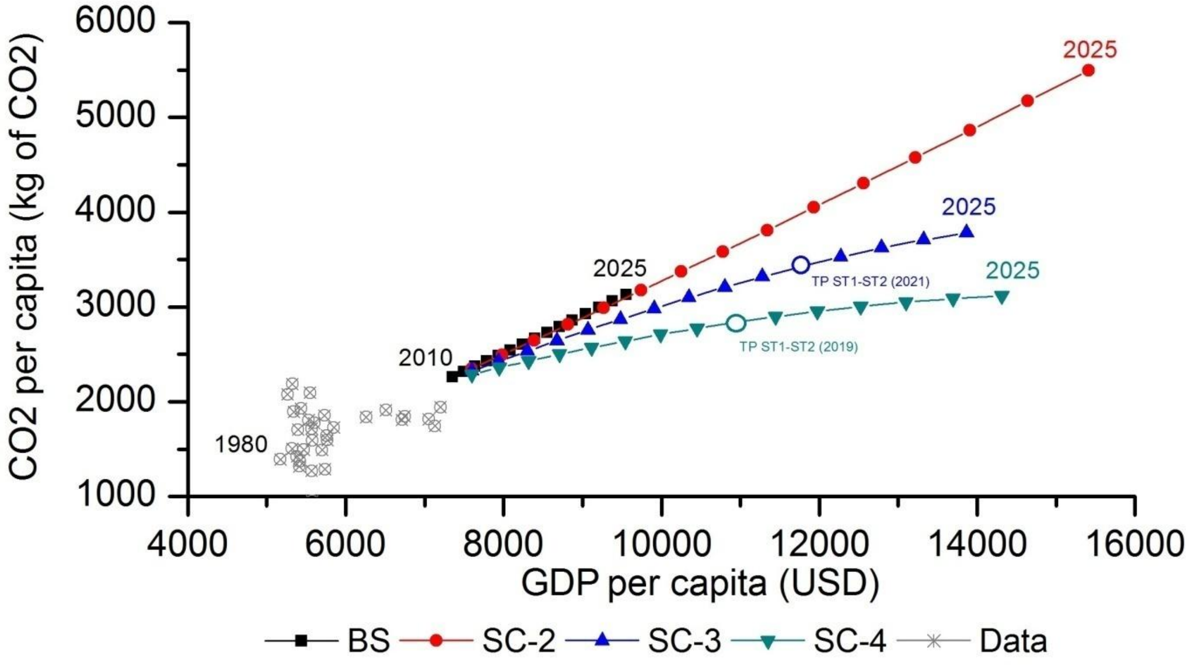

Figure 5: GDP per capita versus CO2 emission per capita for the period 2011-2025 in Ecuador.TD stand for turning point.

Along this section we will study of the EKC hypothesis following Jaunky's specification (Jaunky (2011)) but including a forthcoming period (2011-2025) which up to our knowledge was never considered in the literature.

In Jaunky (2011) the author tries to test the EKC hypothesis in a set of high-income countries for the period 1980-2005. The lower long-run income elasticity does not provide evidence for the EKC, but it indicates that CO_2 emissions are stabilizing in developed countries. Therefore, the extension of this work to other countries and to a forthcoming period is of interest.

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 in Figure 5 CO_2 emission per capita as a function of GDP per capita. According to this figure it seems that the different scenarios generate different regimes and the environmental impact is attenuated in some cases, specially, for *SC-3* and *SC-4* scenarios. The dots denoted by TP correspond for the turning points, i.e., the year in which one passes from stage 1 to stage 2 in the EKC.

To estimate more quantitatively the fulfillment of the EKC hypothesis we follow the Jaunky's specification (Jaunky, (2011)) for testing the EKC hypothesis in Ecuador. The first step in our estimation strategy would therefore consist of the estimation of the coefficients of a long-run dynamic equation including leads and lags of the explanatory variables (GDP) in the long-run regression model, i.e., the so-called Dynamic Ordinary Least Squares regression:

$$LCO2_t = \mu_0 + \mu_1 LGDP_t + \sum \mu_j \, \Delta LGDP_{t-j} + \epsilon_{j.} \qquad (9)$$

In the first region of the simplified Kuznets curve (Figure 4), 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 (*environmental degradation*). 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 mean that the country enters into a phase with intensive use of green technology and e*nvironmental optimization*

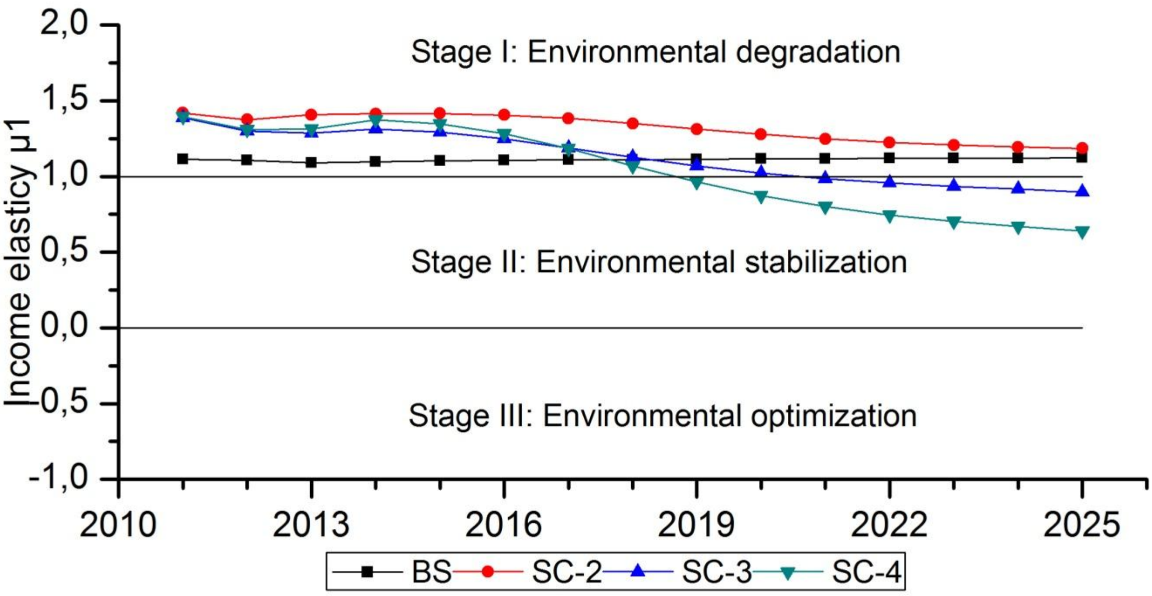

Figure 6: Evolution of CO2-GDP elasticity for the period 2010-2025 in Ecuador.

The results from our analysis are depicted in Figure 6 where the μ_1 elasticity is plotted as a function of the year for the four scenarios under investigation and show that in no scenario Ecuador fulfills the EKC hypothesis. 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 2020s decade than in first decade of the 21th century. 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. 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.

6. CONCLUSIONS

In this paper we have presented a model for estimating CO_2 emissions in a forthcoming period, starting from the Kaya identity and then disaggregating the different factors that made up the identity. In addition we have used a GDP formation as presented in Chien and Hu (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 model has been presented recently in Robalino-López et al. (2014a, 2014b, 2015). We have applied the model to Ecuador in a forthcoming period, 2010–2025 under four different scenarios and moreover we have checked the fulfillment of the Environmental Kuznets Curve hypothesis.

The model allows us to estimate the CO_2 emission as a function of global productive activity, the energy mix and industry sectoral structure. First, a *BS* 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 (in 2020 relative to 2010) of GDP. 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 CO2 intensity. The generated data under the four different scenarios allowed us to see whether the EKC is fulfilled, or not, in Ecuador and to calculate the elasticity between GDP and CO_2 emission.

One of the main conclusions of this work is that in the case of Ecuador it is *possible* to moderate the increase of CO_2 emissions even under a scenario of rapid economic growth. The reduction is twofold, on one hand, due to the increase of the use of renewable energy and, secondly, due to the improvement in the energy intensity. In the case of Ecuador the existence of potential renewable energy sources, still unexploited, make feasible, to increase the use of renewable energies. On the other hand the improvement in the energy intensity proposed in the *SC-4* scenario (1% yearly) is, to our knowledge, rather realistic. In this sense we use the term *possible*, however we do not discuss which kind of policy and type of technology should be implemented to reach this goal.

7. ACKNOWLEDGEMENT

This work has been supported by the Spanish Ministerio de Economía y Competitividad and the European regional development fund (FEDER) under project number FIS2011-28738-C02-02. One of the authors (A.R.L.) gives special thanks to the SENESCYT (Ecuador) and the AUIP (Spain) for the institutional and financial support.

REFERENCES

Canas, A., Ferrao, P., Conceicao, P. (2003). An environmental Kuznets curve? Relationship between direct material input and income per capita: evidence from industrialized countries. *Ecol.Econ.* 46: 217–229.

Chien T. and Hu J.L. (2005). Renewable energy and macroeconomic efficiency of OECD and non-OECD economies. *Energy Policy 35: 3606–3615.*

Cole, M., (2005). Re-examining the pollution–income relationship: a random coefficients approach. *Econ.Bull.*14(1): 17.

Domac J., Richards K., Sarafidis S. (2005). Socio-economic drivers in implementing bioenergy projects. *Biomass Bioenergy 28: 97-106.*

Esteve, V., Tamarit, C., 2012b. Is there and the environmental Kuznets curve for Spain? Fresh evidence from old data. *Econ. Model.* 29 (6):23.

Galeotti, M., Lanza, A., Pauli, F. (2006). Reassessing the environmental Kuznets curve for CO_2 emissions: a robustness exercise. *Ecol.Econ.* 57:152–163.

Hodrick R., Prescott E. (1997). Postwar U.S. business cycles: an empirical investigation. *J Money Credit Bank Feb. 29(No. 1):1–16.*

Jin Y., Yumi T., Tatsuya T., Shigehide S., Kei-ichi T. (2009). Mathematical equivalence of geometric mean fitness with probabilistic optimization under environmental uncertainty. *Ecol Model 220:2611-2617.*

IPCC, Intergovernmental Panel On Climate Change (2006). IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme. Technical Report. IPCC – Intergovernmental Panel On Climate Change.

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

Kaya Y. (1990) Impact of Carbon Dioxide Emission Control on GNP Growth: Interpretation of Proposed Scenarios. *Paper presented to the IPCC Energy and Industry Subgroup, Response Strategies Working Group, Paris, (mimeo).*

Kaya Y, Yokobori K. (1993) Environment, energy, and economy: strategies for sustainability. *Conference on global environment, energy, and economic development. Japan ,Tokyo*.

Mosquera A. (2008) Policies and strategies for changing the energy matrix in Ecuador. Ministry of Electricity and Renewable Energy (Ministerio de Electricidad y Energía Renovable, Ecuador).

Robalino-López A., Mena-Nieto A., and García-Ramos JE. (2014a). System dynamics modeling for green energy consumption and CO2 emissions: a case study of Ecuador. *Energy Sustain Dev* 20:11–20.

Robalino-López A., García-Ramos J.E., Golpe A.A., and Mena-Nieto A. (2014b). System dynamics modelling and the Environmental Kuznets Curve in Ecuador (1980–2025). *Energy Policy* 67:923–31.

Robalino-López A., Mena-Nieto A., García-Ramos J.E., and Golpe A.A., (2015). Studying the relationship between economic growth, CO_2 emissions, and the environmental Kuznets curve in Venezuela (1980–2025). *Renew Sustain Energy Rev* 41:602–614.

Rowland D. (2003). Demographic methods and concepts, chap 2, population growth and decline. Oxford University.