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Environmental Kuznets Curve: An Updated Empirical Vision for Ecuador

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***Abstract* – The Environmental Kuznets Curve provides a conceptual and empirical tool to discuss the relationship between economic development and environmental deterioration in the advancement of the study of the Anthropocene. The analysis is performed using World Bank data from 92 countries with at least 60 interludes and is subjected to a polynomial function model. The results show that the curve is N-shaped for countries with high per capita income. The fulfillment of the turn for Ecuador is related to a trend that can accept the assumption of the Kuznets Environmental Curve. Likewise, the study is limited to the ambiguities in the heterogeneity between countries, therefore, the analysis of the effectiveness of environmental policies, spatial variations and the long-term trend is recommended as future research.**

***Keywords* – Economic growth, CO2 emissions, Environmental Kuznets Curve, environmental degradation, pollution.**

1. Introduction

In the 70s and 80s, there was a pessimistic Outlook on the planet's future. For instance, in 1972, the Club of Rome published a comprehensive study on “The Limits of Growth,” focusing on the shortage of various non-renewable resources [1].

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In the 90s, the issue of the environment was featured on the front pages of newspapers and scientific journals, which mitigated some environmental issues to a large extent in developed countries. However, in developing countries, ecological pressures grew as industrialization and rapid growth often progressed. For example, the World Bank [2], in its “World Development Report,” stated that the concentration of smoke and heavy particles in the air of cities in developing countries was more than five times higher than in the towns of developed countries.

In recent years, the perception of environmental problems has significantly changed. Researchers have begun to ponder the relationship between the economy and the environment, as it plays an essential role in public policies [3]. Improvements in environmental indicators related to economic indicators are often used to explain progress in using natural resources. The Environmental Kuznets Curve (EKC) presents the connection between economic development and the degree of pollution by an inverse U-shaped curve [4], [5]. This means that the environmental indicators first grow with a slight growth of the economic indicator. Since its discovery in 1992, the concept has been used to explain the evolution of ecological degradation through economic development [6].

The goal of this research is to update the empirical studies to validate the supposition of the EKC that corresponds to the data of Ecuador and, in turn, observe through this supposition the stage of development that can be attributed to decision-making in public policies oriented to economic and environmental well-being.

Academic Literature on the Environmental Kuznets Curve

The EKC relationship was defined for the first time by Grossman & Krueger [7], who participated in an environmental impact study by North American Free Trade Agreement (NAFTA). The concept of EKC was disseminated by the World Bank Development Report in 1992, based on a survey [8]. Panayotou [9] named the concept for the first time.

Since then, numerous studies have been published on several polluting indicators.

The EKC raises the relationship concerning the level of CO2 emission and the economic development of a country, often measured by gross domestic product - GDP [10], [11].

In general, economic growth begins with the development of agriculture and the exploitation of other resources. At some point, utilization is greater than the regeneration of resources and the production of waste growth; at this stage of economic development, the environmental impact is growing. At a higher level of economic growth, there is a shift towards information-intensive industries and a higher level of environmental awareness [12], [13], [14].

The last stage results in better production technology and higher environmental protection expenses. As a result, there are restrictions on ecological impact, and the environmental indicator decreases with increasing economic development. In other words, the environmental impact is minimized proportionally faster than the GDP per capita [15], [16]. The EKC supposition explains the correlation amongst income and environment through an inverse U-shaped curve [17], [18], [19].

Several economic factors, such as production, utilization, and investment, speak of the existence of an EKC. Production influences the quality of the environment through three effects, the scale effect, the compositional effect, and the technological effect. The scale effect explains the dependence on the output of the resources used. Production can stimulate growth proportionately, equally, or weaker if all inputs are raised by a specific factor [20], [21]. There is talk of stable economies of scale when a particular factor's growth in the information grows the output by the same factor [22]. Therefore, according to constant economies of scale, the level of environmental pollution rises by the same percentage as the economy. Economies of scale harm the ecological implications [22].

The composition effect explains the connection of economic growth with the change in the structure of an economy in the course of development. In contrast, the technological impact mentions that research spending grows with income [23].

The behavior of the curve differs concerning developed and developing countries; in the case of developed economies, they invest a considerable amount of funds for research and development of technologies since they advance faster and faster [25]. Technological progress results in substituting "dirty" technologies with "clean" technologies and, in turn, gains in production efficiency. Therefore, the effects of composition and technology have an affirmative influence on the quality of the ecosystem [26].

As income grows, so does the demand for a cleaner environment. People with higher incomes value preserving a cleaner environment and, therefore, spend more money on "green" consumer goods. In addition, they grow the pressure for economic regulation through environmental protection policies and expenses [27], [28].

In the case of developing economies, they pay little or no attention to environmental quality. The awareness of investing in a clean environment is growing proportionately more than income [29]. Environmental quality is a luxury item that gains value through education and awareness.

The assumption that a highly developed country can achieve a more significant proportion of the value added in the modern service sectors and growth energy efficiency can be found in study [30]. At the same time, energy-intensive industries are displaced from the domestic economy to countries with lower environmental standards and low per capita income. This mechanism is known as the effect of carbon leakage [31]. This is why recent studies include international trade as a significant contributor to the explanation of the EKC. Work leads to economic growth and, therefore, to more considerable pollution. At the same time, trade growth is the motivation to protect the environment [32].

This is why it is essential to empirically verify the supposition of the EKC; subsequently, it can validate an aid for the environment that would have pleasant long-term consequences through economic and technological development, at least the dependence could be reduced on long-term fossil fuels [33]. According to Ecuador's data, this could quantify current public policies and revise new approaches for sustainable development, pleasing to the various economic agents in the short and long term [34].

2. Methodology

This quantitative study follows a mathematical order with econometric techniques for predicting the behavior of the studied phenomenon. To comply with the research objectives, the World Bank's documentary and database review was to gather the information from the official website, which was later sustained by several public and/or private organizations with their corresponding specialties.

The samples explored are the indicators NY.GDP.PCAP.KD (The World Bank code is included to guarantee the replicability of the analysis), which expresses the GDP per capita data, being the ratio of the Gross Domestic Product and the population of a country; the unit of this variable is in US dollars at constant prices of 2010.

The second variable is EN.ATM.CO2E.PC, which expresses carbon dioxide emissions from the burning of fossil fuels and cement manufacturing, including production during the utilization of solid, liquid, gas, and gas burning, the unit of this variable is in metric tons per capita. The study interludes were from 1960 to 2021. The evidence was managed in the RStudio Statistical Platform.

The studies will be updated with the following information to review compliance with the supposition of the EKC, which will use the econometric model.

$$CO2_t = \beta_0 + \beta_1 Y_t + \beta_2 Y_t^2 + \beta_3 Y_t^3 + \varepsilon_t \quad (1)$$

Where $CO2_t$, represents carbon dioxide emissions per capita. Y_t, means the gross domestic product per capita; this, in turn, is squared and cubed to review its parameters and indicate the functional form of the supposition we will observe. Likewise, ε_t represents the stochastic error with mean 0 and constant variance.

To validate a second and third-degree polynomial function, it will be validated by the Akaike Information Criterion (AIC) as an equitable estimator of the evidence lost when using a model to approximate reality, whose formula is:

$$AIC_i = -2lnL_i + 2N_i \quad (2)$$

Where N_i, is the number of free considerations in the standard and L_i. The likelihood under the model. This statistical data explains that the lower the AIC value, the better the adjustment model to the observable data [35].

Once the data is confirmed, the parameters are evaluated under the supposition of the EKC; for the linear case, the coefficients β_1>0 y β_2=β_3=0. For the quadratic case β_1>0, β_2<0 y β_3=0, the emissions show an inverted U-shaped relation related to the GDP per capita (To meet the functional form of inverted U, it must also meet $|\beta_2|<|\beta_1|$). In the cubic case β_1>0, β_2<0 y β_3>0, an N-shaped relationship concerning emissions and GDP is shown. If the coefficients are reversed β_1<0, β_2>0 y β_3<0, an S shape can be identified.

High, medium, and low-income countries will analyze the coefficients worldwide. The purpose of the analysis is to review the different stages of development explained in the theoretical framework. The research will be extended to Ecuador to observe the functional form of the curve and clarify at what stage of product it is according to empirical evidence.

3. Results

The results obtained in the main statistics of the analyzed variables are described to validate the existence of convergence concerning the research variables. For this study, 92 countries were examined with at least 60 interludes, and an excellent dispersion can be seen in the data.

The average carbon dioxide emission is 3.80 and 10654.50 for the GDP per capita. The standard deviation values, as are the minimum, maximum, and coefficient of variation values, are in the middle range, with average data and possible subsequent analysis.

The dispersion of the data is shown in Figure 1, where you can observe the years of study in different colors; the data has a concentrated behavior and, in turn, shows that income growth is associated with the rise in CO2 emissions when the payment reaches up to 30 thousand dollars. From this range, the change in income keeps CO2 emissions constant, ranging concerning 5 and 15 tons per capita. Similarly, revenues of over $100,000 grow the capacity of CO2 emissions from 5 to 25 tons; this could empirically confirm that the EKC does not yet have a functional inverted U shape.

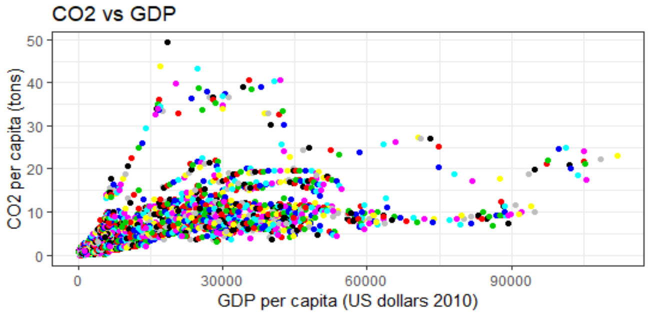

Figure 1. Dispersion Diagram (CO2 Emissions vs GDP Per Capita)

The analysis includes a categorization concerning income since the stages of development are very different. In the case of high-income countries per capita, a developed services sector of the economy, they are the most suitable to test the EKC supposition.

Table 1. CKA Estimate for Countries With High Per Capita Income

Explanatory Variables	CO2 Emissions 1960-2021	
	Estimated coefficients	**Standard error**
$\boldsymbol{\beta_1}$	0.727 (<2e-16)***	0.51
$\boldsymbol{\beta_2}$	-0.50 (9e-16)***	0.04
$\boldsymbol{\beta_3}$	0.119 (0.008)**	0.04
$\mathbf{R^2}$ = 0.8916	$\boldsymbol{\beta_0}$= 2.396	
F-statistic: 139.8 on 3 and 51 DF (2.2e-16) ***		

Note: In brackets, the plausible value. Significance at a level of 0.10%(***), 1%(**) y 5%(*)

In Table 1, the AIC analysis indicates that the cubic model is the most optimal to represent the curve of countries with the highest per capita income. Likewise, the values of the parameters have great significance and explain the model well; therefore, the EKC has a better N shape, although the inverted U shape is only discarded by negligible values both in the parameters and in the statistics analyzed. In this model, the supposition of the researched curve can be accepted, indicating a convergence concerning CO2 emissions and economic growth.

The performance of the function is also reviewed for countries with medium and low income, which are developing, entering and improving their economies with the economic sectors of industrialization and mass sale of raw materials.

In Table 2, the AIC analysis indicates that the squared model is the most optimal by a minimal difference to the cubic function. The parameters for these countries suggest that β_3 is not as represented, validating the AIC statistic and checking a projection of an inverted U function. This model also provides evidence of convergence concerning the research variables and the validation of the EKC supposition.

For Ecuador, the same period is analyzed, including the country’s change in a production model in 2012, which is reflected in the country's economic data.

Table 2. CKA estimate for countries with medium and low income

Explanatory Variables	CO2 Emissions 1960-2021	
	Estimated coefficients	**Standard error**
$\boldsymbol{\beta_1}$	2.867 (<2e-16)***	0.06
$\boldsymbol{\beta_2}$	-0.416 (3e-16)***	0.06
$\boldsymbol{\beta_3}$	-0.082 (0.096) .	0.06
$\mathbf{R}^2 = 0.9759$	$\boldsymbol{\beta_0} = 0.603$	
F-statistic: 687.2 on 3 and 51 DF (2.2e-16) ***		

Note: In brackets, the plausible value. Significance at a level of 0.10%(***), 1%(**) y 5%(*)

In Table 3, the AIC analysis indicates that the squared model is the most optimal to represent the function of Ecuador's economy and emissions; the parameters observed also show that β_3 is not representative of the model. The parameters behave similarly to a country of average per capita income.

Table 3. CKA Estimate for Ecuador

Explanatory Variables	CO2 Emissions 1960-2021	
	Estimated coefficients	**Standard error**
$\boldsymbol{\beta_1}$	4.419 (<2e-16)***	0.18
$\boldsymbol{\beta_2}$	-0.96 (9e-16)***	0.18
$\boldsymbol{\beta_3}$	-0.08 (0.65)	0.18
$\mathbf{R}^2 = 0.9271$	$\boldsymbol{\beta_0} = 0.279$	
F-statistic: 216.1 on 3 and 51 DF (2.2e-16) ***		

Note: In brackets, the plausible value. Significance at a level of 0.10%(***), 1%(**) y 5%(*)

The converging models analyzed have two important limitations; the first is the null value of carbon reduction costs, and the model itself does not allow the empirical calculation of the inflection point [24]. For the latter, the graphic evidence with its adjusted function was used. When analyzing the parameters, the behavior of the estimated curve for the different models studied can be observed. The visual form can guide the verification of the supposition of the EKC, as shown in Figure 2.

The EKC has a second-degree polynomial function in the upper left quadrant of Figure 2. The acceptance of the supposition studied for high-income countries per capita can be evidenced. The parameters and statistics for the curve of high-income countries show that the most optimal is a third-degree polynomial function, which we can observe in the upper right quadrant, where the acceptance of the supposition of the EKC continues to be evidenced. Still, we can also follow that said curve could likely be oriented upwards.

The curve is not yet defined in the middle- and low-income countries per capita. Still, its behavior scheme indicates that it is in the growth stage and has a positive relationship concerning income and emissions.

Similarly, the EKC for Ecuador is very similar to the countries of medium and low per capita income. The difference is that the curve begins to have a point of stability when revenues exceed six thousand dollars; observing probabilities affirm the supposition of the curve analyzed in this investigation.

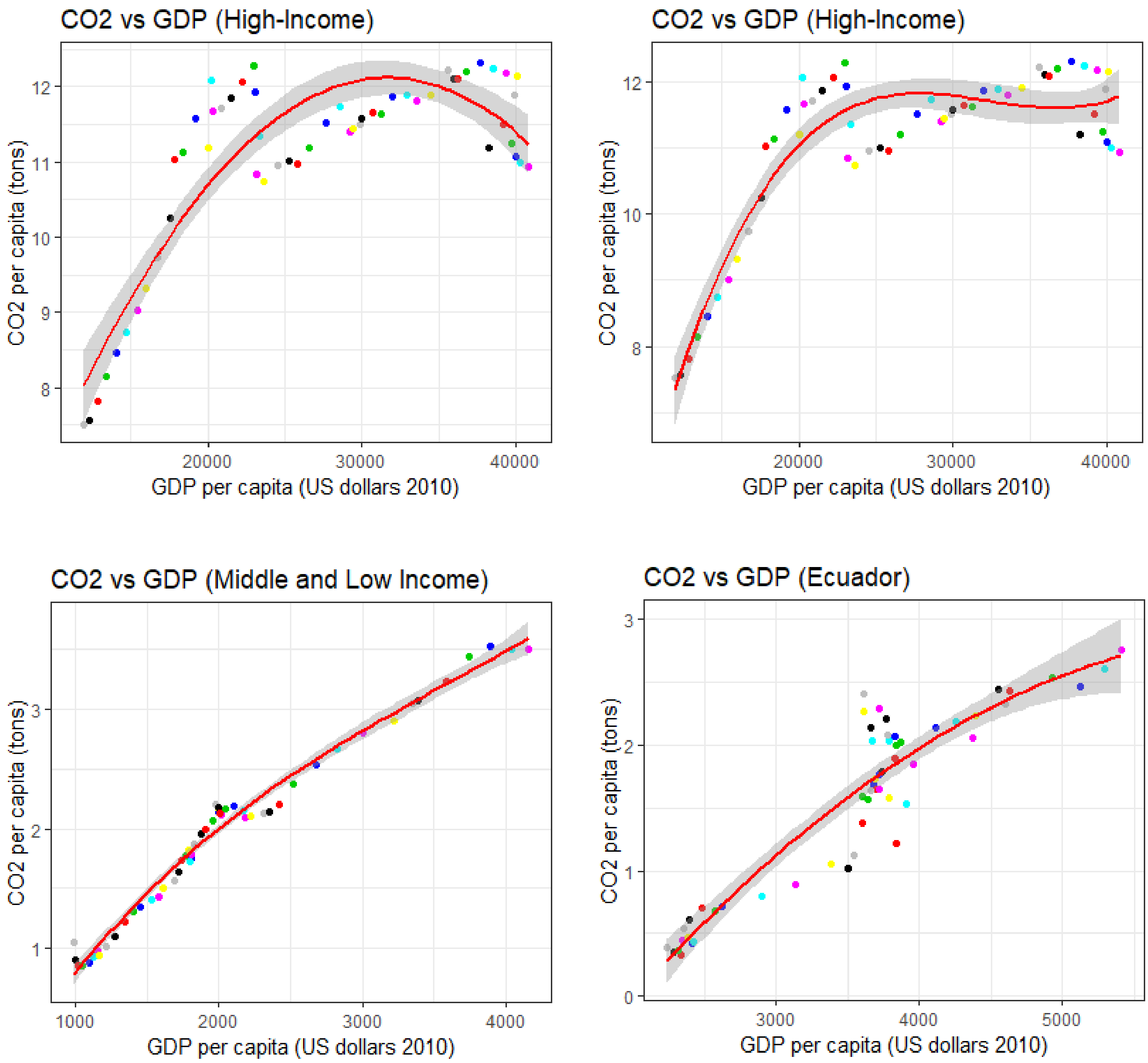

Figure 2. Environmental Kuznets Curve Estimation

4. Conclusions

The results obtained in this work show the relationship concerning the economic growth of a country measured by per capita income and environmental pollution measured by carbon dioxide emissions. Therefore, the supposition of the EKC is tested. In the case of countries with higher per capita income, an N shape is empirically evidenced, which implies that there will be a second turning point that, by increasing revenues, will grow emissions in these types of countries, confirming this supposition. It can only be checked with an update of this study by 2023.

For Ecuador, we can see that it shares many similarities with middle and low-income countries per capita. Still, the EKC for Ecuador shows a positive long-term alternative since the curve tends to have a turning point exceeding 6 thousand dollars. Therefore, it is concluded that the Ecuadorian economy is in the transition of primary activities jointly developing secondary activities for its development stage. This development must go with environmental public policies encouraging incentives to reduce pollutant emissions, especially by adopting more environmentally friendly technologies.

Revalidating the previous studies analyzed in the theoretical framework, we can conclude that an EKC does exist. Still, the main objective of the curve is not only to see the convergence concerning economic growth and its development to minimize CO2 emissions but to become aware that the environment can be healed with responsible production and utilization so that the supposition is validated in all stratifications of per capita income. For a successful long-term transformation and a sustainable future, macro agreements must be signed concerning the various economic agents, such as governments, institutions, industries, and individuals. The purpose is to guide public policies implementing sustainable development strategies that seek coordination concerning the economy and the cleanest environment.

For future research, it is recommended that the study be updated empirically with data from 5 additional years to those researched. With this update, we will be able to analyze a turning point for high-income countries and also monitor the Ecuadorian case, an analysis concerning the high-income and low-income countries, to see if a shift in pollution from developed to less developed economies is met.

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