Gómez, C. F., Cerquera, Ó. H. & Rojas, L. (2024). Europe and the Environmental Kuznets Curve: A Move Toward a Sustainable Economy.
Ánfora, *31*(56), 258-278. https://doi.org/10.30854/anf.v31.n56.2023.923

Research

Europe and the Environmental Kuznets Curve: A Move Toward a Sustainable Economy*

[English version]

Europa y la curva medioambiental de Kuznets: un avance hacia una economía sostenible

A Europa e a curva ambiental de Kuznets: um movimento em direção a uma economia sustentável

Received on 15 March 2022. Accepted on 12 April 2023

› *How to quote:*
Gómez, C. F., Cerquera, Ó. H. & Rojas, L. (2024). Europe and the Environmental Kuznets Curve: A Move Toward a Sustainable Economy. *Ánfora*, *31*(56), 258-278. https://doi.org/10.30854/anf.v31.n56.2023.923
Universidad Autónoma de Manizales. L-ISSN 0121-6538. E-ISSN 2248-6941.

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* This research was endorsed by the Universidad Surcolombiana - IGUAQUE research group and was completed in December 2021. Financing: This research is a team effort carried out by the authors with their own resources. Declaration of interests: The authors declare that there are no conflicts of interest. Availability of data: All relevant data can be found in the paper.

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Abstract

Objective: To test the hypothesis of the Environmental Kuznets Curve (EKC) on Carbon Dioxide (CO_2) and greenhouse gas emissions for European Union (EU) countries during the period 1990-2012. **Methodology**: Input was taken from the World Bank database, which contains 21 indicators: agriculture and rural development, efficiency, economic growth, education, energy and mining, environment, the financial sector, health, infrastructure, labor and social protection, poverty, the private sector, the public sector, science and technology, social development, urban development, gender, sustainable development objectives, climate change, external debt, and trade. Based on this, a panel data model was estimated using three methods: random effects, fixed effects, and first differences. **Results**: It was found that there is an inverted U-shaped relationship between income level (GDP per capita) and pollution indicators. However, high levels of pollution are present with an income level of a country like Luxembourg, which may be due to a decreasing underperformance in GDP per capita with respect to pollution levels. Likewise, it was found that energy use, population, and the industrial sector contribute to increasing levels of environmental deterioration. **Conclusions**: The relationship between economic growth and environmental degradation should not focus only on the economic structure. Solutions to this type of problem must be a part of the economic policy of EU countries and the policy's implementation in Sustainable Development Goals (SDGs).

Keywords: Environmental Kuznets Curve; Carbon dioxide; greenhouse gas; economic growth.

Resumen

Objetivo: comprobar la hipótesis de la Curva Medioambiental de Kuznets (CMK) en las emisiones de Dióxido de Carbono (CO_2) y gas invernadero para los países que pertenecen a la Unión Europea (UE) periodo 1990-2012. **Metodología**: se tomó como insumo la base de datos de Banco Mundial, la cual contiene 21 indicadores: agricultura y desarrollo rural, eficiencia, crecimiento económico, educación, energía y minería, medio ambiente, sector financiero, salud, infraestructura, trabajo y protección social, pobreza, sector privado, sector público, ciencia y tecnología, desarrollo social, desarrollo urbano, género, objetivos de desarrollo sostenible, cambio climático, deuda externa y comercio. Con base en ello, se estimó un modelo de datos panel bajo tres métodos: efectos aleatorios, efectos fijos y primeras diferencias. **Resultados**: se encuentra que existe una relación en forma de U invertida entre el nivel de ingreso (PIB per cápita) y los indicadores de contaminación; sin embargo, presenta niveles elevados de contaminación cuando se tiene un nivel de ingreso de un país como Luxemburgo, lo cual puede deberse a un bajo rendimiento decreciente en el PIB per cápita respecto a los niveles de contaminación. Así mismo, se encuentra que el uso de energía, la población y el sector industrial contribuyen a incrementar los niveles de deterioro ambiental. **Conclusiones**: la relación entre el crecimiento económico y el deterioro ambiental no solo debe enfocarse en su estructura; también es necesario que este tipo de problemática realmente sea parte de la política económica de los países de la UE y su aplicación en los objetivos de desarrollo sostenible (ODS).

Palabras clave: curva medioambiental de Kuznets; Dióxido de Carbono; gas invernadero; crecimiento económico.

Resumo

Objetivo: testar a hipótese da Curva de Kuznets Ambiental (ECK) sobre o dióxido de carbono (CO_2) e as emissões de gases de efeito estufa para os países pertencentes à União Europeia (UE) no período de 1990 a 2012. **Metodologia**: os dados foram extraídos do banco de dados do Banco Mundial, que contém 21 indicadores: agricultura e desenvolvimento rural, eficiência, crescimento econômico, educação, energia e mineração, meio ambiente, setor financeiro, saúde, infraestrutura, trabalho e proteção social, pobreza, setor privado, setor público, ciência e tecnologia, desenvolvimento social, desenvolvimento urbano, gênero, metas de desenvolvimento sustentável, mudança climática, dívida externa e comércio. Com base nisso, foi estimado um modelo de dados em painel com três métodos: efeitos aleatórios, efeitos fixos e primeiras diferenças. **Resultados**: constatou-se que há uma relação em forma de U invertido entre o nível de renda (PIB per capita) e os indicadores de poluição; no entanto, há altos níveis de poluição quando o nível de renda é o de um país como Luxemburgo, o que pode ser devido a um baixo retorno decrescente do PIB per capita em relação aos níveis de poluição. O uso de energia, a população e o setor industrial também contribuem para o aumento dos níveis de degradação ambiental. **Conclusões**: a relação entre crescimento econômico e degradação ambiental não deve se concentrar apenas em sua estrutura; também é necessário que esse tipo de questão realmente faça parte da política econômica dos países da UE e de sua implementação nos Objetivos de Desenvolvimento Sustentável (ODS).

Palavras chave: curva de Kuznets ambiental; dióxido de carbono; gás de efeito estufa; crescimento econômico.

Introduction

In recent decades, there has been continuous productive development based on the utilization of productive factors, one of which is natural resources. In this sense, the question: *Does continuous economic development bring with it a deterioration of the environment?* is worth asking. To answer this question, analyzing that the economic structure in recent years has undergone a transformation due to technological innovation is important. This has led to the improvement of production processes in favor of the efficient use of natural resources (clean technologies). Moreover, if legislation is added against environmental deterioration, remedying the effects of productive activity on the environment is possible.

This is why establishing the causes and consequences of economic activity on the environment is a crucial issue on the global (and, therefore, European) political and economic agenda. An example of this is the position of the European Union (EU) on sustainable development through the implementation of the United Nations Agenda 2030 on the European political framework. This agenda aims to establish and ensure compliance with Sustainable Development Goals (SDGs), which include protecting, restoring, and promoting the sustainable use of natural resources. In this sense, international policy has become aware of the need for sustainable economic growth— in other words, a change in its productive structure that allows for the transformation of production processes in conjunction with technological development to preserve the environment.

One method for estimating or approximating the effects of productive activity on the environment is the well-known Environmental Kuznets Curve (EKC), which involves establishing an empirical inverted U-shaped relationship between economic growth and environmental detriment. Countries with high indicators of environmental degradation are correlated with decreasing income levels, and as per capita income increases, countries tend to experience lower levels of pollution (Grossman & Krueger, 1995).

The work entitled Economic Growth and Income Inequality, developed by Simon Kuznets (1955), becomes the basis of what is known as the Environmental Kuznets Curve (EKC). The idea is that there is an inverted U-shaped relationship between economic growth and income distribution in the long run, mathematically known as the relationship between variables and being strictly concave. In other words, for low-income countries, there is lower income concentration. As income increases, its concentration tends to rise, reaching a maximum point (inflection), which then leads to a decrease in concentration for countries with high income levels. Due to the lack of a formal model to establish this relationship, Kuznets relies on empirical evidence to demonstrate that changes in income distribution are associated with the economic growth of countries. This relationship is based on three components. The first is the population structure, which establishes that the population tends to concentrate in urban areas, where it can be employed in activities with higher wages. Therefore, this concentration contributes to economic growth and generates a change in income distribution due to an increase in the income share of low-wage families. The second is changes in economic activity in favor of industry, which generate an increase in per capita income, mainly in the lower deciles of the income distribution. And finally, the concentration of savings makes it possible to generate investment, translating into the accumulation of productive factors, greater productivity, and economic growth.

Grossman and Krueger (1995) conducted the first seminal study to explore the empirical relationship between economic growth and environmental degradation. Their objective is to establish the effects of trade on the environment for the years 1977, 1982, and 1988. Using a panel data model, the authors found that countries characterized by low levels of GDP per capita exhibited higher indicators of environmental degradation. However, as income level (GDP per capita) increased, pollution indicators decreased. They concluded that high-income countries have undergone changes in their productive structure facilitated by technological development. Concurrently, strict environmental regulations have contributed to the improvement of environmental quality indicators.

Shafik and Bandyopadhya (1992) examined the correlation between environmental degradation and economic growth (GDP per capita) across 149 countries from 1960 to 1990. They established an inverted U-shaped relationship between economic growth and environmental degradation indicators, including airborne particulate matter and deforestation. However, water pollution indicators specifically pertaining to clean water and dissolved oxygen levels show a negative correlation with income levels. According to the authors, high water treatment costs may indirectly reduce income levels.

Grossman and Krueger (1995) conducted the first seminal study to explore the empirical relationship between economic growth and environmental degradation. They used GDP per capita as a variable to measure the level of income and four types of environmental indicators. Using a panel data model, the authors identified an inverted U-shaped relationship between economic growth and environmental degradation indicators. The authors also estimated that countries with a GDP per capita ranging between $8,000 and $10,000 USD exhibited lower pollution rates in comparison to countries with lower income levels.

However, they clarified that this relationship is not deterministic; implying that past information including the monitoring of a country's income, does not precisely forecast its level of contamination. Although, the relationship does indeed exist from an empirical standpoint. Their assertion posits that the implementation of strict environmental regulations implemented as public policies, a shift in preferences toward less pollution-intensive goods among agents, and substantial investments in clean technologies lead the most developed countries toward sustainable growth.

Similarly, Bruyn et al. (1998) examined the KEC in three European countries (Germany, the Netherlands, and the United Kingdom), as well as in the United States for various time intervals between 1960 and 1993. The authors introduced a growth model based on the intensity of the emission of pollutants such as Carbon Dioxide (CO_2), Nitrogen Oxide (NO_X) and Sulfur Dioxide (SO_2). This model offers more effective means of analyzing changes in productive structures, technology, and environmental regulations. Estimates indicated a positive correlation between economic growth and pollutant emission intensity due to a positive effect attributed to changes in production processes and environmental regulations.

Similarly, Stern and Common (2001) endeavored to establish the KEC hypothesis for 73 countries during the period from 1960 to 1990. The authors suggested a correction to the specification of the structural model that originally used sulfur (S) emissions as the dependent variable. As per the authors, the lack of a specific variable to determine pollution behavior implies the possibility of bias stemming from potentially omitted variables or simultaneity. Therefore, sulfur emissions emerge as an indicator, given that technology plays a role in emission control. These results demonstrated that the KEC exists for both developed and undeveloped countries, with a significantly lower turning point (maximum) in pollution levels among developing countries. This is because certain indicators including coal emission production cannot be effectively managed by developing countries due to the high cost associated to their treatment.

Along the same lines, Ahmed et al. (2016) explored the causal relationship between economic growth and Carbon Dioxide (CO_2) emissions in 24 European countries over the period from 1980 to 2010. The authors used a dynamic panel analysis to substantiate the existence of a KEC relationship between economic growth and greenhouse gas emissions over the long-term. They also identified that bioenergy, defined as energy from biomass, which is material of biological origin, does not exhibit a significant relationship. Alternatively, technological progress has had a negative and significant impact on environmental degradation. The findings of the authors suggest that achieving sustainable economic growth may be feasible through the implementation of public policies fostering the use of renewable energy sources.

Pablo-Romero and Sanchez-Braza (2017) analyzed the relationship between residential energy consumption and income for 28 European Union countries,

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spanning the period from 1990 to 2013. The authors used the estimates of a panel data model and a multilevel mixed-effects model to confirm the KEC hypothesis for the residential sector in the 28 European countries. Furthermore, the findings revealed that Denmark, Luxembourg, Finland, the Netherlands, and Sweden were the countries reaching the highest values for their KEC turning points.

For G7 countries, Raza and Shah (2018) examined the impact of trade, economic growth, and renewable energy from 1991 to 2016. The authors used a panel data model and a fixed-effect model, employing fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) techniques to estimate the long-run coefficients. Findings revealed economic growth, (imports and exports) and trade increase CO_2 emissions in the long-run, whereas renewable energy consumption reduces them in the long-run. The authors concluded that these results support the KEC hypothesis in G7 countries and demonstrate a bidirectional causal relationship between renewable energy sources and CO_2 emissions in these countries.

Altintas and Kassouri (2020) examined the nexus between environmental and economic development in a long-term relationship. To this end, they disaggregated the environmental component into CO_2 emissions and the ecological footprint (the amount of biological land necessary for a human being to absorb carbon dioxide emissions) as the dependent variable. The authors followed four panel data models and implemented an estimation approach, which incorporated cross-sectional dependence and conducted a slope heterogeneity test for the 14 European countries. The data pertained to the EU-14 including countries that ratified commitments to increase their share of renewable energy, spanning the period from 1990 to 2014. Their findings demonstrated that the KEC hypothesis is highly responsive to variations in disaggregated variables within the environmental component.

Similarly, Pontarollo and Serpieri (2020) used a spatial panel econometric technique to empirically demonstrate the existence of the KEC hypothesis for certain counties in Romania over the period from 2000 to 2014. They conclude that an inverse U is present, indicating higher levels of urbanized areas for the highest levels of wealth.

Boubellouta and Brandt (2020) sought to test the KEC hypothesis used as an environmental indicator for electronic wastes in 30 European countries (countries that are part of the European Union, Norway, the United Kingdom, and Switzerland) from 2000 to 2016. The authors used generalized methods of moments (GMM) and two-stage minimum square (MC2E) method to generate robust estimators. The results show that there is an inverted U-shaped relationship between economic growth and the generation of electronic waste; however, although sustained economic growth may infer lower levels of e-waste, income levels (GDP per capita) must be very high. Thus, the authors propose a coordinated effort between each of the actors (Government, businesses, and families) to generate an effective and efficient collection scheme for electronic waste.

For the countries of the European Union and the Western Balkans, Pejovic et al. (2021) analyzed the relationship between economic growth (with GDP per capita), energy consumption and CO_2 emissions from 2008 to 2018. They developed a data panel model with a vector autoregression (VAR) approach and evaluated estimators with generalized methods of moments. The authors concluded that the KEC exists depending on the country's income level.

Also, Filippidis et al. (2021) linked variables such as economic growth and energy consumption, energy use and income inequality, and economic development and energy production for approximately 200 countries from 2000 to 2019. They used a nonlinear data panel regression. The authors conclude that in the economic growth and renewable energy relationship there is a U-shaped curve, while in the relationship between economic growth and the consumption of fossil energy there is an inverse U-shape, demonstrating the KEC hypothesis.

In France and Germany, Ma et al. (2021) quantified the ratio between real GDP, CO_2 emissions and the consumption of renewable and non-renewable energy for the available data from 1995 to 2015. A data panel model was developed and cross-sectional dependency test, unit root test in panel data, and co-integration test were applied. The research reveals a relationship between the inverted U-shape in the variables of CO_2 emissions and real GDP over the long term in the two European countries that demonstrates the KEC theory.

Sharman et al. (2021) developed a data panel using Arellano-Bond dynamic and estimations of dynamic systems for the 27 countries of the European Union. They analyzed the relationship between the consumption of renewable and non-renewable energies and economic development over short and long terms. The authors stated that over the short term, the KEC hypothesis is not fulfilled, but over the long term the relationship reflects an inverted U.

To begin with the analysis of this issue in the European Union, Figure 1 shows carbon dioxide emissions (CO_2) greenhouse gas (gases that absorb the infrared radiation from the sun and increase the temperature of the atmosphere) as per capita gross domestic product (GDP) for EU countries during 1990 and 2012. There is a concave correlation between per capita GDP and both indicators. Low-income countries have a positive correlation with environmental deterioration indicators; however, it seems that as countries have higher income levels, carbon dioxide emissions (CO_2) and greenhouse gas increase, it reaches a peak, then tends to decrease. However, this kind of analysis is not enough to assert that there is an inverse U-shaped relationship.

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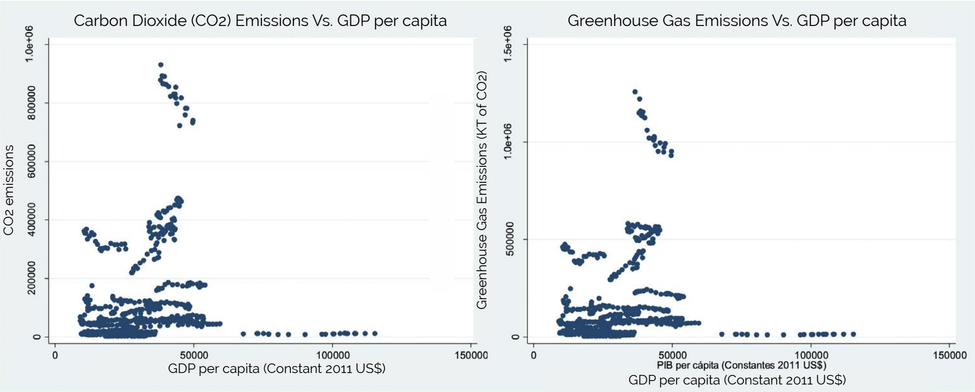
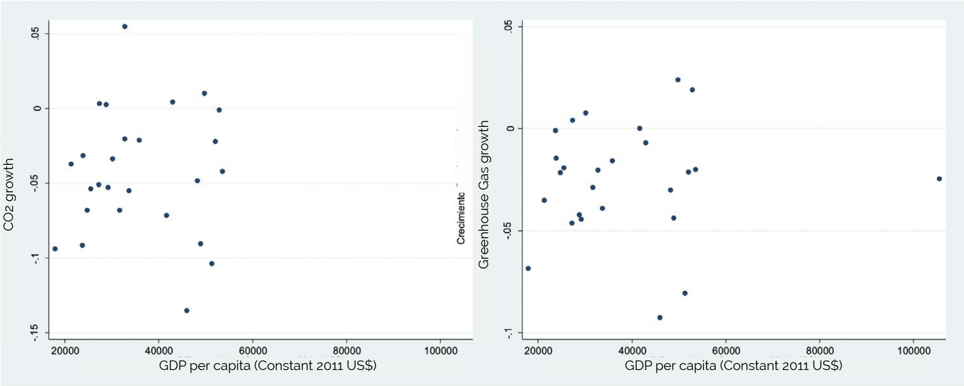
Figure 1. *Carbon Dioxide Emissions (CO_2) and Greenhouse Gas vs. Per Capita GDP for the European Union Countries during 1990 and 2012.*



Source: Author's elaboration based on data from the World Bank.

Figure 2 shows the separation between the increase in carbon dioxide emissions (CO_2) and greenhouse gas in relation to per capita GDP for EU countries during 1990 and 2012. Data show that there is a possible negative convergence between the growth rate of environmental pollution indicators (CO_2 and greenhouse gas) and income level (per capita GDP). In other words, countries with higher income levels tend to have lower carbon dioxide growth rates (CO_2) and greehouse gas.

Figure 2. *Carbon Dioxide (CO2) Increase and Greenhouse Gas vs. Per Capita GDP for European Union countries during 1990 and 2012.*



Source: Author's elaboration based on data from the World Bank.

However, to state that there is a certain correlation between CO_2 emissions and greenhouse gas in relation to income level (GDP per capita) in EU countries through figures is not enough. The Environmental Kuznets Curve emerges as an empirical method that allows verifying whether there is a relationship between economic growth and environmental deterioration. It also helps to generate public policies that enable sustainable economic growth with the environment. The effects of production on natural resources can be established through their use, as well as through the externalities of pollution that it can generate. Thus, the aim of this research is to empirically verify if the relationship exists between the Environmental Kuznets Curve in carbon dioxide emissions (CO_2) and greenhouse gases for EU countries during the period 1990-2012.

Method

The World Bank database was used to develop this research (The World Bank, 2020). It contains information on seven regions, 264 countries and 21 indicators (gender, health, education, agriculture and rural development, climate change, science and technology, social development, urban development, aid effectiveness, energy and mining, infrastructure, environment, poverty and economic policy and debt). This research contains information from the member countries of the European Union; it has an explanatory approach, as seeks to empirically verify the existence of the KEC. According to Grossman and Krueger (1995),

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the following equation presents the quadratic relationship of the KEC through a data panel model:

$$y_{it} = \alpha_i + \varphi_t + \beta_1 PIB_{it} + \beta_2 PIB_{it}^2 + \sum_{j=1}^{k} \beta_j X_{j,it} + v_{it}$$

Where y_{it} indicates the environmental pollution variables (CO_2 and greenhouse gas), GDP is Gross Domestic Product per capita; $X_{j,it}$ eis the matrix of variables that may be correlated with environmental deterioration (energy use, methane emissions, service sector value added, industry value added, manufacturing value added, natural resource depletion, education and population); α_i is the cross-sectional unobservable heterogeneity (across countries); and φ_t includes the unobservable heterogeneity over time. Similarly, β represents the vector of estimators; the subscripts *it* indicate observations for different individuals (countries) and time periods.

There are three methods to estimate the equation. The first, known as fixed effect, explains that the unobserved cross-sectional heterogeneity (α_i) is correlated with the independent variables. In other words, the estimator does not take into account changes in the variables over time. The second method on the contrary, assumes that the unobserved heterogeneity among individuals (countries) is not correlated with the independent variables; that is, both α_i and φ_t are considered as error components (v_{it}). This method is known as the random effect.

Finally, the third method, called first differences, aims to eliminate unobservable cross-heterogeneity by using the difference between them for each period as variables; however, this method generates a loss of information (observations), which can change the analysis of the results and their robustness. To determine, from a statistical point of view, whether the unobservable heterogeneity of individuals (countries) is correlated with the independent variables, generating efficient estimators, the Hausman test is applied, which compares the two types of heterogeneities (α_i and φ_t). If differences exist between them, it establishes that the unobservable cross-observable heterogeneity (α_i) is correlated with the independent variables, which leads to the use of fixed effects.

However, as Lieb (2003) states, this type of method presents problems mainly of heteroscedasticity and autocorrelation. To identify and address the first two issues, the Wald and Wooldridge tests are used. Once this is done, the robust error method is used as an alternative estimation method for models that present this type of problem.

Results

Figure 1 displays in order of income (GDP per capita), the Carbon Dioxide (CO_2) and greenhouse gas emissions for the countries that are part of the EU during 2012. As can be seen, there is no correlation between income level and environmental degradation, given that countries such as Germany – which ranks sixth in the EU in terms of income ($49,769 USD) – have a high concentration of carbon dioxide (170,310 kilotons) and greenhouse gases (951,717 kilotons). The opposite is true for countries such as Latvia, which has a low GDP per capita ($23,912 USD), but low levels of pollution (7,063 kilotons of CO_2 and 13,944 kilotons of greenhouse gas).

Table 1. *GDP Per Capita, Carbon Dioxide (CO2), and Greenhouse Gas Emissions in European Union Countries for 2012.*

Country	GDP Per Capita	Carbon Dioxide	Greenhouse Gas
Luxembourg	105,557	10,664	12,611
Austria	53,591	62,273	90,460
Ireland	52,887	35,592	62,433
Netherlands	52,104	170,310	195,874
Denmark	51,339	36,428	53,703
Germany	49,796	739,861	951,717
Sweden	48,942	47,048	65,768
Belgium	48,249	95,107	133,374
Finland	45,993	49,134	69,073
France	42,968	333,228	499,147
Italy	41,691	369,469	482,634
Spain	35,840	264,779	348,257
Czech Republic	33,711	101,030	138,957
Malta	32,758	2,681	-
Slovenia	32,758	14,782	21,075
Cyprus	31,679	6,920	7,431
Portugal	30,194	46,014	72,524
Estonia	29,198	17,624	23,293
Greece	28,808	80,043	100,571
Lithuania	27,381	13,832	29,442

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Country	GDP Per Capita	Carbon Dioxide	Greenhouse Gas
Slovakia	27,245	32,765	46,301
Poland	25,562	299,931	414,607
Hungary	24,769	44,583	62,988
Latvia	23,912	7,063	13,944
Croatia	23,757	17,994	30,421
Romania	21,358	81,723	121,762
Bulgaria	17,955	44,708	67,943

Source: Author's elaboration based on data from the World Bank.

Due to the difficulty of establishing a correlation between income and pollution levels through a simple descriptive analysis, the following table presents the results of the model proposed above for carbon dioxide CO_2. emissions. The estimates show that there is an inverted U relationship between income (GDP per capita) and carbon dioxide emissions for the EU countries when using the three estimation methods. However, only random effects *(β_1=1.5131 ; β_2=-0.0000074)* and fixed effects *(β_1=3.3755 ; β_2=-0.1305)* are statistically significant. Regarding the other variables, in terms of energy production, an increase in energy use (kg equivalent of petroleum) increases CO2 emissions by 313.17 and 324.82 kilotons for random and fixed effects respectively.

In terms of economic activity, estimates show that only the industry sector has a positive effect on carbon dioxide emissions which is mainly because this sector has production processes that focus on the transformation of raw materials and, therefore, generates environmental pollution. Finally, as expected, an increase in education and population expenditures reduce and increase carbon dioxide levels respectively. Applying the Hausman test confirmed that unobserved heterogeneity over time is correlated with the independent variables, which establishes that random effects estimates should be used.

Table 2. *Results of Estimation for Carbon Dioxide (CO_2) Emissions.*

Carbon Dioxide	First Differences	Random Effects	Fixed Effects
PIB	1.0435***	1.5131***	1.6075***
GDP	(0.2896)	(0.3219)	(0.3257)
	-0.0000053	-0.0000074***	-0.0000077***
GDP Square	(0.0000069)	(0.0000022)	(0.0000022)

Carbon Dioxide	First Differences	Random Effects	Fixed Effects
	1314.1***	593.70***	705.54***
Methane Emission	(285.16)	(182.96)	(193.23)
	455.17***	313.17***	324.82***
Energy Use	(55.901)	(37.567)	(38.632)
	-0.000000085**	-0.00000015***	-0.00000011***
GDP Per Capita	(0.00000003)	(0.000000012)	(0.000000018)
	0.00000048***	0.000001***	0.000001***
GDP Industry	(0.0000001)	(0.000000073)	(0.000000074)
Manufacturing GDP	-0.00000013	-0.0000007***	-0.000000082***
	(0.00000011)	(0.000000083)	(0.000000088)
Education	-355.09	-1462.9*	-1544.03*
	(847.29)	(821.19)	(802.62)
Population	0.0055	0.0057***	0.0042***
	(0.0023)	(0.0004)	(0.0011)
Natural Erosion	1343.98	675.96	655.96
	(2176.57)	(25.058)	(2467.7)
N Observations	478	504	504
R	0.374	-	-
R Within	-	0.654	0.659
R Between	-	0.959	0.951
R Overall	-	0.957	0.949
Hausman Test	-	4.24	-
Prob (Chi2)	-	(0.3748)	-

Note: *p<0.1; **p<0.05; ***p<0.01.

Source: Author's elaboration based on data from the World Bank.

Similarly, in Table 3, estimates for greenhouse gases are presented. It can be seen that it also has an inverted U-ratio relationship between greenhouse gas emissions and GDP per capita for random effects $(\beta_1=1.4304 ; \beta_2=-0.000008)$ and fixed effects $(\beta_1=1.5914 ; \beta_2=-0.0000085)$, which are statistically significant. However, according to the Hausman test, fixed effects estimates are used, because there is correlation between the independent variables and unobserved heterogeneity

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between countries. In relation to energy use, an increase in one kg of oil increases greenhouse gas emissions by 285.19 kilotons. The results for the economic sectors show that only industrial activity generates a positive effect on greenhouse gas emissions, similar to the estimates obtained for carbon dioxide. Finally, an increase in population increases greenhouse gas emissions.

Table 3. *Results for Estimation for Greenhouse Gas Emissions.*

Greenhouse Gas	First Differences	Random Effects	Fixed Effects
GDP	0.8728**	1.4304***	1.5914***
	(0.3324)	(0.1773)	(0.3779)
GDP Square	-0.000066	-0.000008***	-0.0000085***
	(0.000078)	(0.0000026)	(0.0000025)
Methane Emission	3084.25***	1694.5***	1905.7***
	(325.51)	(213.56)	(223.09)
Energy Use	403.56***	285.19***	309.92***
	(63.816)	(44.111)	(44.665)
GDP Per Capita	-0.00000006*	-0.0000002***	-0.0000013***
	(0.00000003)	(0.000000014)	(0.000000021)
GDP Industry	0.00000047***	0.0000012***	0.0000011***
	(0.00000012)	(0.000000086)	(0.000000086)
Manufacturing GDP	-0.00000025**	-0.00000074***	0.00000096***
	(0.00000012)	(0.000000097)	(0.0000001)
Education	-494.08	-560.82	-742.01
	(968.66)	(980.44)	(936.34)
Population	0.0014	0.0070***	0.0024*
	(0.0026)	(0.0005)	(0.0013)
Natural Erosion	4261.8*	1782.9	2341.9
	(315.73)	(2955.06)	(2849.6)
N Observations	475	502	502
R	0.332	-	-
R Within	-	0.730	0.741
R Between	-	0.969	0.957
R Overall	-	0.968	0.953
Hausman Test	-	2.98	-
Prob (Chi2)	-	(0.5619)	-

Note: *p<0.1; **p<0.05; ***p<0.01.

Source: Author's elaboration based on data from the World Bank.

As mentioned above, Table 4 shows the Wald and Wooldridge tests. The estimates confirm that the model presents problems of heteroscedasticity and serial autocorrelation. An alternative to control these types of drawbacks is to use the robust error method, because these types of models are insensitive to atypical data.

Table 4. *Wald and Wooldridge Tests.*

Tests	Wald		Wooldridge	
	Chi2	Prob>Chi²	F	Prob>F
Carbon Dioxide	270000	0.000	10.43	0.003
Greenhouse Gas	64205.1	0.000	128.6	0.000

Source: Author's elaboration based on data from the World Bank.

Additionally, Table 5 presents the estimates with robust fixed effects for the environmental pollution indicators used. As can be seen, the estimates show a result similar to that obtained without controlling for heteroscedasticity and serial autocorrelation. That is, the existence of the KEC in European Union countries can be empirically inferred. However, it is worth clarifying that variables such as population and education under robust errors are not statistically significant.

Table 5. *Results of Estimation with Robust Fixed Effects.*

Variables	Carbon Dioxide	Greenhouse Gas
GDP	1.6075**	1.5914**
	(0.7041)	(0.7090)
GDP Square	-0.0000077*	-0.0000085**
	(0.0000038)	(0.0000043)
Methane Emission	705.54**	1905.7***
	(327.78)	(349)
Energy Use	324.82**	309.92**
	(125.78)	(125.01)
GDP Services	-0.00000011	-0.0000013
	(0.000000078)	(0.000000093)
GDP Industry	0.000001***	0.0000011***

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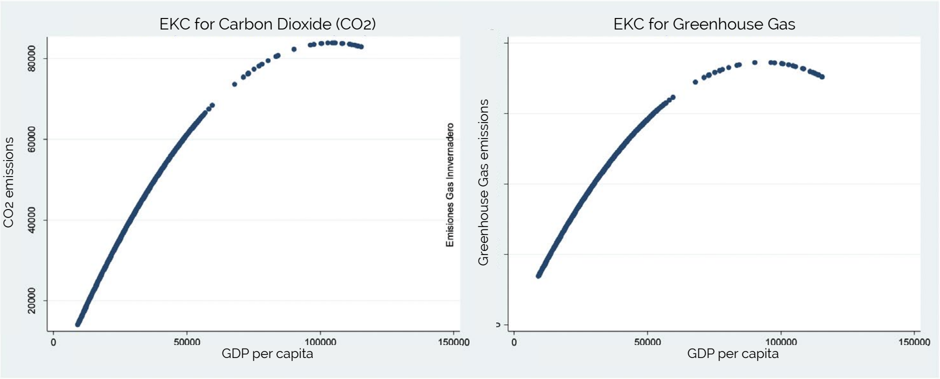
Variables	Carbon Dioxide	Greenhouse Gas
	(0.00000036)	(0.00000031)
Manufacturing GDP	-0.00000082*	0.00000096**
	(0.00000041)	(0.0000004)
Education	-1544.03	-742.01
	(1280.4)	(1103.8)
Population	0.0042	0.0024
	(0.006)	(0.0056)
Natural Erosion	655.96	2341.9
	(5045.09)	(655.07)
N Observations	504	504
R	-	-
R within	0.659	0.741
R Between	0.951	0.957
R Overall	0.949	0.953
	Note: *p<0.1; **p<0.05; ***p<0.01.	

Source: Author's elaboration based on data from the World Bank.

To check the existence of the KEC in the EU countries, the parameters obtained previously (β_1 and β_2), are used, as described in Figure 3. According to estimates, European Union countries reach the maximum emissions of carbon dioxide and greenhouse gas when they obtain a GDP per capita of $102,236 and $89,400 USD respectively; that is, an income level consistent with Luxembourg (in the case of pollution indicators). However, despite having high implicit inflection points (maximum), the results do not contradict the proposed hypothesis, which confirms that EU countries have an inverted U relationship between their income levels (GDP per capita) and pollution levels (CO_2 and greenhouse gas emissions).

Figure 3. *Environmental Kuznets Curve (EKC) for Carbon Dioxide (CO_2) and Greenhouse Gas in European Union Countries..*



Source: Author's elaboration based on data from the World Bank.

Conclusions

It should be noted that this type of work seeks to contribute to the analysis of the impacts of economic growth on environmental pollution. It is also intended to determine whether the development of economies through changes in their productive structure, clean technologies, and the development of environmental regulation policies, and even more so, without a formal structure, can contribute to a general analysis of this problem, despite establishing an empirical relationship that may be biased.

The results obtained prove the existence of the Environmental Kuznets Curve (EKC) for carbon dioxide (CO_2) and greenhouse gas emissions in European Union countries. Likewise, it presents high implicit turning points in terms of GDP per capita consistent only with a country like Luxembourg, due to low diminishing returns in income and pollution levels. In relation to the other variables, energy use and population generate a positive effect on pollution indicators. In terms of economic activity, only the industrial sector increases CO_2 and greenhouse gas emissions, and finally, an increase in spending on education leads to reducing pollution (though only carbon dioxide emissions).

To establish robust results, the Hausman test was applied, which establishes whether unobserved heterogeneity (between countries and over time) is correlated with the independent variables. The test shows that the random effect method presents consistent estimators. However, there may be different effects for different sub-regions or countries. For this, making several estimates is pertinent. Likewise, the Wald and Wooldridge test was performed, which establishes the presence of heteroscedasticity and serial autocorrelation. To control for these problems, the robust fixed effects method was used. The results show a similarity with the fixed effects model, reaffirming the presence of the KEC in European Union countries.

Finally, it should be noted that the solution to this problem should be based on a diagnosis. What matters is to improve the formal structure to determine this type of problems, as well as focus on making this type of analysis part of regions' economic policy. In the case of the EU, the application of the sustainable development goals (SDGs) in the 2030 Agenda, represents progress in these types of guidelines for a problem that long ago ceased to be individual and that now requires joint work.

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