THE CORRELATION BETWEEN CO_2 EMISSIONS AND GDP IN A SUSTAINABLE DEVELOPMENT FRAMEWORK USING KUZNETS ENVIRONMENT CURVE

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Abstract: After 1990, the problem of finding econometric models to assess the influence of economic development on the environment becomes a global goal, a central element of regional, national and Community policies. A perception on the evolution of global climate change and on the impact of human activity on them has been determined by the hypothesis that in the early stages of economic development, pollution and incomes are growing almost simultaneously, and beyond a certain level of incomes, the trend is reversing, therefore at high levels of incomes and economic growth occur improvements in environmental conditions. In this paper, we aim to analyze the relationship between the level of pollution (CO_2 emissions) and revenues (GDP per capita) using the Kuznets Environmental Curve (EKC). To apply the econometric model, two indicators were used:

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CO_2 emissions and GDP per capita, using a panel analysis for the period 2000 - 2016, which included 31 European countries and 527 observations. The article contributes to the development of econometric applications based on panel data and the Kuznets Environmental Curve.

Keywords: Kuznets Environmental Curve, sustainable development, econometric analysis.

JEL Codes: C2, C23, C32, C33

1. Introduction

After 1990, the problem of finding econometric models to assess the influence of economic development on the environment became a global goal. Thus, the analysis of the available data shows that, in the early stages of economic development, pollution and incomes increased almost simultaneously, but beyond a certain level of income per capita, the trend reversed, so that at high levels of incomes and economic growth, some improvements in environmental conditions showed up. This *Pollution-GDP* relationship appeared as a graph in the form of an inverted U.

An example of estimating this curve appears for the first time in 1995, the initiator Simon Kuznets sustaining the hypothesis that, in the first phase of GDP evolution, income inequality increases, after which inequalities are reduced (Kuznets, 1955). The model came to be widely known and applied. Although many of the studies used observational data, their findings and results suggested the feasibility of sustainable development in terms of economic development. Moreover, there are some expectations that this curve could contribute to the long-term forecast of environmental change and thus contribute to the development of prevention policies.

Econometric models of this type appear in the early 1990s in studies made by Grossman, Krueger (1994), Shafik and Bandyopadhyay (1992), which regarded the potential impact of NAFTA on economic growth. The model is popularized by the World Bank Report in 1992, which suggests that after a certain threshold, economic growth leads to a possible improvement in the environment (Meadows et al., 1972).

Some results obtained by applying the Kuznets curve model are presented below:

1. There is an inverted U-shaped relationship between environmental degradation and income, which shows an increase in pollution in low-income intervals, and subsequently, a decrease in income over large intervals (Grossman, Krueger, 1994).

2. Other studies have shown that while GDP growth may be associated with worsening environmental conditions in very poor countries, water and air quality benefit from economic growth at low-income levels.

3. Also, in the conditions of an income per capita of approximately 4,000 - 5,000 US dollars, there is a process of economic growth in parallel with the mitigation of pollution problems.

4. Other studies and researches show that environmental degradation (combined depletion of resources and pollution) occurs at levels of income per capita below 1,000 US dollars. The economy and environmental degradation are undergoing dramatic structural changes at an income value of between 1,000 and 3,000 US dollars. Another structural transformation begins at an income per capita of 10,000 US dollars, countries moving from heavy-intensive industry to advanced services and technology (Panayotou, 1993).

5. The inverted U-shape is consistent with a scenario in which industrial development initially leads to an increase in gross pollutant emissions, but subsequently, net emissions will decrease as a result of the increase in revenues associated with further development. There is a kind of compromise between pollutant emissions and economic growth (Holtz-Eakin & Selden, 1992).

6. Increasing the promotion of trade liberalization will often lead to improved environmental standards (Radetzki, 1992).

The authors of these studies have tried to show that there is no real conflict between economic growth and environment: *economic growth is needed to improve the quality of the environment*. Studies focus on achieving economic aims and less on environmental policy, as economic growth is needed to be able to achieve both economic and environmental goals, while an environmental policy can hamper economic growth. This transforms "growth limits", and the conclusions suggest the idea that the growth process is a condition or a requirement for improving the environment. Most of the conclusions apply, especially in rich countries, because for them, growth seems to promise a cleaner environment.

In developing countries, economic growth can be an important way to improve the quality of the environment. If economic growth is leading to a cleaner environment, then the policies that stimulate economic growth (e.g. trade liberalization, economic restructuring and price reform) must also be favorable to it. It is suggested that the environment does not need any particular attention, either in terms of domestic environmental policy or in terms of international pressure or assistance; resources can be best targeted at achieving rapid economic growth, which will quickly go through the stage of unfavorable development, from an ecological point of view, and reach the ecologically favorable one.

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Several theoretical models can be classified into different categories, the most common being those related to their status: *static models and dynamic models*. Dynamic models describe the changes in the quality of the environment that takes place in the process of economic development of a country. We can mention here the model adopted by John and Pecchenino (1994) which aims to overlapping generations and is computing the pollution stock determined mainly by consumption. Selden and Song (1995) applied a modified Ramsey-Cass-Koopmans model, analyzing pollution emissions (flow-type) resulted from production processes. They conclude that there is a possibility that the relationship between income per capita and indicators of environmental quality may be in the form of an inverted U-shaped curve, but under certain specific conditions. Stokey (1998) elaborates on a study that analyzes the pollution caused by production processes, analyzing both the pollution of flows and also of types of stocks. The study also suggests that in order to improve social welfare, environmental regulations are needed to reduce pollutant emissions.

2. Literature review

Sustainable development, according to Arrow et. al. (2012) has a compressive framework, including not only the produced capital but also the human capital, natural capital and social capital, in order to ensure the well-being of future generations. From this point of view, there is a long debate regarding the externalities of economic expansion and especially environmental damages. Polasky et al. (2019) promote cooperation between specialists on social and behavioral disciplines in order to achieve sustainable development and long-term well-being.

On one hand, specialists talk about the limited resources which are fundamental for economic growth, well-being and wealth creation. Natural elements have critical thresholds beyond which changes to natural capital could be irreversible. Also, some environmental assets are finite, therefore natural capital must be preserved for long-term economic growth and social development (Everett et al., 2010; Kurniawan & Managi, 2018).

On other hand, industrialization increases pollution and has a negative impact on economic growth through the impact on natural capital, human health and productivity (Albrizio et al., 2014; Ghanem, 2018; Bretschger & Vinogradova, 2017). Liu & Lin (2019) had study the relationship between economic growth and urbanization in China and concluded that increasing population and industrialization is positively correlated with environmental pollution.

Thacker et al. (2019) uphold that industrialization, technologization and infrastructure has indeed a negative impact on the environment by overexploitation

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of natural resources, destroying habitats, harmful air quality, greenhouse emissions, but also these are essential through the capabilities and services needed by people, as well as for minimizing the impact of humans on the environment. Some studies show up that economic development and higher incomes have a positive effect on environmental quality indicators. Investments in public health, sanitation and infrastructure can protect vulnerable populations and increase productivity (Neagu et al., 2017; Ali & Puppim de Oliveira, 2018).

A study made by Ota (2017) regarding sustainable development, income inequality and environmental degradation on a sample of 20 Asian countries demonstrated that economic growth has a different impact on environmental deterioration according to national conditions, policy, technology and technical means. Nasrollahi et al. (2018) investigated the relationship between industrialization, technology, population and sustainable development and revealed that in MENA and OECD countries sustainability is negatively influenced by population and industrialization and is positively affected by technology and international environment agreements. The study made by de Angelis, Di Giacomo and Vannoni (2019) regarding the role of environmental policies on pollution and clime change for a sample of 32 countries revealed that policies are effective in reducing pollution and environmental damages associated with economic development.

In terms of globalization, Lim, Menaldo & Prakash (2015) made a study regarding 88 official development assistance recipients and found that at a low level of globalization foreign aid is associated with increased environmental protection. Wiedmann & Lenzen (2018) showed that international trade has a major impact on the environment especially through the large exports from developing to developed countries, which have a negative impact on the quality of the environment.

In this paper, it is analyzed the relationship between economic growth and environmental quality in the case of 31 European countries between 2000 and 2016 using the Environment Kuznets Curve. This work is relevant for empirical researches regarding the economic growth and environmental deterioration of European countries and brings the same insights regarding sustainable development. Our paper also contributes to the development of econometric applications based on panel data and the Environment Kuznets Curve.

3. Hypothesis and presentation of the model

Regarding the relationship between economic development and environmental quality, starting from the premise that sustainable development will take place in the future, it is important to accurately identify past circumstances, but also the current situation.

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The Kuznets environmental curve highlights and considers the hypothesis of a *relationship between economic growth and the environment*. This hypothesis was derived from the observation of statistical, environmental and economic data and indicators. Thus, the income per capita intervals are passed on the horizontal axis, and the environmental degradation shown by specific indicators appears on the vertical axis, the relationship between the two aspects having the shape of an inverted U-shaped curve.

Only models with fixed effects can be estimated consistently. The Hausman test can be used to test inconsistency in estimating random effects by comparing fixed effects and random effects of curve parameters. Patterns with random effects may be inconsistent due to the correlation between explanatory variables and errors. Assuming that there are no other difficulties in the statistical data, the fixed effects model can be estimated constantly, but the estimated parameters are conditioned by the country and the temporal effects in the selected data sample (Hsiao, 2010). Therefore, they cannot be used to extrapolate to other data samples. The use of the Kuznets curve model only for developed countries could say very little about the future behavior of global development. If the regressions of the curve are not cointegrated, then the estimates will be false. Testing for integration and cointegration in panel data was developed by Perman and Stern (2003), who found that sulfur emissions and GDP per capita can be integrated variables.

The standard regression model of the Kuznets curve is of polynomial type of degree two or three. A second-degree model is as follows (Stern, 2003):

$$\ln(E/P)_{it} = \alpha_1 + \gamma_t + \beta_1 \ln(GDP/P)_{it} + \beta_2 (\ln(GDP/P)^2_{it} + \varepsilon_{it} \qquad (1),$$

where E is the emissions, P represents the population and ln is the natural logarithm.

Usually, the model is estimated using panel data. Most studies try to estimate both fixed and random-effects models. Fixed effects models analyze the regression parameters α_1 and γ_1. The random-effects model treats α_1 and γ_1 as random variables.

Another formula used for the analysis of the Kuznets curve is the third-degree polynomial:

$$E_{it} = \beta_0 + \beta_1 y_{it} + \beta_2 (y_{it})^2 + \beta_3 (y_{it})^3 + \beta_4 x_{it} + \varepsilon_{it} \qquad (2),$$

The dependent variable E represents the environmental pollution index, y is the expression of income per capita, x represents other control variables, i represents the country and t time.

If $\beta_1 > 0$, $\beta_2 < 0$ and $\beta_3 = 0$ and have statistical significance then the maximum point of the pollution level can be identified. After this point, the pollution starts to decrease to a reasonable level and then we can talk about a Kuznets curve. In the model of equations presented above, the level of income per capita at the maximum point is given by $\left({}^{-\beta_1}\!/_{2\,\beta_2} \right)$.

A major concern in the empirical analysis is given by the size of the income level that corresponds to the maximum point.

When it is analyzed natural resources (e.g. forests), the linear logarithmic model or the semi-logarithmic model is most often used, because the dependent variable cannot fall below 0.

In the case of $\beta_3 > 0$ with statistical significance, the decrease of the pollution level - in parallel with the increase of revenues - is considered temporary. In the opposite situation, the level of pollution will worsen at a stage when revenues will increase. This situation leads to an estimation model based on the assumption that the curve has the shape of N. In order to control the variable that affects both the environment and the income, the variable x is calculated. Agras and Chapman (1999) study the effect of explanatory variables other than income, concluding that income has the greatest explanatory power. The results obtained by Neumayer (2007) are in line with this result.

The techniques used in the empirical analysis can be classified into different categories. The first category is the one based on countries, and in which the estimation of the Kuznets curve is made for each country individually or globally. From 1990 to 2000, many studies focused on estimating the curve globally. These studies start from the assumption that all countries have the same place, although, in reality, this is not the truth. In developing countries there is a possibility that this curve will change to the bottom right, this process being known as a latecomer advantage.

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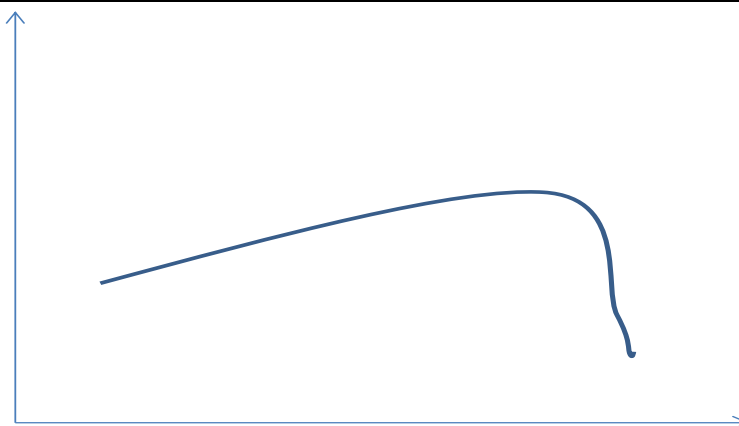
Figure 1 Kuznets curve

The second category is based on estimation methods. The income per capita and pollution levels may be non-stationary; when the data are non-stationary, the regression analysis can give false correlations and the results cannot be interpreted. Therefore, some studies test and then perform the self-regression model and the error self-correlation model after the confirmation of cointegration. Figure 1 shows a typical Kuznets curve model.

But there are other possible forms of relationship between the quality of the environment (Y axis) and income (X axis) (Figure 2).

Figure 2 Possible shapes of the Kuznets curve

Where:

• Figures a) and b) represent linear functions, with $\alpha_1 < 0$, $\beta_1 = \beta_2 = 0$.
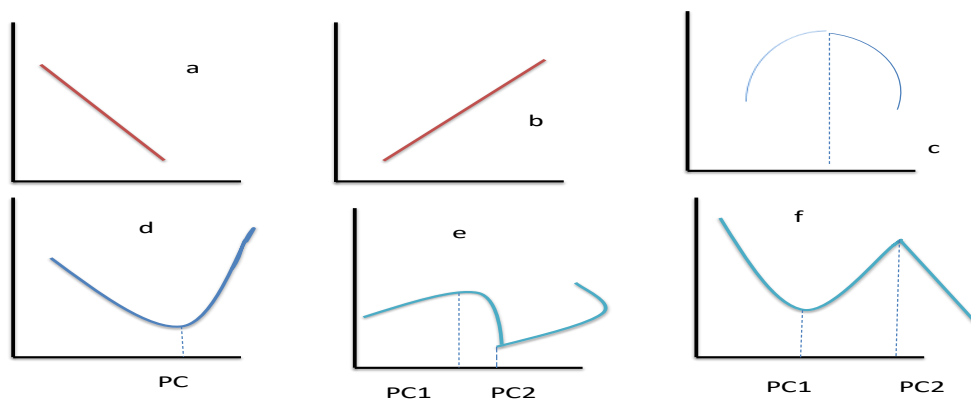• Figure c) is a polynomial relation to the cube, inverted U, $\alpha_1 > 0$, $\beta_1 < 0$ and $\beta_2 = 0$.
• Figure d) is a cube polynomial with normal U shape, $\alpha_1 < 0$, $\beta_1 > 0$ and $\beta_2 = 0$.
• Figure e) represents a third degree polynomial, where: $\alpha_1 > 0$, $\beta_1 < 0$ and $\beta_2 > 0$.
• Figure f) represents a third degree polynomial, where $\alpha_1 < 0$, $\beta_1 > 0$ and $\beta_2 < 0$.

Depending on the stage of economic development in each country, the model showed using polynomial functions has different forms, as will be seen below. The inverted U-shaped relationship between income and environmental quality is generally valid, and if high-income countries are already over the slope, is expected an improvement in the environment of rich countries.

However, the discussions are not as simple as they seem. In the table below we present a study that had the following results, for the period 1970-1988:

Table 1 GDP growth and pollutant emissions

Country	GDP	Energy	C0₂	SO₂	NOₓ	Nitrogen fertilizers	Municipal waste
Canada	208	152	132	57	143	371	121
France	166	135	82	43	121	169	134
Germany	154	115	95	35	123	13 8	100
Italy	178	118	11 7	73	111	15 7	117
Japan	226	135	12 5	17	71	10 9	121
Great Britain	155	100	87	59	101	16 9	10 9
USA	173	117	119	73	107	13 2	133

Note: Index 1970 = 100, except C02 (1071 = 100) and municipal waste (1975 = 100)
Source: Ekins (1997)

The differences between the effects of economic growth and the environment are due to several factors combined in terms of technical and compositional effects, presented below.
1. Technical - more efficient use of inputs, the substitution of more efficient ones, reduction of waste, the transformation of waste into more environmentally friendly products, recycling of waste, change of sectoral structure (from industry to services), cleaner products (eco or green);
2. Composition - changing the model of production or consumption to new more environmentally friendly sectors.
In conclusion, reducing the impact on the environment can have multiple causes and not necessarily economic growth. It is sure, however, that when there is more money in society, in order to increase the quality of life and well-being given by

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people's high incomes, investment funds can be allocated to reduce the overall level of pollution.

4. Application of the model and results obtained. Correlation of CO_2 Emissions - GDP in European Union countries

In this section it is analyzed the dependence of CO_2 emissions - GDP (both per capita) for several European countries, to see if the model discussed above is validated.

Overall, the evolution of GDP per capita in the EU-28 has been increasing, from 22,900 Euro per capita (2000) to 27,100 Euro per capita (2016), while the value of CO_2 emissions has decreased from 10.8 to 8.7 tons-equivalent per capita (Eurostat, 2018).

Drawing by points the graph of CO_2 emission - GDP dependence (GDP is the independent variable) it is found that a variety of curves are obtained either linear or polynomials of degree 2 or 3. No inverse U relationship is observed. Figure 3 shows a polynomial of degree 2 located on a downward slope. It is very likely that some countries such as Germany, Denmark, Austria will be on the downward slope of the inverted U-curve, and the countries in Eastern Europe will be on the downward slope.
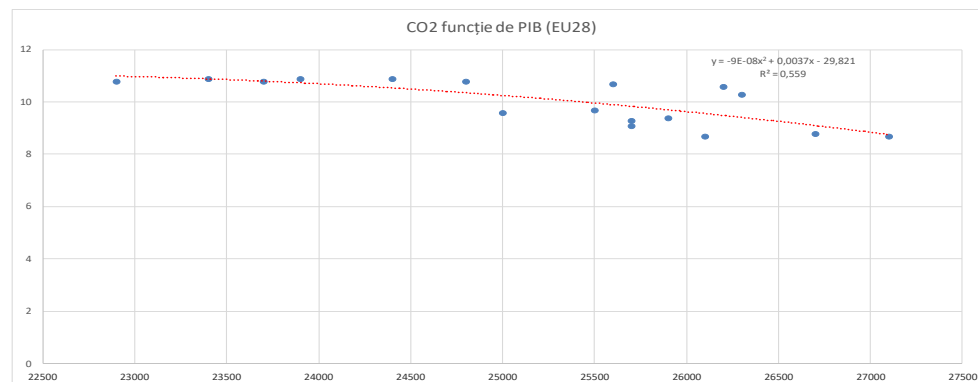
Figure 3 CO_2 per capita by GDP per capita
Source: Own processing.

For Germany, France and Croatia, the relationship between CO_2 per capita and GDP per capita plotted using the Kuznets curve is shown in the representations of Figure 7-7, at points e) a third-degree polynomial where: $\alpha_1 > 0$, $\beta_1 < 0$ and $\beta_2 > 0$ and f) a third-degree polynomial, where $\alpha_1 < 0$, $\beta_1 > 0$ and $\beta_2 < 0$ (both combined) (Figure 4).
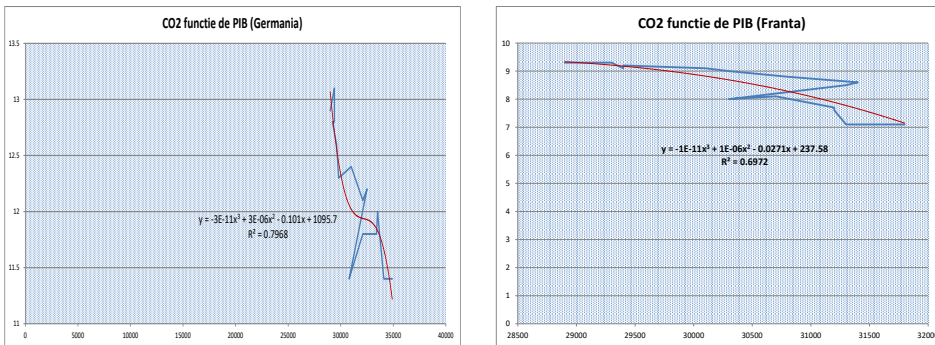
Figure 4 CO_2 by GDP - Germany and France
Source: Own processing

While for the Czech Republic, the relationship between the level of CO_2 per capita and the GDP per capita shown by the Kuznets curve is similar to that recorded at EU-28 level (Figure 5).
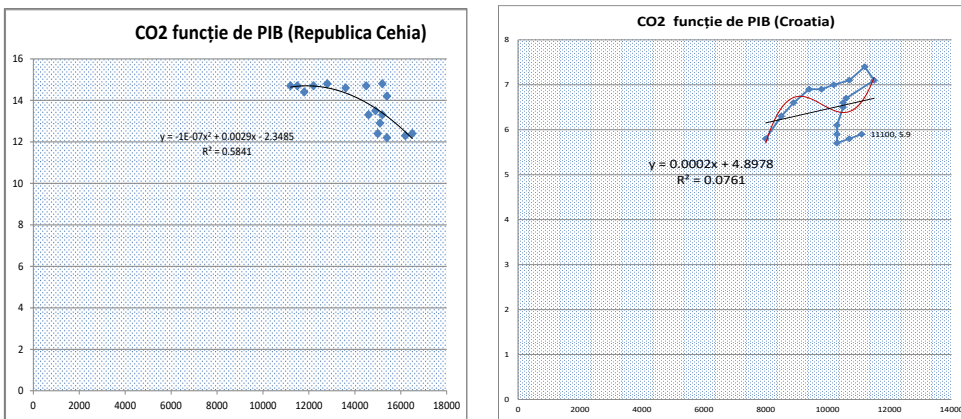
Figure 5 CO_2 by GDP - Czech Republic and Croatia
Source: Own processing

In Romania, the graph below shows that there is a trend shown using category a) in Figure 6, meaning it is given by a linear function, $\alpha_1 > < 0$, $\beta_1 = \beta_2 = 0$, with an ascending slope, and for Bulgaria the trend was one of growth, but the evolution has not been maintained.

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Cosma, I.G., David, K.G., Antonescu, D., Dumiter, F.C., Jimon, Ş.A., (2020)
The correlation between CO₂ emissions and GDP in a sustainable development framework using Kuznets Environment Curve
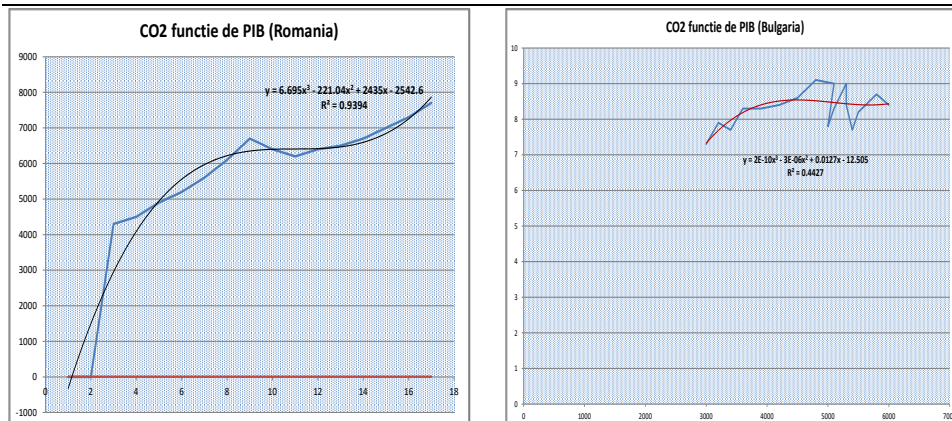
Figure 6 CO$_2$ by GDP - Romania and Bulgaria
Source: Own processing

Greece also has a Kunznets curve similar to Bulgaria, increasing but with a declining tendency, and Hungary is on a downward slope, with a clear downward trend (Figure 7).
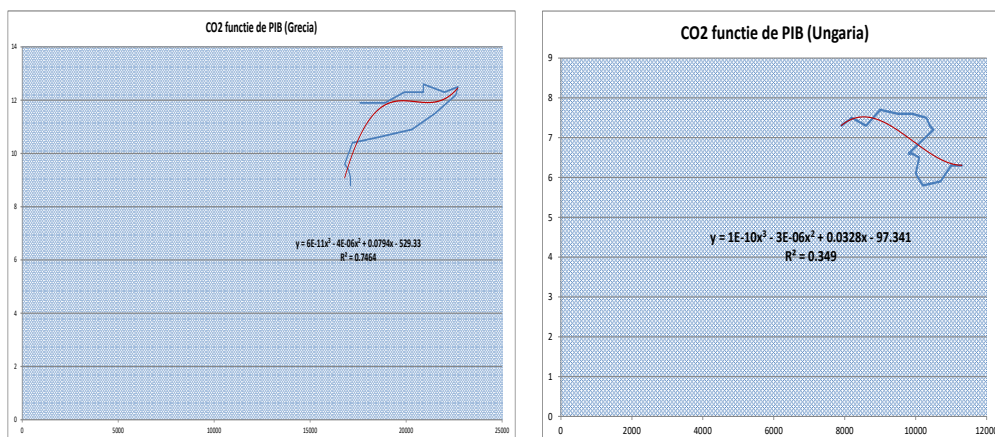
Figure 7 CO$_2$ by GDP - Greece and Hungary
Source: Own processing

Correlation of CO$_2$ emissions - GDP at an aggregate level. Panel models
To see what the CO$_2$ emissions - GDP ratio looks like in Europe, we used a panel analysis for the period 2000-2016, which included 31 European countries. This resulted in 527 observations.

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a. Standard polynomial models

The analyses were performed with the EViews software and the results are presented below. In the first phase, two models were analyzed: a polynomial of degree 2 and another of degree 3. The values of the independent and dependent variables were logarithmic.

Grade 2 polynomial

The equation used was as follows:

Estimated equation: $\ln(CO_2) = C(1) + C(2) \times \ln GDP + C(2) \times ln^2(GDP)$

Replacement coefficient: $\ln(CO_2) = 3.105345 - 0.449066 \times \ln GDP + 0.036908 \times ln^2(GDP)$

For this equation, the estimated values of the coefficients are in Table 2.

The errors are normally distributed (the value of the Jarque-Bera statistic is 3,885, so the null hypothesis of normality has the associated probability of 0.1433, higher than the standard threshold of 0.05). The normality of the error distribution validates the application of the t-statistical test of the significance of the parameters. It can be seen that the t-statistical values are higher than the critical thresholds associated with the quantile of 1%, for the coefficients c (1) and c (3) and at the threshold of 5% for c (2) (EViews program reports the probability associated with the t-statistical test bilateral, so for the standard, unilateral test, p = 0.0664 / 2 = 0.0332 <0.05).

Table 2 Parameter values for the polynomial equation of degree 2

Dependent variable: ln (CO₂)				
Method: EGLS Panel (Period SUR)				
Periods included: 17 (2000 - 2016)				
Cross-sections included: 31				
Total observations (balanced panel): 527				
Covariance matrix: White (period)				
Variables	Coefficient	Std. Error	t-Statistic	Prob.
C	3.105345	1.126981	2.755455	0.0061
ln (PIB)	-0.449066	0.244117	-1.839553	0.0664
ln^2(PIB)	0.036908	0.013293	2.776402	0.0057
R-squared	0.197727	Mean dependent var		0.848265
Adjusted R-squared	0.194665	S.D. dependent var		3.092738
S.E. of regression	1.001353	Sum squared resid		525.4190
F-statistic	64.57218	Durbin-Watson stat		1.997159
Prob(F-statistic)	0.000000			
Source: EViews				

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Specifically, the link parameter between log (GDP) and log (CO₂) is negative, and that between log (GDP)^2 and log (CO₂), both being significantly different from zero. The estimation method (SUR in periods) eliminated serial self-correlation (according to the Durbin-Watson test). Instead, the errors are autocorrelated between the cross-sections (according to Breusch-Pagan LM, Pesaran scaled LM and Pesaran CD tests).

Grade 3 polynomial

The equation used was a polynomial of degree 3 of the form:

Estimated equation: $\ln(CO_2) = C(1) + C(2) \times \ln(GDP) + C(3) \times ln^2(GDP) + C(4) \times ln^3(GDP)$

Replacement   coefficient:
$\ln(CO_2) = -19.9988 + 6.5902 \times \ln(GDP) - 0.6751 \times ln^2(GDP) + 0.024 \times ln^3(GDP)$

For the polynomial equation of order 3, the calculations of the coefficients are detailed in Table 3.

Table 3 Parameter values for the polynomial equation of degree 3

Dependent variable: ln (CO₂)
Method: EGLS Panel (Period SUR)
Periods included: 17 (2000 - 2016)
Cross-sections included: 31
Total observations (balanced panel): 527
Covariance matrix: White (period)

Variables	Coefficient	Std. Error	t-Statistic	Prob.
C	-19.99876	7.961095	-2.512061	0.0123
ln (PIB)	6.590247	2.562987	2.571315	0.0104
ln^2(PIB)	-0.675118	0.272893	-2.473925	0.0137
ln^3(PIB)	0.023913	0.009622	2.485164	0.0133
R-squared	0.240226	Mean dependent var		0.812200
Adjusted R-squared	0.235868	S.D. dependent var		3.115703
S.E. of regression	1.001423	Sum squared resid		524.4893
F-statistic	55.12097	Durbin-Watson stat		1.990468
Prob(F-statistic)	0.000000			

Source: EViews

As for the previous model, the errors are normally distributed (the value of the Jarque-Bera statistic is 3,187, so the null hypothesis of normality is associated with the probability 0.2032, higher than the standard threshold of 0.05). The normality of the error distribution validates the application of the t-statistical test of the significance of the parameters.
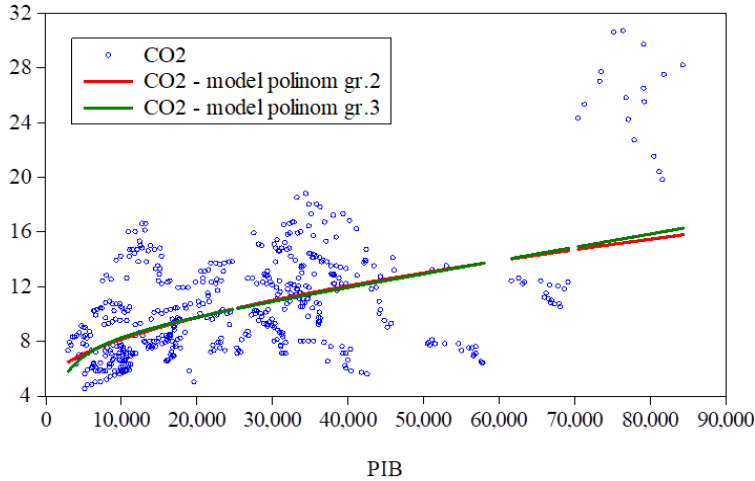
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Figure 8 Estimation of the relationship between CO_2 emissions and GDP - polynomial models
Source: EViews

The coefficients are significantly different from zero at the 1% threshold (for the unilateral t-statistical test). The estimation method (SUR in periods) eliminated serial self-correlation (according to the Durbin-Watson test). Instead, the errors are autocorrelated between the cross-sections (according to Breusch-Pagan LM, Pesaran scaled LM and Pesaran CD tests). The second regression equation (polynomial of degree three) does not bring a significant improvement in the estimation. In comparison, the results of the two models are shown in Figure 8.

Under the mention reservations (cross-section autocorrelation), it can be seen that whatever the polynomial model, the dependence graph CO_2 emissions - GDP is not an inverted U-shape. The resulting graph represents the ascending branch of a second-degree polynomial and it can be hypothesized that, probably, after GDP will increase, the descending branch of the polynomial will also appear.

The co-integration relationship between CO_2 emissions and GDP
We try to identify the reasons for the lack of coherence of the previous results. For this purpose, in the first phase, we test the nature of the series used. If the series are non-stationary, then we test the possibility of a long-term equilibrium relationship (cointegration).

The nature of the series
Series of CO_2 emissions

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Cosma, I.G., David, K.G., Antonescu, D., Dumiter, F.C., Jimon, Ş.A., (2020)
The correlation between CO₂ emissions and GDP in a sustainable development framework using Kuznets Environment Curve

The computation on the unit root tests in the panel (2000 - 2016) for the CO_2 emission series, calculated on the basis of data from the 28 countries of the European Union, plus Switzerland, Norway and Iceland are presented in Table 4.

Table 4 Panel unit root tests for CO_2 emissions series

Method	Exogenous variables:					
	No		Individual fixed effects		Individual trends	
	Statistical test	Prob.	Statistical test	Prob.	Statistical test	Prob.
	Null hypothesis: Common unity root					
Levin, Lin & Chu t	-7.88643	0.0000	2.64372	0.9959	-5.60223	0.0000
Breitung t-stat					0.93053	0.8240
	Null hypothesis: Individual unit roots					
Im, Pesaran and Shin W-stat			5.61573	1.0000	-2.83935	0.0023
ADF - Fisher Chi-square	146.643	0.0000	26.6939	1.0000	93.9821	0.0054
PP - Fisher Chi-square	157.692	0.0000	38.9871	0.9902	110.789	0.0001

Source: EViews

The tests presented in the tables suggest a type I (1) structure for the model with individual fixed effects, a stationary structure for the model without exogenous variables and provide ambiguous results for the model with individual trends. In the first difference, the series is stationary, whatever the hypothesis regarding the exogenous variables (without, constant, trend). For the robustness of the analysis, we apply the efficient unit root tests (second-generation tests) for the series of aggregate CO_2 emissions in the European Union (Table 5).

Table 5 Unit root test for CO_2 emissions - EU-28 average

Test		Exogenous variables:								
		No			Constant			Trend		
		5%	test	conc.	5%	test	conc.	5%	test	conc.
ADF		-1.964	-2.396	I (0)	-3.066	0.297	I (1)	-3.733	-2.523	I (1)
Phillips-Perron		-1.964	-2.497	I (0)	-3.066	0.297	I (1)	-3.733	-2.544	I (1)
KPSS					0.463	0.501	I (1)	0.146	0.137	I (1)
GLS-DF					-1.964	0.157	I (1)	-3.19	-2.371	I (1)
ERS					2.970	65.32	I (1)	5.72	28.105	I (1)
Ng-Perron	MZa				-8.10	0.650	I (1)	-17.30	-3.671	I (1)
	MZt				-1.98	0.528	I (1)	-2.91	-1.355	I (1)
	MSB				0.233	0.813	I (1)	0.168	0.369	I (1)
	MPT				3.170	44.663	I (1)	5.48	24.821	I (1)

Note: 5% - theoretical value for the 5% threshold.

Source: EViews

With the exception of the ADF and Phillips-Perron tests, in the non-constant model, all other tests suggest a non-stationary structure for the CO_2 emission series. Consequently, subject to the small number of time records available, we accept the assumption that the CO_2 emission series are non-stationary, both individually and in the panel.

GDP Series

The computation regarding the unit root tests in the panel (2000 - 2016) for the GDP series, calculated on the basis of data from the 28 countries of the European Union, plus Switzerland, Norway and Iceland are presented in Table 6.

The tests presented in Table 6 suggest a type I (1) structure for the model with individual fixed effects, a stationary structure for the model without exogenous variables and provide ambiguous results for the model with individual trends. In the first difference, the series is stationary, whatever the hypothesis regarding the exogenous variables (without, constant, trend).

Table 6 Panel unit root tests for Gross Domestic Product series

| Method | Exogenous variables: | | | | | |
| | No | | Individual fixed effects | | Individual trends | |
	Statistical test	Prob.	Statistical test	Prob.	Statistical test	Prob.
	Null hypothesis: Common unity root					
Levin, Lin & Chu t	5.77835	1.0000	-1.13307	0.1286	-2.69439	0.0035
Breitung t-stat					-5.01462	0.0000
	Null hypothesis: Individual unit roots					
Im, Pesaran and Shin W-stat			1.81109	0.9649	-0.56162	0.2872
ADF - Fisher Chi-square	7.53102	1.0000	39.9551	0.9867	61.5204	0.4933
PP - Fisher Chi-square	4.22953	1.0000	32.9023	0.9991	34.4852	0.9982

Source: EViews

With the exception of the individual trend model, for which the GDP series is stationary in the panel and non-stationary in cross-sections, under all other assumptions, the series is non-stationary, integrated by order I.

Long-term equilibrium relationship

Since the series that estimate the evolutions of CO_2 emissions and the dynamics of the GDP (in the period 2000 - 2016, for European countries: EU-28 plus Switzerland, Ireland, Norway) are generated by non-stationary processes, we test the hypothesis of a cointegration relationship. The results are presented in Table 7.

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The cointegration relationship (long-term equilibrium) is graphically described in the figure below.
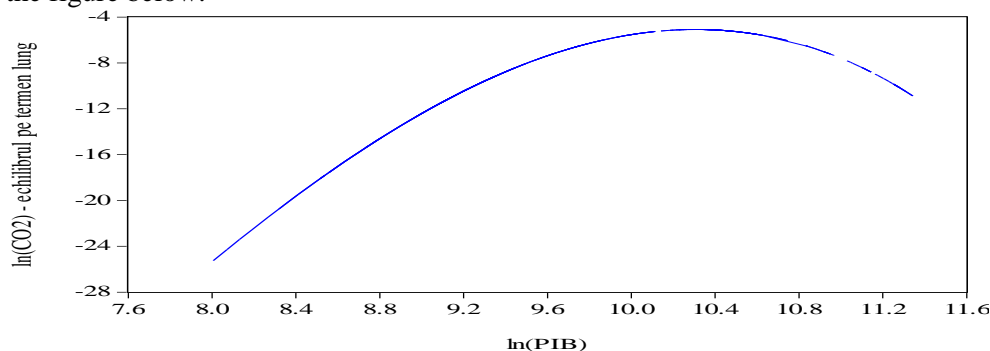

Figure 9 Cointegration relationships in the panel between CO₂ emissions and GDP
Source: Own processing

Table 7 Panel cointegration equation between CO₂ emissions and GDP

Period 2005 2016
Observation included: 372

The cointegration equation			
Variables	Coefficients	Standard deviation of errors	t-statistic
$\ln(CO_2)_{-1}$	1.000000		
$\ln(PIB_{-1})$	52.12805	19.8757	2.62271
$\ln^2(PIB_{-1})$	-9.970356	3.94546	-2.52704
$\ln^3(PIB_{-1})$	0.481288	0.19543	2.46268
Coint Eq (β)	-0.001445	0.00045	-3.21207

The short-term dynamics equation
Exogenous variable: $\mathrm{dln}(CO_2)$

$\mathrm{dln}(CO_2)_{t-1}$	-0.1106 (0.062) [-1.781]	$\mathrm{dln}(PIB_{t-1})$	0.2695 (15.781) [0.017]	$\mathrm{dln}^2(PIB_{t-1})$	0.0371 (1.602) [0.023]	$\mathrm{dln}^3(PIB_{t-1})$	-0.0033 (0.054) [-0.061]
$\mathrm{dln}(CO_2)_{t-2}$	-0.1173 (0.065) [-1.811]	$\mathrm{dln}(PIB_{t-2})$	-19.7547 (17.474) [-1.131]	$\mathrm{dln}^2(PIB_{t-2})$	1.9337 (1.775) [1.090]	$\mathrm{dln}^3(PIB_{t-2})$	-0.0628 (0.060) [-1.048]
$\mathrm{dln}(CO_2)_{t-3}$	0.3086 (0.066) [4.684]	$\mathrm{dln}(PIB_{t-3})$	24.9609 (17.725) [1.408]	$\mathrm{dln}^2(PIB_{t-3})$	-2.5536 (1.800) [-1.419]	$\mathrm{dln}^3(PIB_{t-3})$	0.0860 (0.061) [1.417]
$\mathrm{dln}(CO_2)_{t-4}$	0.1376 (0.065) [2.126]	$\mathrm{dln}(PIB_{t-4})$	14.6167 (15.597) [0.937]	$\mathrm{dln}^2(PIB_{t-4})$	-1.3659 (1.593) [-0.857]	$\mathrm{dln}^3(PIB_{t-4})$	0.0421 (0.054) [0.779]

Note:
- ✓ Standard deviation of errors in (), t-statistic in []
- ✓ $\mathrm{dln}(x) = \ln(x) - \ln(x_{-1})$

Source: EViews

The coefficient of integration (β) is negative and significantly different from zero, which means that at the level of European countries (EU-28 plus Switzerland, Ireland, Norway), there is a stable polynomial equilibrium relationship between CO$_2$ emissions and GDP on long-term:

$$\ln(CO_2) = 52.128051 \times \ln(GDP) + 9.970356 \times ln^2(GDP) - 0.481288 \times ln^3(GDP)$$

But the correction applied in each step is small, in size (β = - 0.001445).

5. Conclusions

Regarding the method of assessing the economic impact and economic growth on the environment, after 1990, the problem of finding econometric models to identify the degree of pollution, more precisely, to analyze the relationship between different indicators specific to environmental degradation. The novelty is the application of a model based on the Kuznets curve in order to identify the evolution of environmental quality given by the level of CO$_2$ in the atmosphere and its relationship with economic development. The model uses two indicators that show two dimensions of the impact of human activity: on the one hand GDP per capita (a measure of economic development) and on the other hand CO$_2$ emissions per capita, both indicators being provided by the European Statistics Directorate (EUROSTAT). To show the relationship between CO$_2$ emissions and GDP at the European level, a panel analysis was used for the period 2000-2016, which included 31 European countries (28 EU countries, plus Switzerland, Norway, Ireland). 527 observations resulted; the values of the coefficients are statistically significant with very high T-test values. Also, the Durbin-Watson statistic has the value 1,802 which indicates a low autocorrelation of the residues. The analyzes were performed with the EViews program, and the results are presented below.

Two models were analyzed: a polynomial of degree 2 and another of degree 3. The values of the independent and dependent variables were logarithmic. Subject to the self-correlation of errors in cross-sections, we have shown that, whatever the polynomial model, the dependence graph CO$_2$ emissions - GDP is not an inverted U-shape. The resulting graph represents the ascending branch of a second-degree polynomial and it can be hypothesized that, probably, after the GDP will increase, the descending branch of the polynomial will also appear.

Because the results obtained by polynomial models are not consistent, we tested the nature of the series used. The calculations on the unit root tests in the panel (2000 - 2016) for the CO$_2$ emissions series, estimated based on data from the 28 countries of the European Union, plus Switzerland, Norway and Iceland suggest that these series are non-stationary, more precisely I (1) - integrated of order I.

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Also, the unit root tests in the panel (2000 - 2016) for the GDP series suggest non-stationary structures (with stochastic trend), at I (1). Starting from the finding that the series that estimate the evolution of CO$_2$ emissions and the dynamics of the gross domestic product (in the period 2000 - 2016, for European countries: EU-28 plus Switzerland, Ireland, Norway) are generated by non-stationary processes, we tested the hypothesis of cointegration relations.

Although the correction applied in each step is small in size, the co-integration coefficient is still negative and significantly different from zero, which means that at the level of European countries (EU-28 plus Switzerland, Ireland, Norway), between CO$_2$ emissions and the GDP is a stable polynomial long-term equilibrium relation. The relationship reveals a U-type graphic structure - inverted.

The findings obtained in conjunction with the results of other studies and analyzes have suggested the idea that economic development may lead to a reduction in pollutant emissions, but under certain conditions. However, economic growth is a necessary process that can lead to improved environmental quality. This transforms the "growth limits", and the conclusions suggest the idea that the growth process is a condition or a requirement for improving the environment. If economic growth is conducive to a clean environment, then policies that stimulate economic growth (e.g. trade liberalization, economic restructuring and price reform) must also be favorable to it.

Author Contributions
This study is the independent work of the authors, from the conception of the topic to the literature review, data collection, and analysis. The authors participated equally in the making of this paper.

Disclosure Statement
The authors declare no conflict of interest.

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