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Impact of Economic Growth and Energy Consumption on Greenhouse Gas Emissions: Testing Environmental Curves Hypotheses on EU Countries

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Abstract: This study analyses the relationship between per capita greenhouse gas (GHG) emissions, gross domestic product, gross inland energy consumption, and renewable energy consumption for a panel of 28 countries of European Union in the period 1990–2016. Two theoretical models, a quadratic and a cubic one, are used to estimate the shape of the environmental curve and to test the Kuznets hypothesis. The panel cointegration approach proved the existence of long-run equilibrium relations among the four macroeconomic indicators. Empirical estimations, using panel data techniques, as well as heterogeneous regression for each individual country in the panel, show non-conclusive evidence for the environmental Kuznets curve (EKC) hypothesis. The least square estimates, with the variables in log per capita form, reveal that the inverted U-shaped EKC hypothesis is verified for the panel and for 17 of the 28 EU countries. Estimates of the cubic model show that the environmental curve has an inverted N-shaped form. These results do not hold when the values are in non-logarithmic form. In addition, the estimations for all models show that an increase of gross energy consumption leads to an increase of GHGs, while an increase of renewable energy consumption leads to a reduction in GHG emissions.

Keywords: greenhouse gas emissions; economic growth; energy consumption; renewable energy consumption; environmental Kuznets curve hypothesis; quadratic model; cubic model; data panel; panel cointegration; panel least square estimates

1. Introduction

1.1. Preliminaries

The World Health Organization links air pollution to airborne presence of gases and particles that are harmful to living beings when they exceed a certain concentration threshold. Greenhouse gases (GHG) are gaseous compounds present in the atmosphere that, absorbing infrared radiation and retaining heat in the atmosphere, are responsible for the greenhouse effect, which eventually leads to global warming.

The most important components of GHG are water vapor (H_2O), carbon dioxide (CO_2) and methane (CH_4). GHGs also include nitrous oxide (N_2O), sulfur hexafluoride (SF_6), hydrofluorocarbons (HFC) and perfluorocarbons (PFC) [1]. Human activities are causing the concentration of carbon dioxide in the atmosphere to steadily rise, contributing to global warming [2]. Traditional fuel combustion is an important source of dangerous emissions (COx, NOx, SOx, etc) [3,4]. Thus, reducing the use of energy from non-renewable resources may lead to a decrease in such emissions [5].

The European Union has set, as primary climate and energy targets [6], the reduction of greenhouse gas emissions by at least 20% from 1990 levels, an increase in the share of renewable energy in final energy consumption to 20%, and an increase in energy efficiency gains by 20%. With regard to the progressive reduction of greenhouse gas emissions, the EU aims to reduce it by 20% in 2020, compared to 1990, and by 40% in 2030, by 60% in 2040 and by 80% or 90% in 2050, and to turn the European economy into a low-carbon energy-efficient one [7]. It is noteworthy that the target of reducing GHG emissions by 80% in 2050 will be very difficult to achieve; it involves acceleration after 2030, and tough decisions for all countries in order to eliminate internal combustion engines. A major problem is that the increasing consumption of non-renewable energy may lead to disasters and catastrophic damage to the environment by also increasing GHG emissions. Higher energy consumption from renewable sources means fewer gas emissions. Renewable energy consumption is steadily increasing in the EU, accounting for 16.7% of gross final energy consumption in 2015 [8]. By 2020, the EU aims to produce at least 20% of required energy from renewable sources, to reach 27% by 2030 [9].

The relationship between economic growth and energy consumption and their effects on the environmental degradation and, implicitly, on greenhouse gas emissions have been intensively studied. One of the models tested for this relationship is the so-called the Environmental Kuznets Curve (EKC) hypothesis, stating that the graph of the environment degradation as a function of the gross domestic product has an inverted U-shaped form. This means that the economic growth of a country leads initially to an increase in environmental degradation up to a turning point, at which point technological advances lead to the development of new technologies, resulting in environmental improvement [10]. Much research has approached studying the environmental Kuznets curve hypothesis, taking as variables GHG emissions, economic growth and different types of energy consumption. Empirical studies in this sense have used either a quadratic or a cubic model, and data from different groups of countries and periods of time [11,12].

1.2. Objectives and Outline of the Study

Motivated by the decisions of the European Commission on reducing greenhouse gas emissions, the main objective of this paper is to analyze the evolution of greenhouse gas emissions in EU countries and how it can be influenced by economic growth, gross energy consumption and renewable energy consumption.

To this end, we used a data panel containing information from Eurostat and the World Bank between 1995 and 2016 for the 28 EU states based on the following four macroeconomic indicators: Gross Domestic Product (GDP), Gross Inland energy Consumption (GIC), Renewable Energy Consumption (REC), and Greenhouse Gas emissions (GHG). These data series are analyzed by means of econometric software. We used both a quadratic and a cubic model to statistically test the EKC hypothesis.

This study extends and completes the knowledge in the following directions:

- the data used concerns a panel of 28 EU countries containing all available information for the period 1990–2016;
- the analysis includes the aggregate influence of GIC and REC, in addition to GDP, on the GHGs, which is a novelty in this configuration of macroeconomic indicators, using both a quadratic and a cubic model to test the EKC hypothesis.

Empirical estimations for the panel and for each individual country, using both nominal and logarithmic values of the indicators, show non-conclusive evidence for the EKC hypothesis.

Using the values of the indicators in log per capita form, the estimations of the quadratic model show that the hypothesis that the environmental curve has an inverted U-shaped form is verified for the all countries panel and for 17 of the 28 EU countries. The estimates of the cubic model reveal that the environmental curve has an inverted N-shaped form.

Using the values of the indicators in nominal form, we found that these results do not hold. The estimations for all models also show that increasing gross energy consumption leads to an increase of GHGs, while increasing renewable energy consumption reduces GHG emissions. This constitutes a premise for sustainable development. The paper is structured as follows. In Section 2, we present a review of empirical studies concerning the analyzed indicators, followed by a short description of the empirical models, estimation methodology and the data source in Section 3. The next section contains our empirical investigations and results. Finally, some conclusions and economic consequences are derived.

2. Brief Literature Review

Economic development has a positive impact on living standards, but also a negative impact on the environment. At the same time, economic growth can lead to increased energy consumption. In this respect, some researchers have focused on the causal relationship between these indicators [13–15]. It should be noted, however, that economic development also causes greenhouse gas emissions, which has led some researchers to include environmental indicators in the causal relationship analysis mentioned above [16–18]. Some researchers have studied the correlation between GDP or GDP per capita with GHG [19–21]. The correlation between economic growth, energy intensity and CO_2 reduction was studied [22], demonstrating a positive impact on the standard of living [23].

Based on these considerations, we believe that in order to efficiently control greenhouse gas emissions and support sustainable development, it is necessary to determine the relationship between greenhouse gases, gross domestic product, and gross inland energy consumption.

Gross inland energy consumption is the amount of energy needed to meet the domestic consumption of a state: own consumption of the energy sector; distribution and transformation losses; final consumption of energy by end-users; non-energy use of energy products; and statistical differences.

As the world's states have adopted sustainable policies and decisions to encourage clean economic development, the share of renewable energy consumption in gross inland energy consumption has had an increasing trend since 1990 [24]. Therefore, we considered it appropriate, alongside the three above-mentioned indicators, to analyze the relationship with renewable energy consumption (from gross inland energy consumption).

In the literature, mainly the causality relations among greenhouse gas emissions, energy consumption and economic growth have been investigated [25,26]. Also, the relations between real GDP per capita, urbanization rate, ratio of tertiary to secondary industry, ratio of renewable energy, and fixed assets investment have been analyzed [27]. At the same time, the link between gas emissions and renewable energy consumption has been studied [28], and other researchers have analyzed this link by adding other indicators, such as capital, labor and fossil fuels [29].

Some researchers have suggested that greenhouse gas emissions in relation to GDP initially increase and then decrease, and so they have turned to the analysis of the Kuznets curve, thus providing a broad range of views on economic growth, in terms of whether it is a necessity for the improvement of the environment or the main reason for its degradation. Therefore, the relation between GHG with GDP was studied for 15 countries around the world [30], and the correlation between GHG, renewable energy consumption and GDP was analyzed for 20 European countries [31], and the EKC hypothesis was tested with respect to the significance of renewable energy and non-renewable energy consumption in the context of Pakistan [32]. Other studies carried out involve Kuznets curve analysis on GHG/CO_2, GDP, and energy consumption, using different methodologies, for different regions and states, such as Turkey [33], countries of the OECD [34–37], China [38], and Russia [39]. Some studies give a 'snap shot' of the literature related to this correlation for multiple countries [40], for 188 countries [41], for low- and middle-income countries [42], or for 106 countries classified into different income groups [43].

In addition, most of the authors have studied carbon dioxide emissions, from among the range of GHG emissions, although the US Environmental Protection Agency [1] considers other gases also to have a major contribution to global warming.

Alongside the main analyzed indicators (GHG/CO_2, GDP and energy consumption real or per capita) over different time periods and regions, some authors have also introduced other indicators they consider representative into the analysis of the EKC hypothesis. Thus, electricity production only from renewable energy for Turkey has been considered [44], as has international trade for 25 OECD countries [45], and some authors have added variables as renewable energy, promotion, energy innovation processes to analyze EKC for 17 OECD countries [12]. Others researchers have analyzed the energy consumption only from natural gas and renewable energy for BRICS countries [46], or added trade openness, financial openness and urbanization to the Myanmar analysis [47], while others studying Singapore have added population density, financial development, trade openness as indicators [48].

For European countries, we found quite few such studies. For Spain, the relations between per capita CO_2 emissions and per capita income was studied, and an inverted U-shaped form was obtained using cointegration and a non-inverted U-shape as methodologies for instability tests [49]; the relationship between GHG emissions and GDP was considered as the main variable of climate change, and the environmental Kuznets curve was analyzed for the relationship between greenhouse gases and the main aspects of economic development on panel data of groups of countries in the EU [50,51]; the impact of agro-economic factors on GHG emissions in Southeastern Europe was analyzed in comparison to advanced European economies, confirming the EKC hypothesis, which is an inverted U-shaped relation between per capita GDP and carbon dioxide emissions [52]; the effects of renewable energy and non-renewable energy, real income and trade openness on CO_2 emissions for EU countries were analyzed, obtaining different shapes for the EKC curve [53]; the Kuznets hypothesis was examined for the G20 group by introducing other variables—trade openness, the ratio of secondary industry value-added to GDP and population density—and concluded that the hypothesis was verified for developing countries and failed for developed countries [21]; the relationship between economic growth, greenhouse gas emissions, energy taxes and R&D was investigated based on panel data of 22 countries of the EU [54]; and it was demonstrated that the GHG-GDP relationship in terms of sustainable agricultural production in EU countries looks rather like an N-shaped curve [55]. As a result of the analyzes performed, statistical evidence in favor of the existence of an EKC for CO_2 emissions per capita in relation to GDP per capita was not found for 16 EU countries [16].

In conclusion, we can say that the literature suggests that there are no consistent relations among variables, an idea supported by the fact that the evidence in favor of the Kuznets environmental curve (represented by the graph of an inverted U-shaped function) is not conclusive, and the results are dependent on regional and national specifics. Since the study of the EKC hypothesis for the relationship between GDP, energy consumption and greenhouse gases or CO_2 emissions for EU countries has not been the subject of much research, we consider the investigation carried out in this study to contribute to the literature by expanding the analysis of the relation GHG–GDP–GIC–REC for the first time for all EU member countries, for the time period 1990–2016.

3. Data, Model, Methodology

3.1. Data

The annual values of the indicators used in this study were taken from Eurostat [56] and the World Bank database [57] during 1990–2016 for the 28 EU members. The macroeconomic indicators analyzed here are:

- per capita greenhouse gas emissions (GHG), measured in tones of CO_2 equivalent;
- per capita gross domestic product (GDP), measured in thousands of US dollars;
- per capita gross inland energy consumption (GIC), measured in tonnes of oil equivalent;
- per capita energy consumption from renewable sources (REC), measured in tonnes of oil equivalent.

As EU countries are very heterogeneous, both in terms of population and level of development, we considered that the results would be much more significant if we used the per capita values of the indicators. To obtain these values, we took the nominal ones and divided them by the respective population numbers.

The data are organized as:

- cross-section data—containing the values for the analyzed indicators (GHG, GDP, GIC and REC) yearly for the 28 EU countries and EU;
- time series data—containing the values of each of the four indicators during 1990 and 2016, for each of the 28 EU countries.

These data series are organized as a panel. As the data for 2016 were not available for all countries, the analysis below refers only to the 1990–2015 period.

3.2. Models

Two models are used in this paper to investigate the existence of an EKC-type relation between GHG emissions and GDP, and the effect of energy consumption on GHGs. To measure the environmental degradation, we use GHG emissions as a dependent variable, while GDP, GIC and REC are independent variables.

Model 1. The first model used to test the environmental Kuznets curve (EKC) hypothesis is the quadratic one

$$Y_{it} = \alpha_0 + \alpha_1 X_{it} + \alpha_2 X_{it}^2 + \alpha_4 Z_{1it} + \alpha_5 Z_{2it} + u_{it}. \quad (1)$$

Here, Y denotes environmental indicators, X represents per capita GDP, Z_1, Z_2 are the explanatory variables, while u_{it} is the error term, i symbolizes the countries, and t is time.

The environmental indicator used is per capita GHG emissions. As an explanatory variable, we consider the per capita gross inland energy consumption (GIC) and energy consumption from renewable sources (REC).

A similar model has been used in other papers; however, with other explanatory variables [16,32,34,36].

Model 2. The second model tests the N-shape hypothesis for the environmental curve, using the cubic equation

$$Y_{it} = \beta_0 + \beta_1 X_{it} + \beta_2 X_{it}^2 + \beta_3 X_{it}^3 + \beta_4 Z_{1it} + \beta_5 Z_{2it} + u_{it}, \quad (2)$$

where the variables have the same significance as in Model 1.

A similar cubic model has been used by many authors [11,37,58].

The variables will be considered both in nominal form and in decimal logarithm form. The parameters in the above equations with the variables in log-form can be interpreted as elasticity coefficients.

The signs of the coefficients of X, X^2, X^3, or specific relations between them determine the shape of the approximating surface. Thus, in the quadratic case (1), the relation between GHG and GDP follows an inverted U-shaped curve if $\alpha_2 < 0$. The critical value $x_0 = -\frac{\alpha_1}{2\alpha_2}$ of X is positive in the case $\alpha_1 > 0$, and for fixed values of the explanatory variable, it corresponds to a maximum value of the dependent variable Y (as in Figure 1a).

In the cubic case (2), the relation between GHG and GDP follows an N-shaped curve if $\beta_3 > 0$, and there exist two real critical values of variable X, namely $x_{1,2} = \frac{-\beta_2 \pm \sqrt{\beta_2^2 - 3\beta_1\beta_3}}{3\beta_3}$, if $\beta_2^2 - 3\beta_1\beta_3 > 0$. In this case, as $x_1 < x_2$, for fixed values of the explanatory variable, the maximum value of the dependent variable Y corresponds to x_1, while the minimum value corresponds to x_2 (as in Figure 2b). The N-shaped curve signifies that environmental degradation starts rising again after a reduction to a specific level, and the inverted N-shaped graph means the opposite of the N-shaped one; that is, environmental deterioration starts falling again after an increase to a certain level.

3.3. Econometric Methodology

The data in the panel contain information on 4 macroeconomic indicators, for 28 countries, over a span of 27 years. First, we analyze the evolution a GHG during 1990–2015, and establish the level of achievement of the EU target with regard to the 20% reduction of GHG. Next, standard statistical descriptors (such as mean value, standard deviation, etc.) are used to derive information about the distribution of the time series for all four indicators, both for overall EU data and the panel. We empirically estimated the theoretical models (1) and (2) using two approaches: (i) panel data techniques, and (ii) heterogeneous regression for each individual country in the panel.

The panel cointegration approach involves (i) examination of the stationarity properties, by means of unit root tests; (ii) testing the existence of a cointegration relationship between the variables, and (iii) estimation of the coefficients of the regression relation, if the variables are cointegrated.

The data analysis was realized with the EViews 9 [59] software product and the tests within.

4. Empirical Findings and Results

4.1. Data Analysis

Analyzing the evolution of GHG from 1990 to 2015, one can see, based on Table 1, a continuous decrease both in nominal and per capita values in most of the EU countries.

Table 1. Evolution of GHG in 2015 compared to 1990 for the EU countries.

Country	Increase/Decrease GHG 2015/1990 (%)	Mean GHG 1990–2015 in Thousand Tonnes of CO_2 Equiv.	Increase/Decrease GHG/Capita 2015/1990 (%)	Mean GHG/Capita 1990–2015 in Tonnes of CO_2 Equiv.
European Union (EU)	76.35	5,067,016.00	71.34	10.33
Austria (AT)	100.06	82,766.96	89.19	10.20
Belgium (BE)	80.28	140,595.80	71.07	13.50
Bulgaria (BG)	59.32	67,294.14	72.21	8.46
Croatia (HR)	75.44	26,024.19	85.21	5.90
Cyprus (CY)	149.97	8246.17	101.39	11.43
Czech Republic (CZ)	64.92	148,803.60	63.83	14.40
Denmark (DK)	69.31	69,154.55	62.89	12.91
Estonia (EE)	44.65	21,420.63	53.34	15.23
Finland (FI)	78.04	71,624.49	70.95	13.75
France (FR)	83.56	531,512.10	NA	9.01
Germany (GE)	72.10	1,036,141.00	55.66	12.91
Greece (EL)	92.85	117,407.40	86.55	10.87
Hungary (HU)	65.06	72,914.87	68.49	7.17
Ireland (IE)	106.73	63,114.66	80.86	15.83
Italy (IT)	83.29	522,948.60	77.67	9.05
Latvia (LV)	43.24	13,131.89	58.08	5.62
Lithuania (LT)	41.83	24,367.81	52.89	7.16
Luxembourg (LU)	80.66	11,408.65	54.35	25.44
Malta (MT)	93.49	2837.46	76.74	7.19
Netherlands (NL)	88.35	216,477.30	77.85	13.57
Poland (PO)	82.47	413,321.70	82.54	10.80
Portugal (PT)	115.72	72,908.22	111.49	7.07
Romania (RO)	47.28	153,165.90	55.22	7.03
Slovakia (SK)	55.42	51,496.57	54.06	9.60
Slovenia (SI)	90.52	19,129.50	87.60	9.52
Spain (ES)	116.62	358,898.20	97.55	8.45
Sweden (SE)	74.95	66,904.26	65.57	7.44
United Kingdom (UK)	63.45	682,999.70	55.90	11.43

In 2015, greenhouse gas emissions in the EU-28 had decreased by 23.65% compared to 1990, meaning that the EU had exceeded, overall, the 2020 target (20% reduction in greenhouse gas emissions by 2020 compared to 1990), but more efforts are needed to achieve the longer-term objectives (40% by 2030, 60% by 2040 and over 80% reduction in 2050 compared to 1990) established by the Kyoto Protocol [60].

The average decrease of the nominal value at the EU level is 20.73%, exceeding the 20% target for 2020, while the GHG per capita decrease is 27.07%, falling within the decreasing trend imposed by the European Union.

Although the GHG average at EU level has fallen according to established targets, the situation is very different across EU countries. Thus, there is a general trend of decreasing emissions, both nominally and per capita, except for 5 states, where gas emissions increased in 2015 compared to 1990 in nominal terms, namely Cyprus (with 49.97%), Spain (16.62%), Portugal (15.72%), Ireland (6.73%) and Austria (0.06%), as well as 2 other countries for GHG per capita, namely Portugal (11.49%) and Cyprus (1.39%).

The countries in the EU with the largest emissions of greenhouse gases in 2015 were Germany (901931.51 thousand tonnes CO_2 equivalent) and the United Kingdom (503499.62 thousand tonnes CO_2 equivalent), representing 32.62% of total EU emissions, although they have substantially reduced GHG emissions compared to 1990 (United Kingdom by 36.55% and Germany by 27.9%).

Compared to 1990, in 2015, the EU countries with the largest decreases in the nominal values of GHG emissions (over 50%), were Lithuania (58.17%), Latvia (56.76%), Estonia (55.35%) and Romania (52.72%). Analyzing GHG per capita, it is noted that Lithuania, with a 47.11% decline, remains the leader, followed by Estonia (46.66%), Slovakia (45.94%), Luxembourg (45.65%), Romania (44.78%), Germany (44.34%), United Kingdom (44.1%) and Latvia (41.92%).

The GHG per capita average for 1990–2015 at EU level is 10.33 tonnes of CO_2 equivalent; the highest value is registered by Luxembourg, with an average of 25.44 tonnes CO_2 equivalent per capita, followed by Estonia (15.23 tonnes CO_2 equivalent per capita), and the smallest values are recorded by Latvia, with 5.62 tonnes CO_2 equivalent per capita, and Croatia, with 5.90 tonnes of CO_2 equivalent per capita.

In Table 2, some statistics for the data in the panel are presented.

Table 2. Descriptive statistics for the overall EU and the panel.

INDIC.	Mean	Median	Max.	Min.	Std. Dev.	Skew.	Kurtosis	Jarque-Bera
				EU				
GDP	26.00	24.368	38.251	15.95	7.967	0.155	1.339	3.214
GHG	10.33	10.572	11.875	8.45	0.938	−0.640	2.448	2.103
GIC	3.493	3.514	3.706	3.17	0.154	−0.517	2.386	1.628
REC	0.256	0.220	0.425	0.15	0.090	0.639	1.968	3.035
				Panel				
GDP	24.14	21.619	120.67	1.101	18.737	1.643	7.677	936.757
GHG	10.84	10.072	34.77	4.340	4.309	1.856	9.006	1428.937
GIC	3.669	3.333	10.408	1.612	1.576	1.611	6.259	602.169
REC	0.351	0.220	1.959	0.001	0.400	2.198	7.436	1118.024

Please note that the average GDP per capita at the panel level (24.206) is lower than that at the level of Europe (26.002), unlike the average values of the other considered indicators. The skewness coefficient for the macroeconomic indicators studied for both the EU and the panel is non-zero, so the distributions are asymmetric; for the EU indicators, the distribution is platykurtic, and for the panel indicators it is leptokurtic.

4.2. Panel Cointegration

The results of the Levin, Lin and Chu (LLC) [61] unit root test performed on the panel, displayed in Table 3, show that the null hypothesis of the existence of a common unit root can be rejected for the GDP and GIC variables, so these processes are stationary at a level of confidence of 1%. The results of the ADF-Fisher and PP-Fisher tests [62], also shown in Table 3, lead us to conclude that the null hypothesis of the existence of an individual unit root can be rejected for the GHG and GIC variable, so these processes are stationary at a level of confidence of 2%. For these tests, we selected the individual effects option and automatic lag selection.

Table 3. Unit roots tests results, period 1990–2015. Variables LGHG, LGDP, LGIC, LREC.

Variable	Levin, Lin & Chu t*		ADF-Fisher Chi-Square		PP-Fisher Chi-Square	
	Statistic	Prob.	Statistic	Prob.	Statistic	Prob.
Log per capita GHG	1.11684	0.868	80.1813	0.0187	99.4034	0.0003
Log per capita GDP	−3.66071	0.0001	29.3748	0.9987	28.4487	0.9992
Log per capita GIC	−4.29757	0	111.882	0	113.261	0
Log per capita REC	−0.22843	0.4097	28.3064	0.9993	24.5547	0.9999

For the first difference processes, similar unit root tests showed that for all four indicators, the corresponding processes are stationary, the null hypothesis being rejected at 1% confidence level.

To test the cointegration hypothesis, we used Kao [63] and Pedroni [64] panel and group statistics. Applying Pedroni residual cointegration test, we found that the values for the panel and group PP and ADF-statistics make it possible to reject the null cointegration hypothesis at a 5% confidence level for both the cubic and quadratic models. Applying the Kao residual cointegration test, we obtained, for the cubic equation (1), with the variables in log form, the ADF t-statistic −6.087362, with the probability 0.00; while for the quadratic model (2), the ADF t-statistic was found to be −6.219405, with the probability 0.00. Consequently, the null hypothesis "no cointegration" can be rejected for both models. The existence of cointegration indicates that there are long-run equilibrium relationships among the variables.

We found similar results when considering the variables in the non-logarithmic form.

As the variables are cointegrated, we can estimate the relationship. To estimate coefficients in Equations (1) and (2), we applied the panel Least Square method within EViews. To decide between fixed or random effects for data, we performed the Hausman test and the redundant fixed effects test. For the cubic equation (1), we obtained the probability P = 0.108 for the Hausman test, while for the redundant fixed effects test, the probabilities equal to 0.0. For the cubic equation (2), we obtained probabilities associated with both tests equal to 0.0. Therefore, the fixed effects model is appropriate for our data set. The parameter estimates for Equations (1) and (2), their standard errors, and some statistics, are reported in Tables 4 and 5.

Table 4. Panel results for coefficients estimates of Equations (1) and (2), variables in logarithmic form.

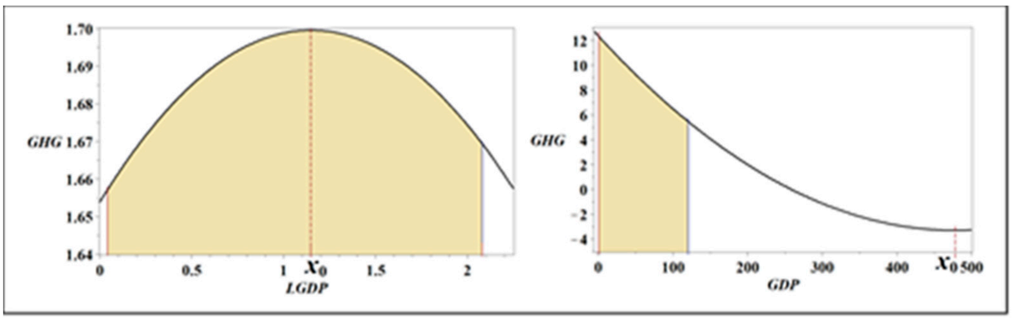
Variable	Quadratic Equation (1)			Cubic Equation (2)		
	Coefficient	Std. Error	Prob.	Coefficient	Std. Error	Prob.
Const.	1.027866	0.032791	0.0000	1.080486	0.038415	0.0000
LGDP	0.079693	0.011436	0.0000	0.010152	0.029077	0.7271
LGDP^2	−0.034711	0.002517	0.0000	−0.001042	0.013194	0.9371
LGDP^3	-	-	-	−0.004628	0.001781	0.0096
LGIC	1.085879	0.026100	0.0000	1.072061	0.026524	0.0000
LREC	−0.028384	0.005918	0.0000	−0.027303	0.005906	0.0000
Statistics						
R-squared	0.980299			0.980500		
S.E. of regression	0.051307			0.051083		
Durbin-Watson stat	0.425081			0.425116		

Table 5. Panel results for coefficients estimates of Equations (1) and (2), variables in non-logarithmic form.

Variable	Quadratic Equation (1)			Cubic Equation (2)		
	Coefficient	Std. Error	Prob.	Coefficient	Std. Error	Prob.
Const.	0.736807	0.348042	0.0346	0.487931	0.351190	0.1652
GDP	−0.065589	0.008009	0.0000	−0.026337	0.013231	0.0469
GDP^2	6.86×10^{-5}	6.31×10^{-5}	0.2771	−0.000907	0.000271	0.0008
GDP^3	-	-	-	6.00×10^{-6}	1.62×10^{-6}	0.0002
GIC	3.357526	0.092212	0.0000	3.332516	0.091578	0.0000
REC	−1.973848	0.380285	0.0000	−1.966560	0.376651	0.0000
Statistics						
R-squared	0.972556			0.973120		
S.E. of regression	0.730559			0.723567		
Durbin-Watson stat	0.290159			0.293170		

For the quadratic Equation (1), from the data in Table 4, we find that the critical value for Log per capita GDP (LGDP) is 1.14795. This value is situated inside the data interval for this variable, namely [0.04, 2.08]. In addition, we have $\alpha_2 = -0.034711 < 0$, $\alpha_1 = 0.079693 > 0$. Thus, for fixed values of the explanatory variables Z_1, Z_2, the resulting environmental curve has an inverted U-shaped form. Inverted U-shaped EKC means that, although the quality of the environment deteriorates with rising GDP level until the turning point (critical value), after that, the quality of environment improves as GDP continues to increase. For instance, considering the mean values for GIC and REC in Table 2, the estimated environmental curve is plotted in Figure 1a. The shaded area corresponds to the interval in which the values of LGDP for the data in the panel are located.

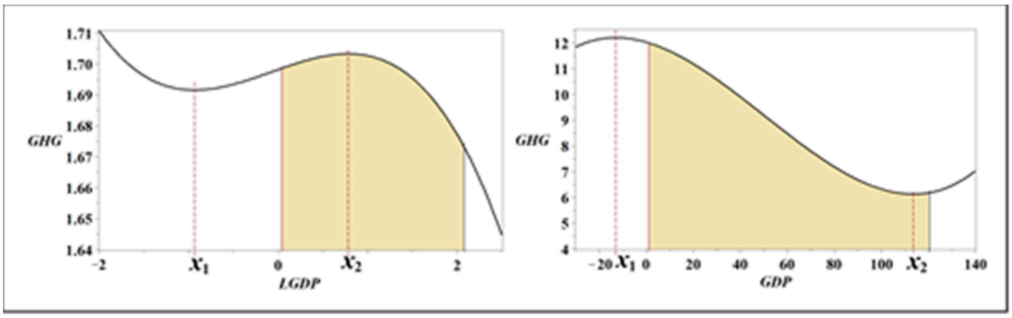
For data in nominal form, from the results in Table 5, we find that the critical value for GDP is 478.05. This value is situated outside the data interval for this variable, namely [1.10, 120.67]. As $\alpha_2 > 0$, $\alpha_1 < 0$, for fixed values of the explanatory variables Z_1, Z_2 the resulting environmental curve is included on the descending slope of a U-shaped parabola (Figure 1b). Thus, a decreasing curve means that the quality of the environment improves as GDP increases.



(**a**) (**b**)

Figure 1. Environmental curve for the quadratic estimations: (**a**) variables in logarithmic form (to the left); (**b**) variables in non-logarithmic form (to the right).

For the cubic Equation (2), using the results shown in Table 4, we find that $\beta_3 < 0$, $\beta_1 > 0$, so there are two critical values for LGDP: $x_1 = -0.93344$, $x_2 = 0.78334$. As $\beta_3 < 0$, for fixed values of the explanatory variables Z_1, Z_2, the resulting environmental curve has an inverted N-shaped form, which means that environmental deterioration increases to a critical value, and then starts falling. As for the data in the panel, LGDP varies in the interval [0.04, 2.08]; only one of the critical values is inside this interval, and this corresponds to the maximum value of LGHG (see Figure 2a).



(**a**) (**b**)

Figure 2. Environmental curve for the cubic estimations: (**a**) variables in logarithmic form (to the left); (**b**) variables in non-logarithmic form (to the right).

When the values are in nominal form, for the cubic Equation (2), with the estimated coefficients given in Table 5, we have $\beta_3 > 0$, $\beta_1 < 0$, and two critical values $x_1 = -12.87$, $x_2 = 113.65$. The estimation of the panel corresponds to the [1.10, 120.67] interval for GDP. For fixed values of the explanatory variables GIC and REC, the resulting environmental curve is a part of the N-shaped cubic form (see Figure 2b), which means that environmental degradation decreases to a critical value level and then starts rising again.

4.3. Heterogeneous Regression

For each individual country in the panel, we tested the quadratic EKC hypothesis, that is, that the environmental curve describing the relation between GHG and GDP has an inverted U-shape. Thus, using the Least Square Method to estimate the quadratic equation (1), with: Y = LGHG, (Log per capita GHG), X = LGDP (Log per capita GDP), Z_1 = LGIC (Log per capita GIC), Z_2 = LREC, (Log per capita REC), we performed estimations for each country in the panel.

The quadratic EKC hypothesis is accepted if, in the estimated equation, the coefficient of square LGDP is negative, and the coefficient for LGDP positive. According to the EKC hypothesis, the increase of GDP leads initially to an increase of greenhouse gas emissions, followed by a decline in these emissions after GDP reaches a critical value. Thus, we obtained the following results:

- The quadratic EKC hypothesis is satisfied for 11 countries, namely: Belgium, Cyprus, Denmark, Estonia, France, Greece, Italy, Poland, Romania, Spain, and Sweden. The results prove that the environment quality degrades as revenue increases to the critical value, after which there is a decrease of greenhouse gas emissions.
- The quadratic EKC hypothesis is not satisfied for the other 17 countries or the EU.
- All estimates for the coefficients of GIC were found to be positive, thus supporting the idea that as the energy consumption increases, the GHG also increases.
- All estimates for the coefficients of REC were found to be negative, thus indicating that with an increase in the energy consumption from renewable sources, greenhouse gas emissions will decrease.

The results also show countries' heterogeneity concerning the EKC hypothesis. In other words, this hypothesis is accepted for some of the EU countries, while for others it is rejected. Energy consumption is a major cause of greenhouse gas emissions. Following the results obtained, we may conclude that economic growth and energy consumption have a high impact on greenhouse gas emissions, implying the need for national renewable energy consumption policies under the EU Directive to promote sustainable economic development.

5. Conclusions

In this paper, motivated by EU Directive 2009/28/EC stating the necessity to decrease the reducing greenhouse gas emissions by at least 20% from 1990 levels by 2020, we first analyzed the evolution of greenhouse gas for European Union countries from 1990 to 2015. Second, using panel cointegration techniques, we investigated whether the Kuznets hypothesis was satisfied for the relationship between greenhouse gas emissions, economic growth, gross inland energy consumption and renewable energy consumption.

The results obtained in the first part of the study prove that at an EU country level, there is a general trend of decreasing gas emissions, in both nominal and per capita units. Only in 5 states were gas emissions increased in 2015 compared to 1990 in nominal values, allowing us to conclude that the reducing of GHGs could exceed the 2020 targets.

The main findings of this study were in the second part, where we tested the validity of the EKC hypothesis (evidence of an inverted U-shaped for the relation between GHG and GDP, with GIC and REC as explanatory variables) for a panel of EU countries using both a quadratic and a cubic model. We found completely different results when considering the variables in logarithmic or non-logarithmic form.

The panel cointegration analysis for the quadratic model revealed evidence for the existence of an inverted U-shaped curve for the relation between GHG and GDP, in log per capita form, while for variables in non-logarithmic form, we found a U-shaped environmental curve.

The results of similar estimations for individual countries in the EU (as suggested in [16]) also showed non-conclusive evidence for the EKC hypothesis.

For the cubic model, the estimated statistical environmental curve is a part of the N-shaped cubic form if the variables are in non-logarithmic form, while when using the log values, we found that the environmental curve is a part of an inverted N-shaped curve for fixed values of the explanatory variables.

For both models, we found that the empirical estimated coefficients of GIC were positive, while those of the REC variable were negative. This means, as expected, that in the long-run, the increase of GIC leads to increases of GHG emissions. However, the increase in the consumption of renewable energy leads to a reduction of GHG emissions. Therefore, the increase of the consumption of renewable energy may lead to a decrease in GHG emissions. As a policy implication, in order to reduce greenhouse gas emissions, EU countries should increase the energy consumption from renewable sources. The increasing use of renewable energy may also lead to a diminished dependence on fossil energy and ensure energy security for energy importing countries.

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