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Fresh Validation of the Low Carbon Development Hypothesis under the EKC Scheme in Portugal, Italy, Greece and Spain

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Abstract: The present study is in line with the United Nations Sustainable Development Goals (UN-SDGs) that address pertinent global issues. This study focuses on the need for access to clean and affordable energy consumption, responsible energy consumption, sustainable economic growth, and climate change mitigation. To this end, this paper evaluates the relevance of the renewable energy sector on the environmental Kuznets curve (EKC) framework in Portugal, Italy, Greece, and Spain for the period 1995–2015. As an econometric strategy, we adopt the use of panel data over the highlighted countries. In the first step, we apply the unit root test recommended by Levin, Lin, and Chu in conjunction with ADF-Fisher, and Phillips-Perron for robustness and consistency. We found that the variables used in this study are integrated I (1) in the first difference. In the second step, we apply the Pedroni cointegration test, and Kao Residual cointegration test, and we observe that the variables are cointegrated in the long run. The generalized least squares (GLS), the panel fully modified least squares (FMOLS), ordinary least squares robust (OLS), and panel quantile regression are considered in this research. The econometric results validate the assumption of the environmental Kuznets curve, i.e., and there is a positive correlation between income per capita and a negative effect of squared income per capita on carbon dioxide emissions. In contrast, we observe that renewable energy reduces CO_2 emissions. Finally, we also find a direct connection between the urban population and the environmental degradation in the examined blocs. These results show that in Portugal, Italy, Greece, and Spain, more is required to achieve environmental sustainability in the respective countries growth trajectory. Further policy prescriptions are appended in the concluding section of this study.

Keywords: environmental sustainability; renewable energy; carbon dioxide emissions; climate change mitigation; carbon-reduction; environmental Kuznets curve; Portugal; Italy; Greece; Spain

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1. Introduction

The economic and financial crisis (subprime) of the years 2008–2009 that stemmed from the United States of America had its adverse effects on European economic growth with an emphasis on four countries to the South of Europe (Portugal, Italy, Greece, and Spain), as well as on the rest of the world economy. This group of countries experienced budget deficit problems and implemented macroeconomic measures trying to stimulate economic growth. Moreover, this group of countries was criticized by the other countries of the European Union and the Eurozone, for their disproportionate deficit and populism policies.

A previous study by Fuinhas and Marques [1] compares the PIGTS (Portugal, Italy, Greece, Turkey, Spain, and Greece) for the period 1965–2009 using the autoregressive distributed lag -ARDL- bound test states that these countries went through different phases and periods with economic problems Fuinhas and Marques [1]. Moreover, the study concludes that there is bidirectional causality between energy consumption and economic growth for this group of countries.

The empirical study of Shahbaz et al. [2] evaluated the impact of economic growth, energy, and financial development on Portuguese carbon dioxide emissions for the period 1971–2013. The study applied a times series (ARDL bound test and VECM Granger causality). In the long-run, the authors proved that economic growth and energy present a positive impact on CO_2 emissions, showing that these variables encourage environmental damage. Furthermore, the financial development indicator confirms an inverted U-shaped curve.

After these years of the economic enclave, our article explores the impact of environmental Kuznets curve and renewable energies on carbon dioxide emissions for Portugal, Italy, Greece, and Spain using a data panel between 1995 and 2015. In this context, the European Commission has been referring that economic growth must have a paradigm shift, namely, by drawing attention to environmental damage and inverting the European path promoting a sustained ecosystem based on cleaner energies. The aftermath of the European debt crisis has a significant toll on the energy sector, especially southern Europe, of which Portugal, Italy, Greece, and Spain had a severe impact. This effect spilt over to her energy mix with less investment in renewable energy commitment. The political intervention has tried to alleviate the economic downturn's adverse effect in these economies after and the global financial crisis of 2008–2009. Thus, society believes in the World Trade Organization intervention, the International Monetary Fund, the European Union, and the World Bank to stabilize the world economy. We can take a lesson from the insolvency of some American banks during the 2008–2009 crisis. Our paper presents relevant empirical advances in the empirical literature, offering robust evidence, and a new battery of policy recommendations to lessen the adverse effects of carbon dioxide emissions over energy systems and their contribution to sustainable economic growth.

Humankind has experienced several pandemic diseases such as bird flu, influenza in Spain in 1918, or influenza in Hong Kong in 1968. These crises explain macroeconomic problems, namely, structural adjustments such as the labour market, fiscal policy in monetary policy, and financial markets. The economic history shows that economic recovery will come naturally after pandemic crises. Despite these macroeconomic problems, the environmental and resource savings have seen exciting improvements concerning climate change; that is, there is already some evidence.

Based on recent empirical studies Alper and Oguz [3]; Marinaş et al. [4]; Karhan [5]; Leitão and Balsalobre-Lorente [6], we observe that renewable energies allow for reducing carbon dioxide emissions and greenhouse effects, thus contributing to a more sustainable ecosystem. Furthermore, according to Eurostat online data on the overall share of energy from renewable sources, Portugal stands out compared to the other countries under study. Additionally, in 2010 energy form renewable sources represented (24.2%), and in 2015 it represented (30.5%). In second-ranking appear Italy in 2010 (13%) and 16.2% of the overall share of energy from renewable sources in 2015. Spain in 2010 reached (10.1%) and 16.2% in 2015. For Greece, the data estimates are 10.1% for the year 2010 and 15.7% for 2015. Recent statistics from the World Bank on the demographics dynamics of the case study are insightful. Portugal GDP (PPP) growth of $372.5 billion while in terms of her carbon dioxide emissions from consumption of energy 54.97 million Mt with a considerable population of 10,295,909. In Italy, the statistic is not much different with a GDP growth (PPP) $2.443 trillion with a teeming population of 60,317,116. In term of the emission of her pollution from non-renewable energy of 351 million Mt. The record for Greece shows that GDP(PPP) is $310.743 billion with a population of 10,724,599 with CO_2 emission from energy consumption of 69.37 million Mt. The highlighted figures show that GDP growth and are on the same positive trajectory with pollution emission that calls for pragmatic strategies among stakeholder and government administrators in the sampled blocs.

The European Council and the European Union Parliament recently adopted the renewable energy directive (RED) goals for 2020. The RED program sets progressive targets for member countries. This target also resonates the renewable energy sources (RES). Thus, the highlighted initiatives and strategies' overall purpose is to ensure the EU countries renewable energy share in her total final energy consumption mix by the year 2020 reaches 20%. Thus, Portugal, Italy, Greece, and Spain's choice become pertinent, given the bloc energy dynamics and commitment to increase her renewable energy mix and mitigate pollution emission in the region. These countries are signatories to the Kyoto Protocol energy agreement. Finally, this study serves as a retrospect into Portugal, Italy, Greece, and Spain's energy mix if the highlighted countries are on the right trajectory to achieve their environmental sustainability target.

The international conferences and agreements (UNFCCC—The United Nations Framework Convention on Climate Change 1992; Kyoto Protocol 1997; Paris Agreement 2015–COP 21) recommended the promotion of renewable energy aimed to reduce climate change and environmental degradation. These actions have been arousing interest on the part of the academic community to study the interdependent relationships between economic growth and environmental degradation. Hence, in the last two decades, there have been several empirical studies to evaluate the sustainability of a group of countries through panel data, or through a case study through time series.

In the case of the group of countries the investigated countries, we observe that it is little or no documentation in the extant literature for the listed blocs as such, this study seeks to fill this identified gap in the literature. This study contributes to the extant literature in two ways. First, in terms of the scope, by augmenting the conventional environmental Kuznets curve (EKC) framework with renewable energy for selected European countries like Portugal, Italy, Greece, and Spain. Second, the relationship between renewable energy and carbon dioxide emissions in a carbon-income function while accounting for the urban population's role. Studies of this sort are timely and worthwhile given the global craving for a greener environment, mainly the EU sustainability target and cleaner ecosystem.

The remainder of this study is organized and proceed with sections two review of related literature: Section 3 data and methodological sequence. The results and discussion are presented in Section 4. Finally, the concluding remarks and policy direction are rendered in Section 5.

2. Literature Review

In this section, relevant empirical studies support the connection between carbon dioxide emissions, economic growth, urban population, and renewable energy. Recently, scholars like (e.g., Grossman and Krueger [7,8]; Douglas and Selden [9]; Balogh and Jambor [10]; Apergis [11]; Saudi et al. [12]; Ridzuan et al. [13] used environmental Kuznets curve (EKC) assumptions to evaluate the impact of income per capita, squared income per capita, energy, and international trade on CO_2 emissions. The EKC hypothesis (See Figure 1) considers that there is a direct impact of income per capita on carbon dioxide emission. This stage represents pre-industrialization and a negative association between squared income per capita and CO_2 emissions (post-industrialization). In this context, the previous study of Leitão [14] explored the connection between environmental Kuznets curve and globalization for Portugal, Spain, Greece, and Ireland. The study considered panel data (Fixed Effects) for the period 1980–2010. The econometric results confirmed that income per capita and squared income per capita are according to the assumptions of EKC. In addition, the variables of globalization (KOF), and energy consumption reflected a positive effect on carbon dioxide emissions.

Shahbaz and Leitão [15] analyzed the Portuguese experience with time series (ordinary least squares (OLS) estimator, autoregressive-moving-average -ARMA- model showed that income per capita and squared income per capita were positively and negatively correlated with carbon emissions. The variables of energy consumption and trade openness presented a positive impact on CO_2 emissions. In the same line, the empirical study of

Shahbaz et al. [16] applied to the Portuguese economy for the period 1971–2008 using time series autoregressive distributed lag—ARDL model proved that in long-run income per capita and energy consumption are positively associated with carbon emissions, and squared income per capita presents a negative impact on CO_2 emissions, validating the EKC empirical evidence. Furthermore, Balsalobre-Lorente and Álvarez [17] explored the relevance of promoting renewable energy sources, applying a dynamic model of finite lags, showing that the renewable energy sector contributes reducing emissions under an EKC scheme. Saudi et al. [12] analyzed the effect of renewable energy, energy consumption, and technology innovation on the EKC model, to Malaysian experience for the period 1980–2017. The authors used as dependent variable the carbon dioxide emissions, and they selected as explanatory variables the income per capita, squared income per capita, energy consumption, renewable energy, and technology. Considering the autoregressive distributed lag—ARDL model, the econometric results revealed that the lagged variable of carbon dioxide emissions presented a direct effect in the long-run.

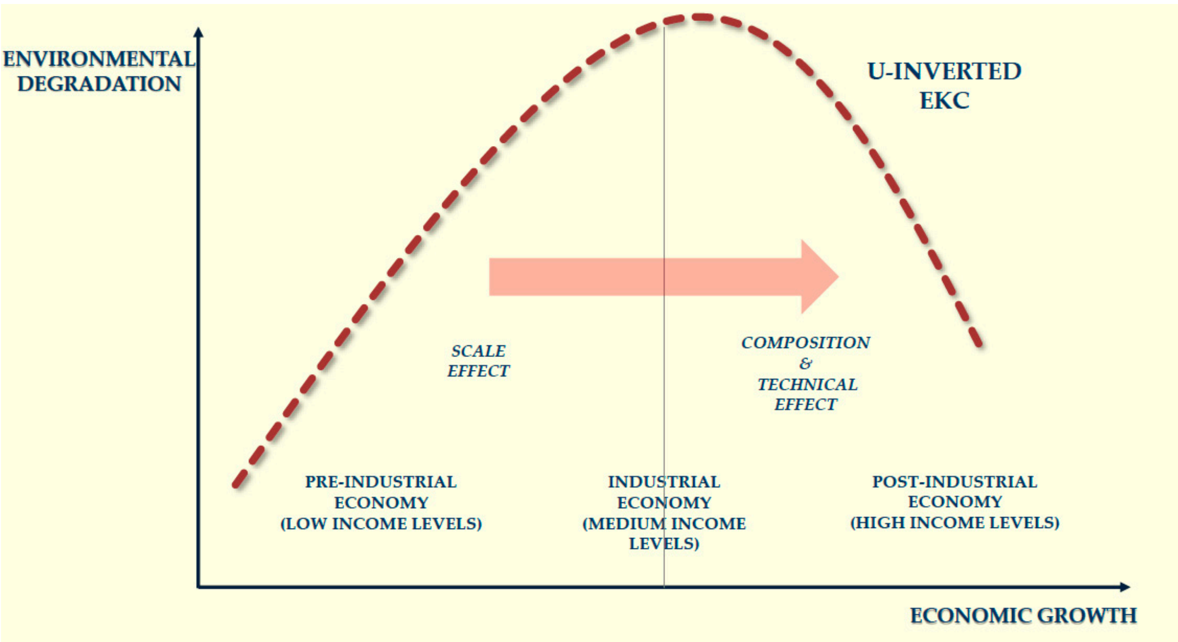

Figure 1. The traditional inverted-U EKC.

Moreover, the econometric results also showed that the variable of energy consumption presents a positive impact on carbon emissions, and renewable energy is negatively correlated with carbon emissions, as the previous studies. In the same line, the empirical research of Ridzuan et al. [13] evaluated the effects of energy consumption, income per capita, squared income per capita, trade openness, and foreign direct investment on carbon emissions by Malaysia, Indonesia, and Thailand. The econometric results with the autoregressive distributed lag—ARDL model, in the long-run, demonstrated that income per capita presents a positive effect on carbon emission by Malaysia and Thailand. However, the income per capita showed a negative association with carbon emissions in Indonesia. The variable of squared income per capita confirmed a negative impact on carbon-emissions by Malaysia, and Thailand, and a positive effect on CO_2 by Indonesia. The variable of international trade presents a negative sign by Indonesia, Malaysia, and Thailand.

However, there are empirical studies as Beyene and Kotosz [18], Adu et al. [19], Monserrate et al. [20] tested EKC hypotheses, and they do not support the EKC assumptions, or others Yao et al. [21], Lægreid and Povitkina [22], Jardón et al. [23] that only found a positive and monotonal correlation between economic growth and carbon dioxide emissions.

The study of Boamah et al. [24] investigated the case of Ghana using different econometric methodologies such as dynamic ordinary least squares (DOLS), and ARDL model. The authors tested the EKC assumptions and found cointegration between the variables (ecological footprint, income per capita, urbanization, energy consumption, financial development, exports, and imports) used in the long-run. In this context, Dogan et al. [25] investigated the linkage between carbon dioxide emissions and renewable energy using different methods: a panel cointegration (panel fully modified least-squares—FMOLS and panel dynamic ordinary least squares—DOLS), and panel ARDL model, applied to 28 OECD countries for the period 1990–2014. The econometric results demonstrated that population and income per capita are positively connected with carbon dioxide emissions. Furthermore, the index of economic complexity and renewable energy showed a negative impact on CO_2 emissions. Moreover, the empirical study of Wang et al. [26] considered Chinese provinces' experience to test the causality (vector autoregressive—VAR model) between CO_2 emissions, foreign direct investment, income per capita, exports and imports for the period 1997–2015. The authors found a unidirectional causality between the variables used in research.

In exploring the relevance of factors on carbon emissions, traditionally, the empirical models have included income and energy consumption (see, Ang [27]; Soytas et al. [28]; Apergis and Payne [29], Shahbaz et al. [30]; Ozcan [31], among others) as main explanatory variables in a model, known as the income-energy-carbon emissions nexus Baek [32]. According to more recent literature, (Leitão and Balsalobre-Lorente [6]; Karhan [5]) renewable energy allows the reduction of climate change and greenhouse gas, and simultaneity contributes to economic development. There is a generalized consensus in the literature that there exists a negative connection between renewable energy on CO_2 emissions. The empirical studies of Alper and Oguz [3], and Marinaş et al. [4] used as econometric strategy an autoregressive distributed lag—ARDL model. These studies concluded that renewable energy encourages economic growth, and renewable energy permits reduce climate change. In this context, others study as in Karhan [5], employed Granger causality test, or vector error correction model (VECM), and the studies found bidirectional causality between renewable energy and economic growth. Koengkan and Fuinhas [33]) apply panel data, and the results are similar.

The recent literature (e.g., Ike et al. [34]; Koengkan et al. [35]; Ma et al. [36]; Cheng et al. [37]) tests the environmental Kuznets curve using the method of moments quantile regression (MMQR), suggested by Machado and Silva [38]. This econometric strategy allows observing the heterogeneous effect of the exogenous variables on CO_2 emissions, i.e., across quantiles.

Recently, Ike et al. [34] applying the Fully Modified Least Squares—FMOLS validated EKC assumptions in 15 oil-production countries for the period 1980–2010. The econometric results showed that democracy index, electricity production, and oil production present a positive impact on carbon dioxide emissions, while trade openness exhibited a negative effect on CO_2 emissions. Considering the method of moments quantile regression (MMQR), the authors found a heterogeneous impact of the democracy index, electricity production, and oil production on CO_2 emissions. In this context, Koengkan et al. [35] also used the method of moments quantile regression (MMQR) for 19 Latin America and the Caribbean countries for the period 1990–2016, and the authors found that economic growth and fossil fuel consumption present a positive effect on carbon dioxide emissions. However, renewable energy reveals a negative impact on CO_2 emissions.

The empirical study of Cheng et al. [37] considered the link between non-fossil energy, energy consumption, economic growth, oil price, and carbon dioxide emissions for EU-28. The authors proved that the explanatory variables (non-fossil energy, energy consumption, economic growth, and oil price) presented heterogeneous and asymmetric results across different quantiles. Moreover, the non-fossil energy showed a negative effect on carbon intensity, and the variable crude oil price presented an inverted U-shaped curve across different quantiles.

The effect of economic growth, foreign direct investment, and energy intensity on carbon dioxide emissions for the China experience was investigated by Ma et al. [36]. The empirical results revealed that economic growth, foreign direct investment, and energy intensity positively impact CO_2 emissions.

Several studies have explored the nexus between urban population and carbon dioxide emissions (e.g., Shahbaz et al. [16]; Salahuddin et al. [39]; Sarwar and Alsaggaf [40]; Dong et al. [41]). The empirical approach of Sarwar and Alsaggaf [40] referred that the link between urbanization is ambiguous, i.e., there exist studies that found a positive correlation between urban population and CO_2 emissions, and other studies that found an inverted U curve (Martínez-Zarzoso and Maruotti [42]). Using a dynamic panel data (GMM-DIF, GMM-System, and dynamic mean group—DGM), Sarwar and Alsaggaf [40] showed that lagged variable of carbon dioxide emissions presented a positive effect at the long-run in China. Moreover, the variables economic growth, urban population, and coal and oil consumption presented a positive effect with statistically significant on carbon dioxide emissions. However, the authors showed that urban income is negatively correlated with CO_2 emissions showing that urban income contributes to decreasing CO_2 emissions.

Salahuddin et al. [39] evaluated the impacts of globalization and urbanization on carbon dioxide emissions for the experience of 44 Sub-Saharan Africa countries. The authors considered a panel data (Pooled Mean Group estimator–PMG), and the explanatory selected variables were income per capita (economic growth), the access to electricity, urban population, and globalization index (KOF) from Swiss Economic Institute. The empirical results showed that the coefficients of income per capita, globalization and urbanization were positively correlated with carbon dioxide emissions.

Subsequently, Fong et al. [43] validated the environmental Kuznets curve in Asian countries. This study applied a spatial and non-spatial econometric model proved that income per capita and squared income per capita are according to EKC hypothesis's assumptions when the study used as dependent variables (NO_X, SO_2 and PM2.5 emissions). Moreover, the variable of renewable energy presents a negative effect on NO_X, and SO_2 emissions.

Given the trajectory mentioned above on the extensive EKC literature, there is still a vacuum and limited studies that have tested the EKC via renewable energy channels, with each providing no consensus. The very few existing empirical evidence for the EU, like Shahbaz and Leitão [15] and Shahbaz et al. [16], highlighted the relevance of renewable energy consumption to environmental sustainability targets and decreased CO_2 emissions. However, there exist some studies that fail to validate the EKC phenomenon. Following the extant literature reviewed with inconclusive findings, the current study advances the literature in the following ways, namely:

First, the current study augments the traditional EKC setting by incorporating the carbon-income function with renewable energy consumption, urban population to re-examine the EKC framework for Portugal, Italy, Greece, and Spain between 1995 and 2015. The variables included in this study are in line with the United Nations Sustainable Development Goals (SDGs) target projected to be visible by 2030, which seems a mirage in most economies.

Second, we explore the nexus between the highlighted variables. To investigate the combination of these variables (renewable energy, urban population, and economic growth) progressively to explore the dynamic interaction if these highlighted variables positively or negatively affect the quality of the environment in the EKC setting. In the context of Portugal, Italy, Greece, and Spain, few studies exist in the literature. Thus, this study seeks to serve as a policy document for the investigated blocs and other European countries

Third, this study investigates the EKC hypothesis with a battery of estimation techniques, namely Generalized Least Squares (GLS), panel Fully Modified Least Squares (FMOLS), Ordinary Least Squares robust (OLS), and Panel Quantile Regression, for consistency and robustness of empirical finding which seems to be rare in the extant literature.

Fourth, we explore the theme under consideration with Panel Quantile Regression, which is unique to explore the different characterization (quantiles) of the data that offers more insightful results for more robust policy direction for the investigated blocs.

3. Materials and Methods

This empirical study considers panel data from 1995 to 2015 (the period is informed by data availability from World development indicators, which coincidentally reflect the sampled countries financial crisis period and energy dynamics period as well to show to what extent the countries are true to achieving their environmental sustainability target), to test the effect of renewable energy on carbon emissions under the environmental Kuznets curve scheme, using generalized least squares (GLS), panel fully modified least squares (FMOLS), ordinary least squares robust (OLS), and panel quantile regression are considered in this research. Our model is tested for Portugal, Italy, Greece, and Spain. To adequately account for common shock among the investigated countries, the presence of cross-sectional dependence in the panel, we apply Pesaran's test.

The panel unit root test is applied considering the traditional methodology of Levin–Lin–Chu [44], ADF-Fisher Chi-square, and Phillips-Perron suggested by Maddala and Wu [45], and Choi [46] to confirm if the selected variables are stationary at level. In this context, and following the previous literature, if the variables have unit root in level, the researchers should be verifying if the variables are integrated at first differences I (1). In the long-run, the cointegration between variables is confirmed by the selected estimators (Pedroni [47,48], and Kao Residual Cointegration Test [49] panel data cointegration tests.

The econometric strategy of ordinary least squares (OLS) robust, the panel fully modified least squares (FMOLS), and the method of moments quantile regression (MMQR) for the case of robustness. The test of heteroskedasticity proposed Breusch–Pagan [50] is applied by OLS. The methodology of FMOLS proposed by Phillips and Hansen [51] allows evaluating the long-run relationship among the variables.

The method of moments quantile regression (MMQR) allows to analyze the heterogeneous covariance effects across quantiles of environmental Kuznets curve (e.g., Ike et al. [34]; Koengkan et al. [35]).

Considering the contributions of Chen et al. [37], Machado and Silva [38], Ike et al. [34], Koengkan et al. [35] the method of moments quantile regression assumes the following expression:

$$Q_y\ (\tau \mid X_{it}) = (\alpha_i + \delta_i q\ (\tau)) + X_{it}{}'\beta + Z_{it}{}'\gamma\ q\ (\tau) \quad (1)$$

where the dependent variable is the logarithm of carbon dioxide emissions, i.e., $Q_y\ (\tau \mid X_{it})$ signifies the quantile distribution of carbon dioxide emissions (CO_2), and $X_{it}{}'$ represents the explanatory variables of income per capita (*LnINC*), squared income per capita (INC^2), renewable energy (*LnRENO*), and urban population (*LnUrbanPop*). All variables are expressed in logarithm form. The expression $(\alpha_i + \delta_i q\ (\tau))$ shows the scalar effect (the quantile fixed by the individual in the analysis). Moreover, the vector of components X is designed by Z_t.

The post estimation test computed by E-views allows considering the Wald test. Symmetric quantiles can interpret this test. The symmetric quantiles test establishes a comparison between the first and third quantiles, showing that the coefficients are not constant across quantiles.

The hypotheses formulated in this research aims to discuss the impacts of economic growth, renewable energy, and urban population on carbon dioxide emissions.

Hypothesis 1 (H1). *There is an inverted U-shaped relationship between income per capita and CO_2 emissions.*

The studies of Grossman and Krueger [8], Grossman and Krueger [7] Douglas and Selden [9], Apergis [11], Saudi et al. [12]; Ridzuan et al. [13], Ike et al. [34] testing the assumptions environment Kuznets curve (EKC), and showed that economic growth encourages climate changes and environmental damage. According to the EKC empirical evidence, there is a direct impact of income per capita ($LnINC > 0$) on carbon dioxide emission and a negative association between squared income per capita ($LnINC^2 < 0$) and CO_2 emissions.

Hypothesis 2 (H2). *Renewable energy reduces carbon emissions and energy dependence in selected countries.*

The empirical studies of Koengkan and Fuinhas [33], Leitão and Balsalobre-Lorente [6], Singh et al. [52], Karhan [5], Soava et al. [53], Mahmoodi [54], Khobai and Roux [55] suggested a negative correlation between renewable energy ($RENO < 0$) and carbon dioxide emissions. These studies demonstrated that renewable energy stimulates sustainable development.

Hypothesis 3 (H3). *There is a positive impact of urban population on carbon emissions.*

As we referred in the literature review, the connection between urbanization and climate change is not conclusive (Sarwar and Alsaggaf [40]; while some studies revealed a negative correlation between urbanization and carbon emissions (Wang et al. [56]), other studies concluded that that urban density contributes to mitigating carbon emissions, and these results are related to the urban structure (Meng et al. [57]; Dodman [58]). Chikaraishi et al. [59] also found that urbanization is more environmentally friendly when urban development is high. However, big cities demand more energy consumption than in small cities. In this sense, the studies of Shahbaz et al. [16], Salahuddin et al. [39], Sarwar and Alsaggaf [40] demonstrated that urban population is positively correlated with carbon emissions.

For testing the impact of renewable energy in the environmental Kuznets curve, the model adopts the following expression:

$$LnCO_2 = \alpha_0 + \alpha_1 LnINC + \alpha_2 LnINC^2 + \alpha_3 LnRENO + \alpha_4 LnUrbanPop + \mu_{it} \quad (2)$$

Table 1 shows the description of the variables used in this research, and the expected signs according to the literature review.

Table 1. Definitions of variables and expected signs.

Variable	Definition	Expected Sign	Source
$LnCO_2$-	Logarithm of per capita carbon dioxide emissions		World Bank–World Development Indicators (2020)
LnINC-	Logarithm of income per capita based on purchasing power parity (PPP)	[+]	World Bank–World Development Indicators (2020)
$LnINC^2$-	Logarithm of squared income per capita based on purchasing power parity (PPP)	[−]	World Bank–World Development Indicators (2020)
LnRENO-	Logarithm of renewable energy use	[−]	World Bank–World Development Indicators (2020)
LnUrbanPop-	Logarithm of Urban population	[+]	World Bank–World Development Indicators (2020)

Source: Authors composition.

4. Results and Discussion

This section presents the empirical results that test the environmental Kuznets curve using moments quantile regression (MMQR) to Portugal, Italy, Greece, and Spain for the period 1995–2015. Before we present the econometric results, it will be necessary to achieve some routines in the variables used in this research. After we present the description of summary statistics, we analyze the cross-sectional dependence and unit root test. In the next step, we will observe the panel cointegration test Pedroni [47,48], and Kao residual cointegration test [49]. The empirical study will be considered with generalized least squares (GLS), ordinary least squares (OLS) robust, the panel fully modified least squares (FMOLS), and the method of moments quantile regression (MMQR).

Table 2 reports the descriptive statistics for the variables utilized in this empirical study. The variables of squared income per capita ($LnINC^2$), and carbon dioxide emissions ($LnCO_2$) present higher means. Moreover, the variables of squared income per capita ($LnINC^2$) and carbon dioxide emissions ($LnCO_2$) are Maximum's higher values.

Table 2. Descriptive statistics.

Variables	Observations	Mean	Std. Dev.	Min	Max
$LnCO_2$	83	5.1848	0.368	4.649	5.675
LnINC	84	4.402	0.107	4.157	4.567
$LnINC^2$	84	8.804	0.215	8.315	9.134
LnRENO	84	1.062	0.231	0.649	1.484
LnUrbanPop	84	7.2020	0.366	6.709	7.626

Source: Own composition based on WDI (2020) data.

Table 3 reports the test of Pesaran exhibiting cross-sectional dependence results. According to the test results, we observe that carbon dioxide emissions, income per capita, renewable energy, and urban population display cross-sectional dependence. Based on Koenghan et al. [35] and Fuinhas et al. [60], we can conclude the presence of cross-sectional dependence reflecting the common-shock effect within the bloc investigated. The effect of cross-sectional dependency is circumvented for this study's econometrics modelling by the panel quantile regression to offer robust and reliable coefficients.

Table 3. Pesaran's CD Test: Cross-Sectional Dependence.

Variables	CD Test
$LnCO_2$	5.1734 *** (0.000)
LnINC	3.266 *** (0.001)
LnRENO	3.187 *** (0.001)
LnUrbanPop	6.284 *** (0.000)

Source: Own composition based on WDI (2020) data. Statistically significant at 1% level (***).

Table 4 presents the unit root test results using the arguments of Levin–Lin–Chu [44], ADF-Fisher Chi-square, and Phillips-Perron (e.g., Choi [46]). Therefore, the test's null hypothesis indicates that the variables used in this study have a unit root or stationarity. We observe that the variables have unit root (not stationary) in level; however, in the first difference, the variables (economic growth, renewable energy, urban population, and carbon dioxide emissions) are integrated I (1). Subsequently, the Pedroni cointegration test investigates the equilibrium relationship between the outlined variables, as reported in Table 5. The Kao residual cointegration test is used as a robustness test to affirm cointegration among the variables, as presented in Table 6.

Table 4. Panel Unit Root Test.

	Levin, Lin & Chu		ADF-Fisher Chi-Square		PP-Fisher Chi-Square	
			Level			
Variables	**Statistic**	***P*-value**	**Statistic**	***P*-value**	**Statistic**	***P*-value**
$LnCO_2$	−0.955	(0.169)	6.104	(0.635)	7.051	(0.531)
LngINC	3.374	(0.999)	0.360	(1.000)	0.041	(1.000)
LnUrbanPop	−0.463	(0.322)	6.204	(0.624)	0.003	(1.000)
LnRENO	2.098	(0.982)	0.901	(0.998)	0.564	(0.999)
			First Difference			
Variables	**Statistic**	***P*-value**	**Statistic**	***P*-value**	**Statistic**	***P*-value**
$DLnCO_2$	−2.036 **	(0.021)	14.678 *	(0.066)	11.529	(0.174)
DLngINC	−2.806 ***	(0.002)	15.986 **	(0.042)	18.519 **	(0.017)
DLnUrbanPop	−6.409 ***	(0.000)	46.840 ***	(0.000)	56.430 ***	(0.000)
DLnRENO	−4.680 ***	(0.000)	37.065 ***	(0.000)	57.828 ***	(0.000)

Source: Own composition based on WDI (2020) data. Statistically significant at 1% (***), 5% (**), and 10% level (*).

Table 5. Pedroni Cointegration Test.

		(Within-Dimension)		
Test Method	**Statistic**	***P*-Value**	**Weighted Statistic**	***P*-Value**
Panel v-Statistic	0.782	(0.217)	0.782	(0.217)
Panel rho-Statistic	−0.009	(0.497)	−0.009	(0.497)
Panel PP-Statistic	−3.037 ***	(0.001)	−3.037 ***	(0.001)
Panel ADF-Statistic	−1.472 *	(0.071)	−1.472 *	(0.071)
		(Between-Dimension)		
Test Method	**Statistic**	***P*-Value**		
Group rho-Statistic	0.425	(0.665)		
Group PP-Statistic	−3.760 ***	(0.000)		
Group ADF-Statistic	−1.653 **	(0.049)		

Source: Own composition based on WDI (2020) data. Statistically significant at 1% (***), 5% (**), and 10% level (*).

Table 6. Kao Residual Cointegration Test.

Test Method	t-Statistic	*P*-Value
ADF	−1.481 *	(0.069)
Residual variance	0.000230	
HAC variance	0.000204	

Source: Own composition based on WDI (2020) data. Statistically significant at 10% level (*).

Following Grossman and Krueger [8] seminar work, we apply the generalized least squares (GLS) model to validate the EKC in Portugal, Italy, Greece, and Spain as reported in Table 7. According to our econometric results, the EKC hypothesis is validated in our proposed model (Equation (2)), in line with previous literature (Leitão [14]; Shahbaz and Leitão [15]; Shahbaz et al. [16]). The validation of EKC is confirmed by the positive coefficient in real income with a magnitude of (81.019%). Otherwise, the quadratic form of income is negative with a magnitude of (−40.488%) affirming validation of the tradeoff between real income and CO_2 emission. Regarding the coefficient of renewable energy (*LnRENO*), we observe a negative effect of this variable on carbon dioxide emissions, revealing that renewable energy encourages sustainable development due to a correction in emissions. The recent empirical studies of Koengkan and Fuinhas [33], Leitão, and Balsalobre-Lorente [6] also found a negative connection between renewable energy and carbon dioxide emissions.

Table 7. Testing the Environmental Kuznets Curve with generalized least squares (*GLS*) estimator.

Dependent Variable: $LnCO_2$	
Variables	**GLS**
LnINC	81.019 *** (0.000)
$LnINC^2$	−40.488 *** (0.000)
LnRENO	−0.3102 *** (0.000)
LnUrbanPop	0.871 *** (0.000)
Constant	−0.9507 *** (0.000)
Mean dependent var.	5.185
Sum squared residual	0.211
Akaike info criterion	−3.014
Hannan–Quinn criteria	−2.955
Deviance statistic	0.002
LR statistic	4040.875
Pearson SSR	0.211
Dispersion	0.002
SD. Dependent var	0.369
Log-likelihood	130.065
Schwarz criterion	−2.868
Deviance	0.211
Restricted. Deviance	11.152
Prob(LR statistic)	0.000
Pearson statistic	0.003

Source: Own composition based on WDI (2020) data. Statistically significant at 1% level (***).

Subsequently, the urban population (*LnUrbanPop*) presents a positive sign, as we expected. This result confirms that the urban population stimulates carbon emissions, namely in big cities. Shahbaz et al. [16], Salahuddin et al. [39], Sarwar, and Alsaggaf [40] give support to our result.

The econometric results with the panel fully modified least squares (FMOLS) is presented in Table 8. The variable of income per capita (*LnINC)* positively impacts carbon emissions being statistically significant at 1% level. Leitão and Balsalobre-Lorente [6], Koengkan et al. [35] also found a positive correlation between income per capita and carbon dioxide emissions.

As previous studies of Ridzuan et al. [13], Ike et al. [34], the coefficient of squared income per capita (*$LnINC^2$*) is negatively correlated with CO_2 emissions. These results are according to EKC assumptions. The coefficient of squared income per capita (*$LnINC^2$*) is negatively correlated with CO_2 emissions, and statistically significant at 1% level. These results are according to the U-inverted EKC shape (Ridzuan et al. [13]; Ike et al. [34]). Regarding the variable of renewable energy (*LnRENO*), the econometric results demonstrate a negative impact of this variable on carbon dioxide emissions, proving that renewable energy allows decreasing climate change. The studies of Koengkan and Fuinhas [33], Leitão, and Balsalobre-Lorente [6], Singh et al. [52] also found a negative correlation between renewable energy and carbon emissions. These studies argue that renewable energy stimulates sustainable development.

Table 8. Testing the impact of Environmental Kuznets Curve with Panel Fully Modified Least Squares estimator.

Dependent Variable: $LnCO_2$	
Variables	***FMOLS***
LnINC	15.459 *** (0.000)
LnINC^2	−7.516 *** (0.000)
LnRENO	−0.4921 *** (0.000)
LnUrbanPop	0.994 *** (0.000)
SE of regression	0.033
Long-run variance	0.000
Mean dependent var	4.936
SD dependent var	0.056
Sum squared residual	0.013

Source: authors own composition based on WDI (2020) data. Statistically significant at 1% level (***).

Finally, the result obtained by the urban population (*LnUrbanPop*) presents a positive impact on carbon emissions, and the variable is statistically significant at 1% level. In this context, an increase in a 1% level of urban population (*LnUrbanPop*) represents an increase in carbon emissions and environmental damage of 0.94%. This result confirms that urban areas contribute to climate change in selected countries.

Table 9 presents the econometric results with ordinary least squares (OLS) robust, and the method of moments quantile regression (MMQR). According to the results obtained with OLS robust estimator, we can infer that the estimated coefficients are in the presence of heteroskedasticity (Breusch-Pagan test). All explanatory variables (income per capita, squared income per capita, renewable energy, and urban population) are statistically significant at 1% level with OLS robust estimator. The results confirm the assumptions of the EKC model. The estimated coefficient of renewable energy (*LnRENO*) harms carbon dioxide emissions, proving that renewable energy allows decreasing climate change.

Table 9. Testing the impact of renewable energy on the Environmental Kuznets Curve with ordinary least squares (OLS) and Panel Quantile Estimations.

Dependent Variable: $LnCO_2$				
Variables	**OLS Robust**	**Quantile 25th**	**Quantile 50th**	**Quantile 75th**
LnINC	81.098 *** (0.000)	33.387 (0.355)	75.274 * (0.092)	11.094 *** (0.003)
LnINC^2	−40.488 *** (0.000)	−16.742 (0.354)	−37.732 * (0.091)	−55.683 *** (0.003)
LnRENO	−0.310 *** (0.000)	−0.390 *** (0.000)	−0.302 *** (0.000)	−0.237 *** (0.000)
LnUrbanPop	0.872 *** (0.000)	0.832 *** (0.000)	0.882 *** (0.000)	0.928 *** (0.000)
C	−0.951 *** (0.000)			
Breusch-Pagan	39.701 *** (0.000)			
Wald test (Symmetric Quantile)—Chi-sq. Statistic	0.230 (0.994)			

Source: Own composition based on WDI (2020) data. Statistically significant at 1% (***), and 10% level (*).

We also detect that the variable of the urban population is positively correlated with carbon emissions, as previous studies (Shahbaz et al. [16]; Salahuddin et al. [39]; Sarwar and Alsaggaf [40]. Additionally Figure 2 depicts the graphical schematics of the outlined variables as seen below:

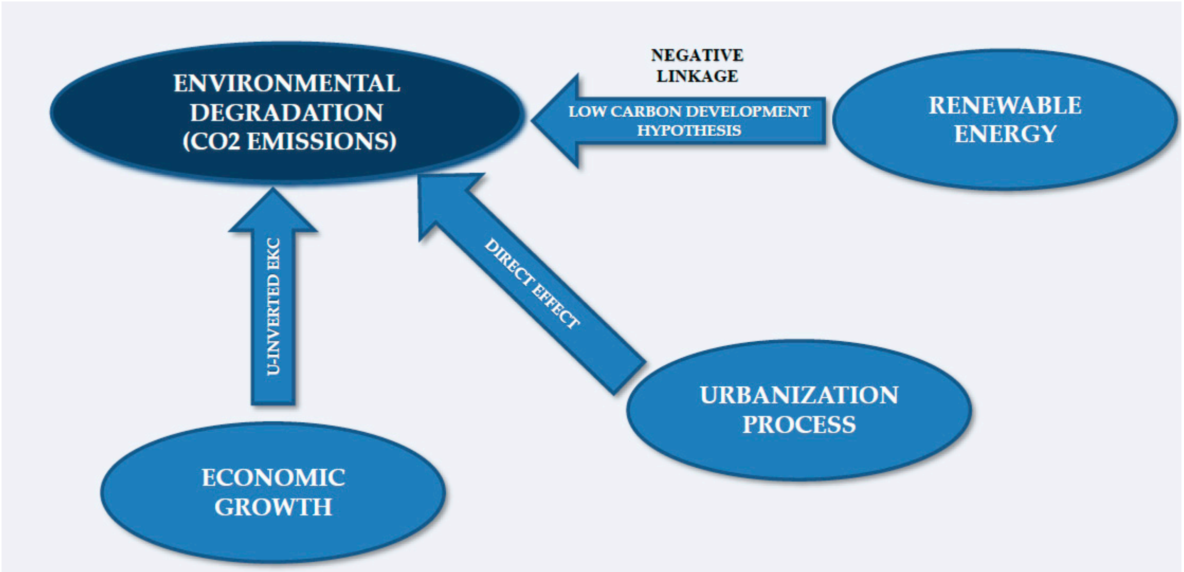

Figure 2. Summary of impacts between variables.

Regarding the method of moments quantile regression (MMQR), we observe (Table 9) that the Wald test should be interpreted by symmetric quantiles. Moreover, the symmetric quantiles test demonstrate that the coefficients are not constant across quantiles. This test establishes a comparison between the first and third quantiles. The variables of income per capita (*LnINC*) and squared income per capita ($LnINC^2$) are statistically significant across the 50th and 75th quantiles and confirming the expected signs suggested by the literature to EKC hypothesis. The current empirical studies of Ridzuan et al. [13] and Ike et al. [34] also found a positive impact of income per capita (*LnINC*) on CO_2 emissions designed by the literature as a pre-industrialization stage, and a negative effect of squared income per capita ($LnINC^2$) on carbon emissions; considered by the post-industrialization stage.

As the previous studies (Koengkan and Fuinh [33]; Leitão and Balsalobre-Lorente [6]; Singh et al. [52]; Karhan [5] the renewable energy consumption (*LnRENO*) allows a decrease in climate change and CO_2 emissions in the 25th, 50th and 75th quantiles.

Finally, the urban population (*LnUrbanPop*) variable has a positive effect on carbon emissions across the 25th, 50th, and 75th quantiles. In this context, Shahbaz et al. [16], Salahuddin et al. [39], Sarwar and Alsaggaf [40] also found a positive correlation between urban population and environmental degradation. These outcomes suggest a need for government administrators, energy practitioners in Portugal, Italy, Greece, and Spain countries to regulate and drift into more renewables as it is observed in our study to improve the quality of the environment and ecosystem.

5. Conclusions

European region most especially the country on focus—Portugal, Italy, Greece, and Spain faced the enormous task of increasing energy demand and its requisite environmental implications. According to the International Energy Agency (IEA), by 2030, there is a possibility for an energy deficit in the coming years given global energy demand and its growing population. The increasing urbanization of the global population and energy demand comes with its environmental implications. This preposition has aligned with The United Nations SDGs goals as supported by the empirical study of (Liu et al. [61]; Jones, and Warner [62]; Saidi and Hammami [63]; Rasli et al. [64]; Dasgupta et al. [65]; Kaika and Zervas [66]). This study contributes to energy–income–environment nexus debate. Thus, we revisit the energy–income–carbon emissions linkage, offering a fresh advanced perspective for the case of Portugal, Italy, Greece, and Spain during 1995–2015. We apply several econometric techniques, namely (FMOLS, OLS, and panel quantile estimation) that reinforce previous empirical literature, enriching the EKC analysis, offering useful results for academics and policymakers. In this sense, we confirm the relevant role of promoting renewable energy use and redesigning urban areas in selected countries for controlling emissions. Our results advance on numerous aspects offering significant econometric advances. In a first step, stationarity properties are tested by the Pesaran's Cross-Sectional Dependence test and the traditional Levin–Lin–Chu, ADF-Fisher Chi-square, and Phillips-Perron unit root tests, respectively. Pedroni and Kao cointegration tests confirm a long-run equilibrium relationship among the selected variables. These previous steps allow the FMOLS method to obtain robust results. This paper's main novelty is the use of panel quantile estimation for reinforcing the main hypotheses of a validation of the EKC, where renewable energy contributes to control and reduce carbon emissions.

The econometric results confirm a direct connection between urbanization and environmental degradation. These econometric results drop a battery of policy recommendations aimed to reach the EU key targets for 2030. (European Green Deal Investment Plan, [67]; Avtar et al. [68]). Therefore, European policymakers should circumcise their actions to achieve these goals. From empirical results, selected countries need to reinforce renewable energy sources and integrate them into their urban planning to advance into sustainable big cities to reduce fossil dependence and emission levels. The nexus observed between real income level and energy (renewable) consumption draws the attention of energy practitioners, energy stakeholders, and policymakers for more aggressive thrives into more advocacy for sustainable energy consumption to achieve IEA energy-environment target. More efficient energy would contribute positively to reducing inequality problems and the transition to clean technologies and economic diversification based on climate-resilient investments. Future studies should pay attention to the low carbon economy.

The recent proposal of the European Commission for Horizon Europe [69] explicitly refers to the Sustainable Development Goals (SDGs) of the United Nations Agenda 2030 as the global challenges. This program considers energy usage's relevance for stimulating economic growth, expanding industrial capacity, and ensuring societal well-being in selected European countries. The promotion of renewable accompanied by cleaner production will contribute to achieving the synergy effect between renewable electricity prices, SDG 7 (affordable and clean energy), and SDG 8 (decent work and economic growth). From empirical results, we consider most of the effects of renewable electricity on sustainable development goals (SDGs) are related to the price effect. So, an increasing renewable electricity demand within the EU regions will have a direct impact on electricity prices, as a consequence of an increase in the direct generation cost (via investment cost), and the indirect cost related to the intermittency of some of the renewable sources (wind and solar).

Consequently, the increasing cost of balancing requirement imposed by the intermittency on the power system will pass onto the final consumer through higher electricity prices [70]. This process could delay the transition to a technical effect (SDG 9-industry innovation and infrastructures), generating a pernicious impact on economic systems. Hence, the future renewable price movements are likely to be influenced more by SDG 12 (excluding the effect from itself). In contrast, the future direction in both SDG 7 (affordable and clean energy) and SDG 13 (climate actions) is likely to be influenced more by SDG 8 (decent work and economic growth) and SDG 12 (responsible consumption and production).

Finally, the econometric results reveal that urbanization increases environmental degradation in selected European countries. Consequently, policymakers should adopt an economic development related to environmental protection, the investment in cleaner infrastructures, the advancement in the promotion of cleaner buildings (SDG 11-sustainable cities and communities), to diminishing the direct pollution linkage between the increasing urbanization and the environmental degradation process.

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