Is the share of renewable energy sources determining the CO2 kWh and Income relation in electricity generation?

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Abstract

The present study examines the long and short-run causality of the share of renewable energy sources in the relation between Carbon Dioxide emissions of electricity generation and real income for 20 European countries over the 2001-2010 period. We used Cointegration Analysis and the Innovative Accounting Approach that includes Forecast Error Variance Decomposition and Impulse Response Functions. Our results provide supportive evidence for the validity of the Environmental Kuznets Curve and suggest that renewable energy can be a potential determining driver of the difference in the emissions-income relations across European countries and a significant way of reducing CO2 kWh.

Keywords: Carbon Dioxide Emissions per kWh, Electricity Generation, Environmental Kuznets Curve, Innovative Accounting Approach, Panel Cointegration Tests, Renewable Energy.
JEL Codes: Q430, Q400, Q530, Q560.

1. Introduction

European countries have shown a special concern in reducing emissions of greenhouse gases (GHG) that materialized in a practical way with the signing of Kyoto Protocol, with the implementation of the European Union Emissions Trade System (EUETS) and more recently with the adoption of the "20-20-20" targets. In 2020, these targets specifically aim for a 20% cut in GHG emissions from 1990 levels; for an increase of renewable energy sources to 20%; and for a 20% improvement in the energy efficiency.

The use of fossil fuels is the biggest culprit of anthropogenic air pollution (in particular by the emission of Carbon Dioxide (CO2)), being responsible for about 90% of total global CO2 emissions. Despite the recent economic crisis, it is expected that the use of fossil fuels will continue to increase in the future (Olivier et al. [1]).

In the European electricity sector, more than 50% of the primary energy used is based on fossil fuels, coal representing approximately 30%. This translated into CO2 emissions represents 70% of total emissions in electricity production and 24% of the emissions of all European sectors (Commission of European Communities [2]).

This makes the European Union (EU) have a growing concern in creating and implementing policies to limit CO2 emissions, primarily through the reduction of the use of coal in the electricity sector. For instance, through the EUETS, EU limited the allowances allocated to installations that produce electricity as well as to energy-intensive industries, in order to cut 21% compared to 2005 levels (European

Commission [3]).

There are several articles that have studied the connection between economic growth and emissions, testing the hypothesis of the Environmental Kuznets Curve (EKC). This hypothesis suggests that there is an inverse U-shaped relationship between income and environmental pollution, which means that there is an increase in pollution as the economy grows, but from a certain point, the economy can grow decreasing environmental degradation.

The relation between emissions from electricity production and GDP is not focused on literature. Those studies that include electricity are based on the amount of energy consumed, which is inherently linked to a volume of emissions, but don’t directly include the emissions resulting from its production. Studies focus specifically on the relationship between economic growth and energy consumption, in particular electricity consumption. The study of the latter relationship is important because electricity production is, as we have seen, a major source of emissions, but on the other hand it is also an important way to reduce them, if there is a replacement of fossil fuels with renewable energy in electricity production. It is then important to analyze, how the reduction of emissions in this sector may undermine the economic growth of European countries.

Moreover, it is important to analyze how the percentage of renewable energy used for electricity production affects the relationship between economic growth and emissions from this sector. The study of these relationships is important from the point of view of environmental and energy policy as it gives us information on the costs in terms of economic growth, on the application of restrictive levels of emissions and also on the effects of the policies concerning the use of renewable energy in the electricity sector (see for instance European Commission Directive 2001/77/EC, [4]).

For that purpose, in this study we use Cointegration Analysis on the set of cross-country panel data between CO_2 emissions from electricity generation (CO2 kWh), real income (GDP) and the share of renewable energy for 20 European countries. We estimated the long–run equilibrium to validate the EKC with a new approach specification.

Additionally, we have implemented the Innovative Accounting Approach (IAA) that includes Forecast Error Variance Decomposition and Impulse Response Functions (IRFs), applied to those variables. This can allow us, for example, to know (i) how CO2 kWh responds to an impulse in GDP and (ii) how CO2 kWh responds to an impulse in the share of renewable sources.

By combining these two methodologies, we will not only give an outline of what has been a past reality for CO2 kWh emissions and their relation to economic growth and to the use of renewable energy in European countries, but also how the last two variables can influence CO2 kWh emissions in the future.

This paper is divided into five sections including this introduction. In Section 2 we make a brief literature review, in Section 3 we present the data and the model, in Section 4 the econometric methodology and the main results are presented and in Section 5 the conclusions and policy recommendations.

2. Literature review

First, we will present some studies that relate emissions to economic growth, that is, that study the validity of EKC hypothesis. Some studies validate the hypothesis like Hettige et al. [5], Martinez-Zarzoso and Bengochea-Morancho [6] for OCDE countries, Acaravci and Ozturk [7] for Europe, Cropper and Griffiths [8] for non-OECD countries in Africa, Asia, and Central and South America, Pao et al. [9] for Russia, Apergis and Payne [10] for Central America, Iwata et al. [11], for 28 countries (OECD countries, and non-OECD countries), Mongelli et al. [12], for Brazil, Ang [13], [14] for France and Malaysia, Jalil and Mahmud [15] for China, Halicioglu [16] for Turkey, Alam et al. [17] for India, Fodha and Zaghdoud [18] for Tunisia and Nasir and Rehman [19] for Pakistan, are some examples.

Secondly, as mentioned in the introduction, the relation between emissions from electricity production and GDP is not focused on literature. Electricity is included in the causality relations through the amount of energy consumed and not through the emissions resulting from its production. Representative studies are for instance: Aqeel and Butt [20], Shiu and Lam [21], Lee and Chang [22], Altinay and Karagol [23], Yuan et al [24], Halicioglu [25]. They concluded that electricity consumption causes economic growth and as a result supports the growth hypothesis. The opposite causality is also found running from economic growth to electricity consumption, supporting the conservation hypothesis, by Narayan and Smith [26], Yuan et al [27], Squalli [28], Mozamder and Marathe [29], Hu and Lin [30], Reynolds and Kolodziej [31], Sari et al [32], Halicioglu [25]. Akbostanci et al [33], Dhakal [34], Jalil and Mahmud [15], Fodha and Zaghdoud [18], Gosh [35], Payne [36]. Other studies like Lean and Smith [37], found a unidirectional relationship, and support the growth effect for the period 1980-2006 in Asian countries. They found a statistically significant positive association between electricity consumption and emissions and a non-linear relationship between emissions and real output. In the long-run they found a unidirectional causality running from electricity consumption and emissions to economic growth and in the short-run found unidirectional causality running from emissions to electricity consumption.

In a third strand of literature, some studies include renewable energy in the relation of causality with GDP. There is a wide variety of research for different countries and groups of countries, of which we shall give some examples. The following studies obtained positive results in what concerns causal relationships between the referred variables. Bidirectional causality between GDP and renewable energy consumption was found for Eurasian countries (Apergis and Payne [38]), for OECD countries (Apergis and Payne [39]), for emerging economies (Sadorsky [40]), for six Central American countries (Apergis and Payne [41]), for 80 countries (Apergis and Payne [42]) and for Brazil (Pao and Fu [43]).

Al-mulali et al. [44] examined high income, upper middle income and lower middle income countries and found a feedback hypothesis in 79% of the countries, with a positive bidirectional long-run between renewable energy consumption and real GDP. 19% of the countries represent the neutrality hypothesis (no long causality exists), while 2% of the countries confirm the conservation hypothesis (a one way long-run relationship between GDP and CO2 emissions). Frequently, as in Al-mulali et al [44], and the referred studies of Apergis and Payne [42], the electricity consumption from renewable sources measured in kilowatt-hour is used as an indicator of renewable energy consumption. Silva et al. [45] studied the relation between renewable energy, GDP and CO2 emissions, using the share of Renewable Energy Sources on Electricity generation. They concluded for a sample of four countries, that an increase on the share of renewable energy led to economic costs in terms of GDP per capita and to a decrease on CO2 emissions per capita.

Bowden and Payne [46], employ a Toda-Yamamoto approach to study the relationship between real GDP, renewable and non-renewable energy in the USA, and found that renewable and non-renewable energy directly and indirectly affects the real GDP. Tiwari [47] analyzed the relationship between renewable energy, economic growth, and CO2 emissions for India, using a SVAR and concluded that an increment on renewable energy increases GDP and decreases CO2 emissions, and an increase on GDP has a strong positive impact on CO2 emissions.

Less positive results were obtained for the following studies. Menyah and Wolde-Rufael [48], using a modified version of the Granger causality test found that in the US there is no causality running from renewable energy to CO2 emissions, which means the renewable energy consumption has not reached a level where it can make a contribution to mitigate the emissions; on the other hand, Menegaki [49] used a random effect model to study the relationship between growth and renewable energy in 27 European countries and suggested empirical evidence of the neutrality hypothesis in both short and long-run. Nevertheless, there is evidence of causality of emissions and employment to economic growth and vice versa. Tugcu et al. [50] employed the Autoregressive Distributed Lag Approach (ARDL), and their long-run estimates showed evidence of no causal relationship between renewable energy consumption and real GDP in France, Italy, Canada and USA; however, the feedback is present for

England and Japan and the conservation hypothesis is supported for Germany.

3. Data and EKC model

This study covers annual data from 2001 to 2010 from 20 OECD European countries: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Netherlands, Slovenia, Poland, Portugal, Slovak Republic, Spain, Sweden, Estonia and United Kingdom. Given the interest in analyzing the effects of the European Directive 2001/77/EC [4], and the fact that there was a lack of data for the share of renewable energy before 2000 and after 2011 for certain variables, the period considered was 2001 to 2010.

The variables used are CO2 emissions from electricity generation (CO2 kWh), real income (GDP) and the share of renewable energy sources in electricity generation (RES). CO2 per kWh is a ratio that in the numerator includes emissions from fossil fuels, industrial waste and non-renewable municipal waste that are consumed for electricity generation and in the denominator includes electricity generated from fossil fuels, nuclear, hydro (excluding pumped storage), geothermal, solar, biofuels, and so on. (IEA [51]). GDP, is the real Gross Domestic Product (billions of dollars, 2005), based on World Bank World Development indicators [52] and International Financial Statistics of the International Monetary Fund. RES is presented as a percentage of gross electricity consumption and is the ratio between the electricity produced from renewable energy sources and the gross national electricity consumption. Electricity produced from renewable energy sources comprises the electricity generation from hydroelectric sources (excluding pumping), wind, solar, geothermal, and electricity from biomass/wastes. Gross domestic national electricity consumption comprises the total gross national electricity of all fuels (including auto production), plus electricity imports, minus exports (source: Eurostat).

The existence of multicollinearity between variables can cause problems in the accuracy of the estimates and the size of the standard errors. To investigate whether the variables used had this problem, we estimated the correlation coefficients (see Table A1 and A2 in Appendix) and applied the Variance Inflation Factor (VIF) test.

Both procedures suggest that there is no collinearity between variables. The VIF test presents 4.72 as individual largest value and a mean of 4.72, with the critical value being 10.

We estimated the long–run equilibrium to validate the EKC, which assumes a homogeneous pattern for all countries. In this analysis we studied the relation between CO2 kWh, GDP and RES, through the equation 1 as follows:

$$\log CO_2Kwh_{it} = \alpha_{i,t} + \beta_1 \log GDP_{i,t} + \beta_2 \log GDP^2{}_{i,t} + \beta_3 \log RES_{i,t} + \varepsilon_{i,t} \ , \qquad \text{(Equation 1)}$$

Where the subscripts *i* and *t* refer to country and time respectively, the prefix "log" represents the natural logarithm, whereas β_1, β_2 and β_3 are the slope parameters to be estimated and ε is the model´s error term.

The EKC hypothesis postulates that as GDP increases, CO2 kWh increase untila certain level of GDP is attained, and after that, emissions start to decline. The EKC hypothesis is verified if β_1 is significantly positive and $\beta 2$ significantly negative. The GDP turning point (in natural logarithms) can be estimated as $-\frac{\beta_1}{2\beta_2}$.

Accordingly, β_3 in equation 1, is expected to be negative since higher share of renewable source use in electricity tends to reduce the CO2 kWh.

However, for examining our central hypothesis where the share of renewable energy in electricity output can be a potential determining factor of the difference in the emissions-economic growth relation across European countries (in particular after European Directive 2001/77/EC), we included the share of renewable energy in electricity output connected with GDP and with GDP squared, as in equation 2:

$$\begin{aligned} \log CO_2Kwh_{it} &= \alpha_{i,t} + \beta_1 \log GDP_{i,t} + \beta_2 \log GDP^2{}_{i,t} + \beta_3 \log RES_{i,t} + \\ &+ \beta_1^* \left(\log GDP \times RES\right) + \beta_2^* \left(\log GDP^2 \times RES\right)_{i,t} + \varepsilon_{i,t} \end{aligned} \qquad \text{(Equation 2)}$$

Based on that new relation, the EKC is supported when $\beta_1 + \beta_1^* \left(\log GDP * \mathrm{R}\, ES\right)$

is positive and $\beta_2 + \beta_2^* \left(\log GDP^2 \times RES \right)$ is negative and the income turning point (in natural logarithms) is $-\dfrac{\left[\beta_1 + \left(\beta_1^* \times RES \right) \right]}{2\left[\beta_2 + \left(\beta_2^* \times RES \right) \right]}$

The expected signals of $\beta 1$, $\beta 2$ and $\beta 3$ are positive, negative and negative, respectively, as explained for equation 1.

The cross between RES and GDP allows us to see if there is any synergy between the two variables in explaining emissions. For example if β_1^* is negative, it means that the higher the percentage of renewable energy, the less the positive effect of GDP on emissions, or the higher the GDP, the less the negative effect of RES on emissions. In fact, the expected signals for β_1^* and for β_2^* are negative and positive respectively. Specifically, as countries invest more in renewable energy, they can grow without compromising the environment significantly, or as they become richer, they need not increase the share of renewable energy proportionally to reduce emissions.

If β_2^* is positive , it means that the higher the percentage of renewable energy, the higher the negative effect of GDP squared on emissions, or the higher the GDP squared, the less the effect of RES on emissions. If the income level of the country is already very high, a higher percentage of renewable energy will enhance the ease of economic growth without compromising the environment, otherwise we do not need to increase renewable energy too much to reduce emissions.

Moreover, from this new model, we can also infer that the share of renewable energy in electricity output will have significant influence on the shape of the EKC if β_1^* is significantly negative. This means that EKC will shift downward as RES increases, suggesting lower (environmental) costs of development. The income turning point is lowered with higher level of share of renewable energy in electricity output if β_2^* is significantly less than 0. However, if β_2^* is positive, whether share of renewable energy in electricity output lowers or increases the turning point depends on the relative size (in absolute term) of β_1^* and β_2^*.

4. Econometric Methodology and Results

We will try to answer our goal-research using a methodology that goes through five different but complementary types of tests or estimations: (i) Panel Unit root tests, (ii) Panel Cointegration tests, (iii) Panel Long run Estimates; (iv) Panel Granger Causality and (v) Innovative Accounting Approach (which comprises Variance Decomposition Analysis and Impulse Response Functions).

4.1 Panel Unit root tests

Panel data is generally characterized by unobserved heterogeneity with parameters that are cross-section specific, although in some cases it is not appropriate to consider independent cross-section units. The test outcomes are difficult to interpret because the rejection of the null hypothesis of no unit root means that a significant fraction of cross-section units is stationary; however, there is no explicit quantification of the size of this fraction.

The unit root test was employed to ascertain whether or not the time series of each variable included in the Autoregressive Distributed Lag (ADL) contained a stochastic trend and to test whether the set of variables are stationary or not.

The panel unit root test is based on the following autoregressive specification (Mahadevan and Asafu-Adjaye [53]): $y_{it} = \rho_i \cdot y_{it-1} + \Delta_i \cdot X_{it} + \mu_{it}$, where $i = 1, 2, ..., N$, represents countries observed over periods $t = 1, 2, ..., T$. X_{it} are exogenous variables in the model including individual deterministic effects, such as constants (fixed effects) and linear time trends, which capture cross-sectional heterogeneity, and ρ_i are the autoregressive coefficients. If $\rho_i < 1$, y_i is said to be weakly trend-stationary. Conversely, if $\rho_i = 1$, then y_i contains a unit root; μ_{it} are the stationary error terms.

In order to test, under the null hypothesis, that all individual series of the panel contain a unit root, Levin, Lin and Chu [54] proposed the following panel-based ADF test that restricts parameters by keeping them identical across sectional regions: $\Delta y_{it} = c_i + \rho_i \cdot y_{it-1} + \sum_{j=1}^{k} c_j + \rho_i \cdot y_{it-j} + \varepsilon_{it}$, where $t = 1, 2, ..., T$ represents time periods and $i = 1, 2, ..., N$ represents members of the panel. The Levin-Lin-Chu test (LLC) adopts the null hypothesis of $\rho_i = \rho = 0$ for all *i*, against the alternative $\rho_1 = \rho_2 = ... = \rho < 0$ for all *i*, with the test based on the statistics $t_\rho = \hat{\rho} / s.e.(\hat{\rho})$. However, one drawback is that ρ is restricted by being kept identical across regions under both the null and alternative hypotheses.

Im, Pesaran and Shin [55] (hereafter IPS) assume that panels share a common autoregressive parameter. However the null hypothesis is only rejected if there is sufficient evidence against it (according to classical statistical methods). The IPS test uses a null hypothesis of $\rho_i = 0$ against the alternative $\rho < 0$ for all *i*, and is based on the mean-group approach which uses the average of the t_ρ statistics to obtain the z statistic.

We also perform the Hadri [56] method that tests the null hypothesis that the data are stationary against the alternative hypothesis that at least one panel contains a unit root. Hadri [56], regardless of the alternative hypothesis used, implements heterogeneous and serially correlated errors on account of their improved explanatory power. The results of panel tests are difficult to interpret if the null hypothesis is rejected. In the LLC and IPS tests, cross-sectional means are subtracted to minimize problems arising from cross-section dependence.

Table 1 displays the results of panel unit root tests in level and in the first differences for all the variables. We performed a LLC, IPS and Hadri test including an intercept and a linear trend. The non-stationarity of the variables CO2 kWh, GDP, GDP squared and RES, can be seen, indicating the possibility of long-term relationships between those variables.

In general, the remaining statistics provide strong evidence that the variables contain a panel unit root. Given that the variables CO_2 kWh, GDP and RES are integrated of the same order, it is natural that we proceed by testing the cointegration in order to establish if a long term equilibrium relationship among certain variables exists.

Table 1: Panel Unit Root Tests Results- period 2001- 2010

	Levels			First differences		
	LLC	**IPS**	**Hadri**	**LLC**	**IPS**	**Hadri**
Ln CO2 kWh	-12.459*** [0.0000]	-2.8596*** [0.0021]	11.4042*** [0.0000]	-14.8861*** [0.0000	-4.4267*** [0.0000	19.3053*** [0.0000]
Ln GDP	-9.8880*** [0.0014]	-1.7146** [0.0432]	9.3851*** [0.0000]	-8.7320*** [0.0000]	-1.34011* [0.09806]	14.9028*** [0.0000]
Ln GDP^2	-9.0567*** [0.0000]	-1.9245** [0.0271]	9.4069*** [0.0000]	-8.7372*** [0.0000]	-1.35270* [0.0881]	15.1796*** [0.0000]
Ln RES	-14.0879*** [0.0000]	-3.8479*** [0.0001]	10.7574*** [0.0000]	-12.7156*** [0.0000]	-3.1782*** [0.0000]	17.9613*** [0.0000]

Notes: *, ** and * represent significance at the 10%, 5% and 1% levels respectively.**

4.2. Panel Cointegration Tests

The Engle-Granger methodology (Engle and Granger, [57)] is usually used in testing cointegration. It examines the residuals of a regression and contends that there is cointegration if $u_t \sim I(0)$. The first contribution, among others, for this approach, has been presented by Pedroni [58], [59], [60] and Kao and Chiang [61].

Given the following equation: $y_{it} = \alpha_i + \delta_{it} + \beta_{1i} \cdot x_{1i,t} + \beta_{2i} \cdot x_{2i,t} + ... + \beta_{ki} \cdot x_{ki,t} + \varepsilon_{it}$ where i = 1,2,…N, for each country in panel; $t = 1, 2, ..., T$, refers to the time period; parameter α refers to the possibility of country-specific fix effects and the parameter δ refers to the possibility of deterministic trends. It is further assumed that variables y and x are integrated of order one, that is, I(1). Thus, under the null hypothesis that there is cointegration, the residuals will also be I(1).

Pedroni [58], [59], [60] proposes several cointegration tests that allow the heterogeneity of the intercepts and coefficients among individuals. Their alternative hypothesis can be considered homogeneous or heterogeneous. The residuals from the static long-run regression are used to build seven panel cointegration test statistics: four of them are based on pooling, which assumes homogeneity of the AR term, whilst the remaining are less restrictive, as they allow for heterogeneity of the AR term.

The statistics based on the homogeneous alternative hypothesis consist of estimates of pooled type, which ([59], [60]) call statistics within-groups. When considering the heterogeneous alternative hypothesis, test statistics are formed by means of the estimated individual values for each panel unit i, which ([59], [60]) call between-group estimators.

The results of panel cointegration tests are shown in table 2. It can be seen that four of the seven panel tests indicate that the null hypothesis of no cointegration is rejected at the 1% level, more specific, there are two panel statistics that reject the null hypothesis of no cointegration and two other statistics admit there is no cointegration between the variables. In group cointegration tests, two group statistics reject the null hypothesis and one admits it.

Table 2: Results of Panel Cointegration Tests

	Kao Statistics	Pedroni Statistics			
Equation 1	-2.3777* [0.008]*	Panel v-Statistic	-1.253915 [0.974]	Group rho-Statistic	5.47486 [1.000]
		Panel rho-Statistic	2.790618 [0.999]	Group PP-Statistic	-14.6521*** [0.000]
		Panel PP-Statistic	-4.6363*** [0.000]	Group ADF-Statistic	-2.2542*** [0.000]
		Panel ADF-Statistic	2.15667* [0.081]		
Equation 2	-2.2307** [0.0128]	Panel v-Statistic	-2.1416 [0.9839	Group rho-Statistic	6.31205 [1.000]
		Panel rho-Statistic	4.0760 [1.000]	Group PP-Statistic	-7.81559*** [0.000]
		Panel PP-Statistic	0.34096*** [0.000]	Group ADF-Statistic	-2.3145*** [0.0100
		Panel ADF-Statistic	-0.0960*** [0.008]		

Notes: Tests results were generated by Eviews. Pedroni's and Kao Panel statistics as well as all of variables. Values in [ ] are robust p-values generated through bootstrapping because of cross-sectional dependence in the residuals. *, **, and *** indicates significance at 10%, 5% and 1% respectively.

We decided it may be reasonable to accept the existence of cointegration relationship if we consider the fact that rho-statistics have lower power than the PP-statistics.

4.3 Panel Long run Estimates

Based on error correction models, we used the Full Modified Ordinary Least Squares (FMOLS) and Dynamic Ordinary Least Squares (DOLS) methods. This procedure follows Pedroni's [58] recommendations, in which FMOLS and DOLS estimators are more advantageous in other group-means versions, due to the greater flexibility under the presence of heterogeneity in the cointegration vectors and to the lower size distortion, than the estimators within groups. This allows to correct both the endogeneity bias and serial correlation, and to achieve consistent and efficient estimators of the long-run relationship.

The results from the estimation of the model proposed are given in table 3, and confirm our expectations that CO2 kWh tend to decrease with the share of renewable energy sources used. In Model 1, the FMOLS estimates indicate for the long-run relationship, that GDP has a positive statistically significant impact on CO2Kwh and GDP squared has a negative statistically significant impact on CO2 Kwh at 10% level significance. Moreover, the share of renewable energy sources has a negative statistically significant impact on CO2 Kwh at 10% level significance. The results suggest that a 1% increase in the share of renewable energy is related to the decrease in expected CO2Kwh by 0.05%.

Table 3: Panel Cointegration Estimation Results

	Model 1		**Model 2**	
2001 – 2010	**FMOLS**	**DOLS**	**FMOLS**	**DOLS**
Dependent variable:	**CO2 kWh**	**CO2 kWh**	**CO2 kWh**	**CO2 kWh**
Ln GDP	**7.2381***	5.9678	**5.7280***	4.5422
	(0.094)	(0.206)	**(0.089)**	(0.128)
Ln GDP^2	**-3.6745***	-2.9256	**-2.9427***	-2.4138
	(0.091)	(0.138)	**(0.088)**	(0.119)
Ln RES	**-0.05012***	-0.0501*	**-0.0605***	-0.0102*
	(0.098)	(0.0101)	**(0.071)**	(0.092)
Share of RES* Ln GDP			**-0.29312****	-0.2391*
			(0.033)	(0.102)
Share of RES*Ln GDP^2			**0.14551****	0.101*
			(0.034)	(0.103)
R-squared (r^2)	**0.981**	0.984	**0.983**	0.985
No. of Countries	20	20	20	20
No. of Observations	200	200	200	200

Notes: Values in [ ] are robust p-values ; the *, **, and *** indicate significance at 10%, 5% and 1% respectively.

According to our central hypothesis, from FMOLS estimation, we obtain empirical support for the presence of the EKC, as indicated by the significantly positive effect of GDP and significantly negative coefficient of GDP squared in both equations 1 and 2. However, the results are more statistically significant in equation 2. They suggest that 1% increase in the share of renewable energy decreases CO2 kWh by 0.06%; while 1% increase in the interactive effect between the share of renewable energy and GDP decreases CO2 kWh by 0.29%. On the other hand, the validity of EKC is confirmed by the positive coefficient of GDP, that is 5.7280 - (0.29312 x RES), and by the negative coefficient of GDP squared, that is -2.942 + (0.1455 x RES).

These results suggest several noteworthy points. First, they do not overturn the validity of the traditional EKC, in fact, the coefficient of GDP remains positive while that of GDP squared remains negative, regardless of the level of proportion of renewable energy sources in electricity generation.

Secondly, as reflected by the statistical significance of the two interactive effects at 5% level of significance, the results suggest the importance of the proportion of renewable energy sources in electricity generation in influencing the EKC. If a country uses more renewable energy, it can grow economically without many environmental costs, because the share of renewable energy will make the EKC drop.

Thirdly, the significant negative coefficient of the interaction between the share of renewable energy and GDP suggest that the environmental costs of European economic development are lower for a European country with a higher level of share of renewable energy sources used in electricity generation. That means the EKC shifts downward as the share of renewable energy sources increases. Finally, the positive coefficient of the interaction between GDP squared and the share of renewable energy sources in electricity generation suggests that the threshold point can be lower or higher for a European country with higher level of share of renewable energy depending on the relative reduction in the coefficient of GDP in relation to the reduction in the coefficient of GDP squared.

4.4. Panel Granger Causality

An implication of co-integration is that there must be causality in at least one direction. For this we estimated the following VECM (Vector Error Correction Model). The VECM is the short-run model and it gives the adjustment mechanism when CO2 kWh, GDP, RES and the cross product between RES and GDP and GDP squared deviate, in the short-run, from the long-run equilibrium. We estimated that the simple VECM for the long-run relationship and the short-run equations are as follows for cointegration model:

$$\begin{aligned}\Delta CO_{2\,Kwh\,it} &= \alpha_{1j} + \lambda_{1i}\varepsilon_{it-1} + \sum_{k=1}^{q}\gamma_{11ik}\Delta CO_{2\,Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{12ik}\Delta GDP_{it-k} + \sum_{k=1}^{q}\gamma_{13ik}\Delta GDP^{2}{}_{it-k} \\ &+ \sum_{k=1}^{q}\gamma_{14ik}\Delta RES_{it-k} + \sum_{k=1}^{q}\gamma_{15ik}\Delta GDP \times RES_{Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{16ik}\Delta GDP^{2} \times RES_{Kwh\,it-k} + \mu_{1it}\end{aligned}$$

Eq. 3.1

$$\begin{aligned}\Delta GDP_{it} &= \alpha_{2j} + \lambda_{2i}\varepsilon_{it-1} + \sum_{k=1}^{q}\gamma_{21ik}\Delta GDP_{it-k} + \sum_{k=1}^{q}\gamma_{22ik}\Delta CO_{2\,Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{23ik}\Delta GDP^{2}{}_{it-k} \\ &+ \sum_{k=1}^{q}\gamma_{24ik}\Delta RES_{Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{25ik}\Delta GDP \times RES_{Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{26ik}\Delta GDP^{2} \times RES_{Kwh\,it-k} + \mu_{2it}\end{aligned}$$

Eq. 3.2

$$\begin{aligned}\Delta GDP^{2}{}_{it} &= \alpha_{3j} + \lambda_{3i}\varepsilon_{it-1} + \sum_{k=1}^{q}\gamma_{31ik}\Delta GDP^{2}{}_{it-k} + \sum_{k=1}^{q}\gamma_{32ik}\Delta GDP_{it-k} + \sum_{k=1}^{q}\gamma_{33ik}\Delta CO_{2\,Kwh\,it-k} \\ &+ \sum_{k=1}^{q}\gamma_{34ik}\Delta RES_{it-k} + \sum_{k=1}^{q}\gamma_{35ik}\Delta GDP \times RES_{Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{36ik}\Delta GDP^{2} \times RES_{Kwh\,it-k} + \mu_{3it}\end{aligned}$$

Eq. 3.3

$$\begin{aligned}\Delta RES_{Kwh\,it} &= \alpha_{4j} + \lambda_{4i}\varepsilon_{it-1} + \sum_{k=1}^{q}\gamma_{41ik}\Delta RES_{Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{42ik}\Delta CO_{2\,Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{43ik}\Delta GDP_{it-k} \\ &+ \sum_{k=1}^{q}\gamma_{44ik}\Delta GDP^{2}{}_{it-k} + \sum_{k=1}^{q}\gamma_{45ik}\Delta GDP \times RES_{Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{46ik}\Delta GDP^{2} \times RES_{Kwh\,it-k} + \mu_{4it}\end{aligned}$$

Eq.3.4

$$\begin{aligned}\Delta GDP \times RES_{Kwh\,it} &= \alpha_{5j} + \lambda_{5i}\varepsilon_{it-1} + \sum_{k=1}^{q}\gamma_{51ik}\Delta GDP \times RES_{Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{52ik}\Delta CO_{2\,Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{53ik}\Delta GDP_{it-k} \\ &+ \sum_{k=1}^{q}\gamma_{54ik}\Delta GDP^{2}{}_{it-k} + \sum_{k=1}^{q}\gamma_{55ik}\Delta RES_{Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{56ik}\Delta GDP^{2} \times RES_{Kwh\,it-k} + \mu_{5it}\end{aligned}$$

Eq. 3.5

$$\begin{aligned}\Delta GDP^{2} \times RES_{Kwh\,it} &= \alpha_{6j} + \lambda_{6i}\varepsilon_{it-1} + \sum_{k=1}^{q}\gamma_{61ik}\Delta GDP^{2} \times RES_{Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{62ik}\Delta CO_{2\,Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{63ik}\Delta GDP_{it-k} \\ &+ \sum_{k=1}^{q}\gamma_{64ik}\Delta GDP^{2}{}_{it-k} + \sum_{k=1}^{q}\gamma_{65ik}\Delta RES_{Kwh\,it-k} + \sum_{k=1}^{q}\gamma_{66ik}\Delta GDP \times RES_{Kwh\,it-k} + \mu_{6it}\end{aligned}$$

Eq. 3.6

The errors for period *t*-1 are estimated from the long-run equation. The inclusion of the lagged dependent variable as an instrument variable estimator is necessary to account for correlation between the lagged dependent variables and the error term. The coefficients are adjustment parameters, showing the degree with which the respective left hand side variables adjust in period *t* to disequilibrium shocks in period *t*-1.

In Equation 3.1, the error correction term indicates the speed of adjustment towards long-run equilibrium and has a statistical significance at the 5% level with a speed of adjustment to long-run equilibrium of 23.42 years. All variables have a statistically significant impact at 10% level of significance on carbon dioxide emissions from electricity generation in the short run.

Table 4: Panel Granger Causality Results

Model 2 **EKC approach**		**Eq.3.**1	Eq.3.2	**Eq.3.3**	**Eq.3.4**	**Eq.3.5**	**Eq.3.6**
	ect (-1)	**Δ LCO$_2$ kWh**	**Δ LGDP**	**Δ LGDP^2**	Δ Renewable	**Δ Renewable x L GDP**	**Δ Renewable x L GDP^2**
Constant		-0.01161 (0.0385)**	0.0174 (0.000) ***	-0.0350 (0.000) ***	-5.4908 (0.000)***	-0.4807 (0.000)***	0.9600 (0.000)***
Δ LCO$_2$ kWh	0.0427 (0.0427)**		0.0026 (0.1039)	-0.0055 (0.1031)	-0.8535 (0.1023)	-0.0650 (0.1216)	0.1298 (0.1362)
Δ L GDP	-0.139 (0000)***	7.9444 (0.1013)*		2.0214 (0.000)***	289.322 (0.000)***	23.8249 (0.000)***	-47.5750 (0.000)***
Δ L GDP^2	00386 (0.000)***	- 3.9904 (0.1003*)	0.4940 (0.000) ***		-143.292 (0.000)***	-11.7549 (0.000)***	23.4721 (0.000)***
Δ RES	-0.0587 (0.000)***	- 0.1152 (0.096)*	-0.0142 (0.000) ***	0.0287 (0.000)***		0.5007 (0.000)***	1.9988 (0.000)***
Δ RES **x** L GDP	00531 (0.000)***	- 0.2303 (0.068)*	0.0284 (0.000) ***	-0.0574 (0.000)***	-6.4040 (0.000)***		1.9969 (0.000)***
Δ RES **X L** GDP^2	-0.1061 (0.000)***	0.1152 (0.076)*	-0.0142 (0.000) ***	0.0287 (0.000)***	3.2052 (0.000)***	0.5007 (0.000)***	

Notes: *, ** and * represent significance at the 10%, 5% and 1% levels respectively.**

With respect to Equation 3.2, the GDP squared and the interactive effect between GDP and RES, have a positive and statistically significant impact on GDP while RES and the effect between GDP squared and RES have a negative and statistically significant impact on GDP in the short run. However, carbon dioxide emissions from electricity generation have a statistically insignificant impact on GDP in the short run. The error correction term is statistically significant at 1% level with a speed of adjustment to long-run equilibrium of 7.20 years.

In terms of Equation 3.4, RES is positively affected by GDP and by the interactive effect between GDP squared and the share of renewable energy, and negatively affected by GDP squared and by the effect between GDP and the share of renewable energy sources. Carbon emissions per kWh have a statistically insignificant impact on the share of renewable energy sources in electricity generation output in the short run. On the other hand, the statistical significance of the error correction term suggests that the share of renewable energy sources responds to deviations from long-run equilibrium with an adjustment of roughly 17.04 years.

In Equation 3.5, GDP, RES and RES interactively with GDP squared, have a positive and statistically significant impact on RES interactively with GDP in the short-run, while GDP squared affect it negatively. Carbon emissions per kWh have a statistically insignificant impact on RES interactively with GDP. The error correction term indicates that the speed of adjustment towards long-run equilibrium is approximately 18.82 years.

With regard to Equation 3.6, GDP squared, RES and RES interactively with GDP have a positive and statistically significant impact on RES interactively with GDP squared in the short-run, while GDP has a negative impact and carbon emissions per kWh is statistically insignificant. The correction term is statistically significant with the slowest adjustment equilibrium of 9.43 years.

In summary, the Granger causality tests reveal that there is unidirectional causality from RES interactively with GDP (negative) and from RES interactively with GDP squared (positive), both towards CO2 kWh, which confirms the ideas exposed in section 3. There is also bidirectional positive causality between GDP and RES interactively with GDP, between RES and RES interactively with GDP squared and between RES interactively with GDP and RES interactively with GDP squared. There is bidirectional negative causality between GDP and RES interactively with GDP squared. Finally, there is bidirectional causality between GDP and RES (positive from GDP to RES and negative from RES to GDP) and between RES and RES interactively with GDP squared (positive from RES to RES interactively with GDP squared and negative from RES interactively with GDP squared to GDP).

4.5 The Innovative Accounting Approach

4.5.1. Generalized forecast variance decomposition

The generalized forecast variance decomposition approach estimates the simultaneous shock effects using a VAR system to test the strength of causal relationship between CO2 kWh, GDP and RES of European countries.

The variance decomposition approach indicates the magnitude of the predicted error variance for a panel series accounted by innovations from each of the independent variables over different time horizons (2001-2010). Furthermore, the generalized forecast error variance decomposition approach estimates the simultaneous shocks stemming in other variables.

For instance, if the share of renewable energy sources explains more of the forecast error variance of CO2 kWh, then we deduce that there is unidirectional causality from renewable energy sources to CO2 emissions in electricity generation. The bidirectional causality exists if shocks in CO2 kWh emissions also affect the share of renewable energy sources in a significant way. If shocks occurring in both series do not have any impact on the changes in CO2 kWh emissions and in the share of renewable energy sources then there is no causality between the variables.

Table 5 presents the results of the generalized variance decomposition over a ten-year period for 20 European countries. The variance decomposition explains how much of the predicted error variance of a variable is described by innovations generated from each independent variable in a system, over various time horizons.

Hereafter, we will point out the most important shocks that can change each variable. The empirical evidence indicates that 93.5 per cent of CO2 kWh emissions is due to its own innovative shocks. The standard deviation shock in coefficient of the interaction between GDP and the share of renewable energy sources in electricity generation is the variable that better explains electricity pollutants, although with a low percentage (2.13%). A 7.3 per cent of GDP is explained by one standard deviation shock in CO2 kWh emissions and 91.2 per cent is due to its own innovative shocks. GDP squared is affected mainly by GDP (91.125%) and by CO2 kWh (7.3%). A significant portion of RES is explained by its own shocks (60.3%), by shocks in CO2 kWh (27.3%) and in GDP (10.9%).

The contribution of CO2 kWh and RES to the interactive effect between the share of renewable energy and GDP is 31.6% and 23.7% respectively, while 42.1% per cent is due to its own innovative shocks. The interactive effect between the share of renewable energy and GDP squared is mainly affected by the interactive effect between the share of renewable energy and GDP (42.1%), by CO2 kWh (31.6%) and by RES (23.7%).

Taking 5% as a threshold, we can infer that there is unidirectional causality from CO2 kWh to all the other variables. On the other hand, GDP causes GDP squared and RES. The share of renewable energy causes the interaction between GDP with the share of renewable energy sources and the interaction between GDP squared with the share of renewable energy sources.

Table 5: Generalized variance decomposition results

Variance Decomposition of CO2 kWh

Period	CO2 kWh	GDP	GDP^2	RES	RES x GDP	RES x GDP ^2
1	100.0000	0.000000	0.000000	0.000000	0.000000	0.000000
2	95.70979	0.358865	0.002397	0.339409	3.393501	0.196041
3	94.91419	0.691613	0.387879	0.283483	3.383464	0.339370
4	94.58039	0.753891	0.608483	0.219638	3.051695	0.785905
5	94.21208	0.852751	0.739070	0.182729	2.941178	1.072196
10	93.54845	1.006484	1.263403	0.149724	2.133950	1.897989

Variance Decomposition of GDP:

Period	CO2Kwh	GDP	GDP^2	RES	RES x GDP	RES x GDP ^2
1	3.730948	96.26905	0.000000	0.000000	0.000000	0.000000
2	6.454976	92.76140	0.433054	0.062536	0.132503	0.155535
3	6.963128	91.97080	0.773274	0.092796	0.090252	0.109754
4	7.041224	91.80773	0.920940	0.077054	0.076331	0.076723
5	7.240532	91.54068	1.024609	0.061533	0.065428	0.067215
10	7.296354	91.18002	1.371585	0.054998	0.032187	0.064852

Variance Decomposition of GDP^2:

Period	CO2Kwh	GDP	GDP^2	RES	Period	CO2Kwh
1	3.377360	95.64327	0.979370	0.000000	0.000000	0.000000
2	6.189603	92.52312	0.905826	0.050729	0.168586	0.162138
3	6.900450	91.75080	1.042793	0.091057	0.113498	0.101402
4	6.987130	91.66213	1.106393	0.077659	0.095516	0.071172
5	7.197560	91.41858	1.175315	0.062290	0.081849	0.064408
10	7.274337	91.12557	1.440077	0.055482	0.040299	0.064235

Variance Decomposition of RES:

Period	CO2Kwh	GDP	GDP^2	RES	RES x GDP	RES x GDP ^2
1	*4.260251*	*0.471332*	0.080418	95.18800	0.000000	0.000000
2	*24.69815*	*3.241228*	0.953793	70.69848	0.218404	0.189937
3	25.41025	6.013492	0.733833	67.14475	0.466479	0.231194
4	25.28372	7.779919	0.899354	65.38899	0.385814	0.262203
5	26.09383	8.879068	0.866784	63.59838	0.330153	0.231786
10	27.32478	10.90364	0.775544	60.34912	0.484046	0.162862

Variance Decomposition of %RES x GDP :

Period	CO2Kwh	GDP	GDP^2	RES	RES x GDP	RES x GDP ^2
1	0.522200	0.030992	0.005008	36.06358	63.37822	0.000000
2	30.41284	0.847496	0.553905	21.59948	45.01988	1.566395
3	30.57755	0.978598	0.678492	21.47143	45.03736	1.256565
4	29.99322	1.112133	0.542212	22.20978	45.11503	1.027636
5	30.82390	1.254742	0.496109	22.24054	44.29788	0.886831
10	31.55757	1.684093	0.375858	23.71961	42.10195	0.560924

Variance Decomposition of : %RES x GDP ^2

Period	CO2Kh	GDP	GDP^2	RES	RES x GDP	RES x GDP ^2
1	0.522095	0.031450	0.000500	36.09407	63.35042	0.001465
2	30.42772	0.855392	0.561585	21.63125	44.97507	1.548979
3	30.58164	0.987989	0.689062	21.50553	44.99499	1.240788
4	30.00473	1.122238	0.550564	22.23915	45.06900	1.014319
5	30.83652	1.264432	0.503496	22.26653	44.25376	0.875265
10	31.57363	1.690938	0.379969	23.73604	42.06518	0.554247

Finally, the interaction between GDP with the share of renewable energy sources causes the interaction between GDP squared with the share of renewable energy sources.

4.5.2 Impulse Response Functions

We also provided a rough analysis of how long it takes for the variable to go back to the equilibrium after the long run relationship has been shocked. The IRFs show the dynamic responses of time series to a one period standard deviation shock and indicate the direction of the response to each of the shocks.

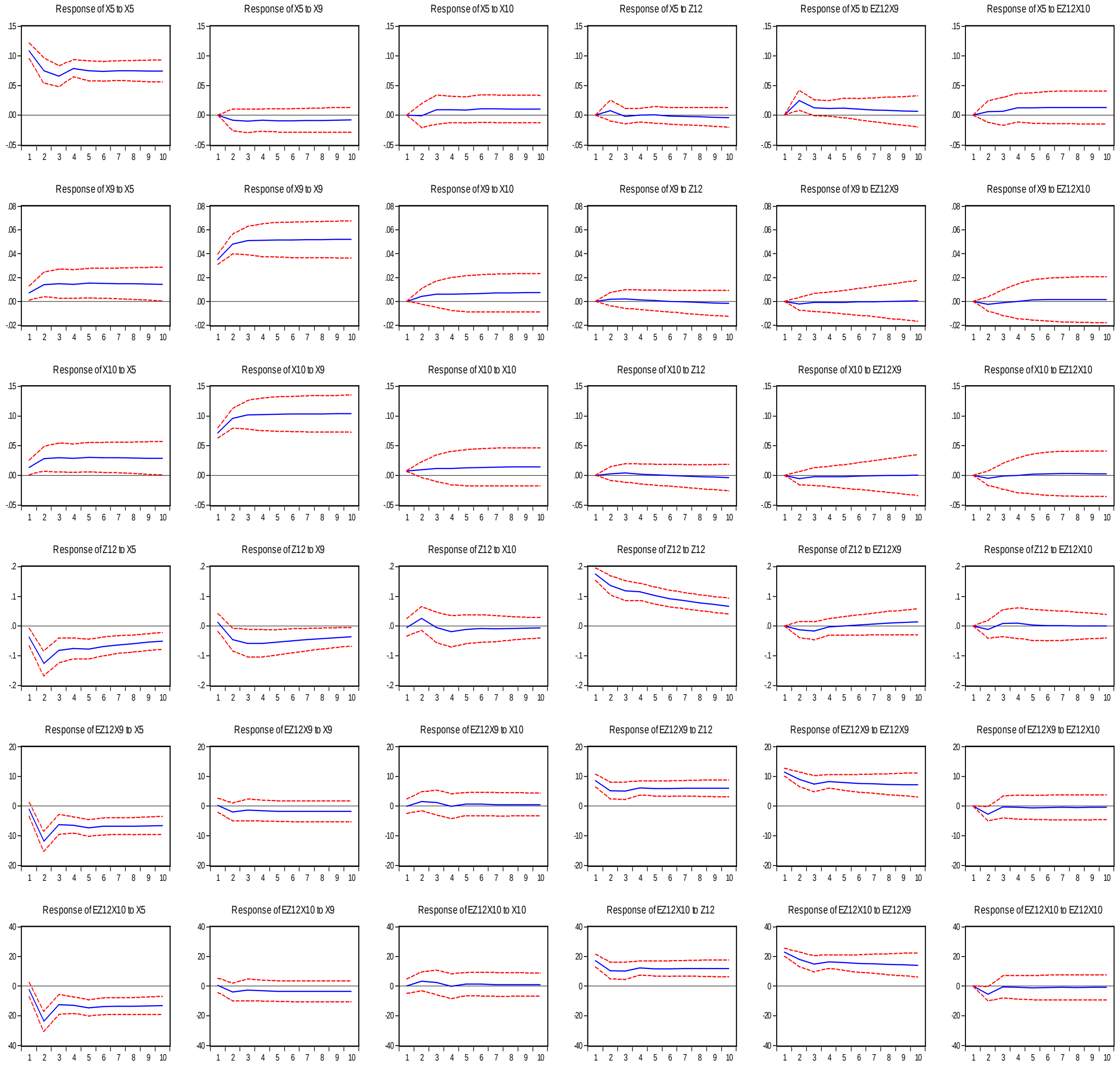
One can determine how CO2 kWh responds due to its shock and to shocks in the other variables. For instance, we support the hypothesis that the share of renewable energy sources causes CO2 kWh if the impulse response function indicates significant response of CO2 kWh emissions to shocks in the share of renewable energy sources compared to shocks in the other variables.

We have the IRFs represented in figure 1. We can see that CO2 kWh reacts positively and significantly to shocks in the interaction between GDP squared with the share of renewable energy sources in electricity, and reacts negatively to shocks in GDP. The GDP reacts positively to shocks in CO2 kWh. Concerning the share of renewable energy sources, in the short-run the reaction is positive but after the fourth period the reaction is negative. We can see that the share of renewable energy sources in electricity generation reacts negatively to shocks in CO2 kWh and in GDP.

The reaction of the interaction effect between GDP and the share of renewable energy sources in electricity generation is negative to CO2 kWh and positive to RES and to the interaction effect between GDP squared and the share of renewable energy sources.

Figure 1: Impulse Response Function results

Response to Cholesky One S.D. Innovations ± 2 S.E.



Notes:Name of the variables X5- LnCO2 kWh, X9- lnGDP, X10- lnGDP squared*, Z12 -ln share of renewable sources, EZ12- share of renewable sources in electricity generation respectively.

5. Concluding remarks

This study aims to evaluate in 2001-2010 the renewable resource and environment efficiency problem in electricity generation of European countries. We specify a new EKC, where the share of renewable energy in electricity production is considered as an important driver for determining the difference in the emissions–income relations across European countries. Our results provide supportive evidence for the validity of EKC, as reflected by the positive coefficient of GDP and negative coefficient of its squared value.

These results have important implications. Among others, the significant evidence that the share of renewable energy in electricity output is a potential driver for reducing the carbon emissions in electricity, tends to be large at the early stage of European economic development. With the obtained estimates, we can see that as countries invest more in renewable energy, they can grow without compromising the environment too much, or as they become richer, they don't need to increase proportionally the share of renewable energy to reduce emissions. We can illustrate this with countries with lower income on average for this period, such as Austria or Sweden that made a strong investment in renewable energy and were able to grow without too many emissions. Richer countries, such as Germany, United Kingdom and France, did not need to significantly increase their share of renewable energy in the period 2000-2010, to reduce emissions (see figure A1 in Appendix). If the income level of the country is already very high, a higher percentage of renewable energy will enhance the ease of economic growth without compromising the environment otherwise we do not need to increase renewable energy significantly to reduce emissions.

Moreover, from this new model, we can also infer that the share of renewable energy in electricity output will have significant influence on the shape of the EKC, which will shift downward as RES increases, suggesting lower (environmental) costs of development. As β_2^* is positive, the share of renewable energy in electricity output lowers the turning point because, in absolute term, β_1^* is greater than β_2^*.

From Panel Granger Causality tests we can highlight the bidirectional causality between GDP and RES (positive from GDP to RES and negative from RES to GDP). From Variance Decomposition analysis we confirm the relation of causality from GDP to RES. This shows that richer countries will naturally have more willingness to invest in renewable energy. The negative causality from RES to GDP can somehow support the results of Menegaki [49], who claims that the leading countries in renewable energy are less technically efficient than renewable energy laggards that are among the most technically efficient countries in Europe. However, it must be pointed out that the period of analysis and methodology used in Menegaki [49] is different from the present study.

From IRFs we can see that CO2 kWh reacts positively and significantly to shocks in the interaction between GDP squared with the share of renewable energy sources in electricity, and reacts negatively to shocks in GDP. These results show that the crossing effect between the share of renewable energy in electricity output and income is crucial to reduce the CO2 intensity of European Countries, particularly in energy supply, in what concerns increasing energy efficiency and the use of renewable energy. The GDP reacts positively to the share of renewable energy sources in the short-run, but after the fourth period the reaction is negative, which may support the conclusions of Menegaki. [49]

All these results, in particular the results reported in Model 1B, show a common pattern expected of CO2 emissions in electricity generation after the European Directive 2001/77/EC, including the first and part of the second period of the Kyoto Protocol (2005-2007 and 2008-2012). These results are relevant to identify that the share of renewable energy sources can be a potential determining driver of the difference in the emissions-income relation across European panel country level. Moreover, these results reveal the importance of the interactive impact of the share of renewable energy sources and of GDP in reducing the CO2KWh in electricity generation.

In addition, these results claim the importance of the points highlighted by the European policy (2009/28/CE directive) [62]. European policies are not only focused on market-based instruments as energy or environmental taxes/subsidies or the European Carbon Market (ECM), but also on the improvement of technology that focuses on energy efficiency and renewable energy and on the EU financial instruments supporting the achievement of political goals.

All these guidelines, especially at a domestic European level, and/or at an international one, are linked to the mitigation mechanism, which should be granted exclusively in promotion and development of clean technologies to ensure better energy efficiency.

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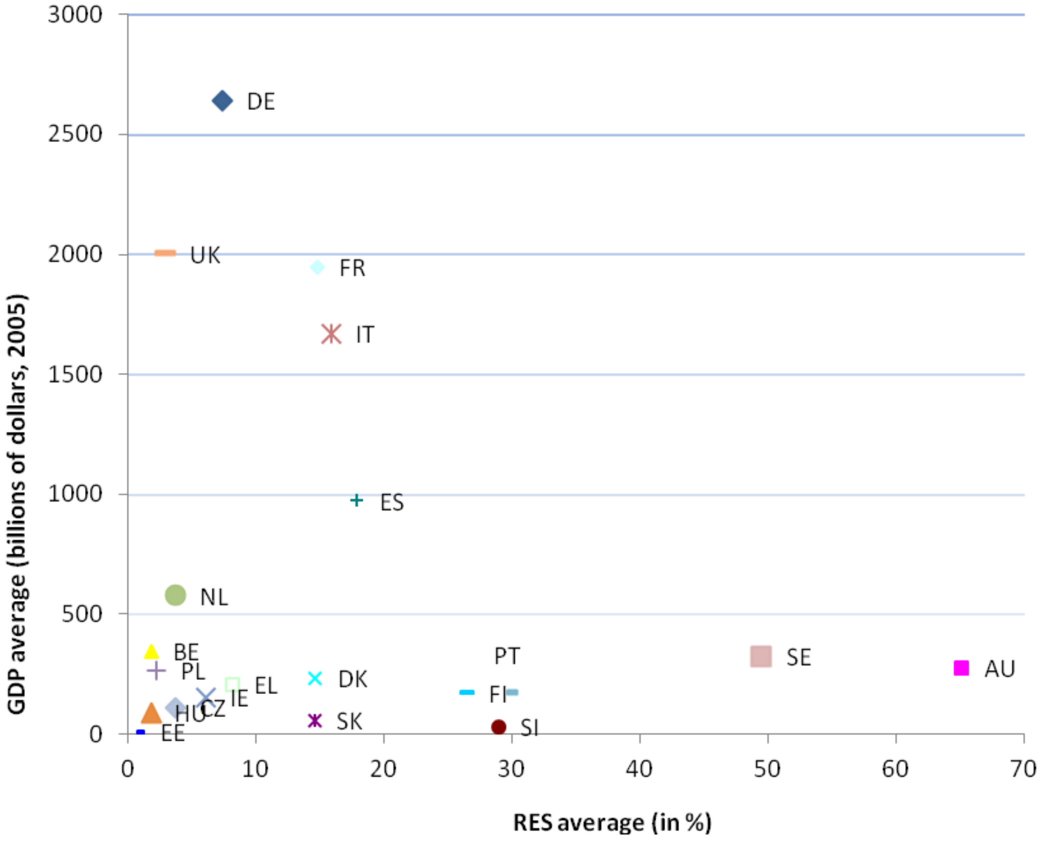
Appendix

Figure A1 – Relation between GDP and RES (in average for period 2001-2010) for European countries



Country	Country Code	Country	Country Code
Germany	DE	Greece	EL
Austria	AT	Hungary	HU
Belgium	BE	Ireland	IE
Denmark	DK	Italy	IT
Slovak Republic	SK	Netherlands	NL
Slovenia	SI	Poland	PL
Spain	ES	Portugal	PT
Estonia	EE	United Kingdom	UK
Finland	FI	Czech Republic	CZ
France	FR	Sweden	SE

Source: Own elaboration with data from World Bank World Development indicators, International Financial Statistics of the IMF and Eurostat

Table A1 -Descriptive statistics

Variable	**Period**	**Obs**	**Mean**	**Std. Dev.**	**Minimum**	**Maximum**
CO2 kWh	2001-2010	200	430,1065	243,2643	17,46512	1085,721
Ln CO2 kWh			5,821444	0,849131	2,86	6,99
GDP	2001-2010	200	684,1233	843,9022	11,02318	2980,958
Ln GDP			5,733389	1,366776	2,4	9
GDP ^2	2001-2010	200	1175220	2214589	121,5104	8886111
RES	2001-2010	200	16,55141	15,89933	0,227638	66,68632
Ln RES			2,283056	1,153398	-1,48	4,2

Table A2 - Correlation matrix and Variance Inflation Factor *VIF*– Period 2001-2010

	Ln CO2 kWh	Ln GDP	RES	Ln RES
Ln CO2 kWh	1			
Ln GDP	-0.2187***	1		
RES	-0.6108***	-0.0063	1	
Ln RES	-0.5536***	0.1826**	0.8431***	1
VIF		4,72	-	4,72
1/VIF		0.2117	-	0.2117
Mean VIF				4,72

	CO2 kWh	GDP	RES
CO2 kWh	1		
GDP	-0.1362*	1	
RES	-0.5834***	-0.157**	1