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The effect of renewable energy use and economic growth on pollution in the EUROZONE

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Abstract

The aim of this paper is to empirically examine the effect of renewable energy use and economic growth on pollution within EUROZONE from 2005 to 2013 by utilizing Dynamic Panel Generalized Method of Moments approaches. The empirical results reveal that economic growth positively affects environmental pollutants. The use of renewable sources of energy negatively affects pollution. The more the renewable energy we use the less the air pollution. However, energy saving and energy intensity contribute to more air pollution.

Keywords: economic growth; EUROZONE; environmental pollutants; energy use; dynamic panel data
JEL Classification Codes: C21, C23, C51, L16, R12

1. Introduction

The empirical literature the last four years regarding the effect of renewable energy use and economic growth on pollution shows a considerable heterogeneity between environmental and economic growth variables within EU countries[1]. The main source of the divergence may be linked to the rate of productivity and nations' specific characteristics.

Apergis (2016) explores the relationship between per capita CO_2 emissions and real Gross Domestic Product (GDP) by using panel and time-series based methods of cointegration for a dataset of 13 European countries. The empirical results are mixed both under panel or time-series techniques. Sephton and Mann (2016) investigate the relationship between per capita

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[1] In this paper we are not indented to present the whole literature concerning the relationship between energy use – economic growth and pollution. For a survey of this relationship on an empirical and theoretical perspective see Istaiteyeh (2016), Anastasia (2015), Kalaysi and Koksal (2015), Bernard et al. (2014), Kapusuzoglou (2015) and Polemis and Dagoumas (2013). For relevant studies prior to 2010 see Lopez-Menendez et al. (2014), Markandya et al. (2006), Galeotti et al. (2009), Dinda (2004), Stern (2004) and Panayotou (2000).

emissions of SO_2 and CO_2 and per capita GDP in the United Kingdom and show that the Environmental Kuznets Curve (EKC) hypothesis (Shafik and Bandyopandhyay 1992; Grossman and Krueger 1995; Holtz-Eakin and Selten 1995; Panayotou 1995)[2] is valid with estimated turning points in 1966 and 1967 for CO_2 and SO_2 respectively. Rodriguez et al. (2016) examines the EKC hypothesis over the period 1979-2004 and find a positive, but marginally decreasing relationship between CO_2 emissions and GDP per capita and a relative decoupling between the two variables. Mazur et al. (2015) empirically explore the relation between CO_2 emissions and GDP per capita during the period 1992–2010. The authors find strong evidences in favor of EKC hypothesis. Ajmi et al. (2015) consider annual data from 1960 to 2010 and support the non - existence of EKC hypothesis since they find evidences of cubic N-shaped (United Kingdom) and inverted N-shaped (Italy and Japan) relationships between CO_2 emissions and real GDP per capita. Lopez-Menendez et al. (2014) explore the EKC hypothesis over the period from 1996 – 2010. The authors show evidences of inverted-N shaped curve for the EU27. However, the consideration of specific country effects in the empirical model lead to the conclusion that only 4 countries (Cyprus, Greece, Slovenia and Spain) exhibit an inverted U – shaped relationship, while 11 countries correspond to increasing patterns, 9 countries show a decreasing path and the remaining 3 countries lead to U-shaped curves. Sephton and Mann (2013) show that economic growth and emissions are non linearly cointegrated, while the process to the long – run equilibrium involves asymmetric behavior. They generally support the existence of EKC hypothesis for Spain.

This paper empirically explores the effect of renewable energy use and economic growth on environmental pollutants within EUROZONE. For this purpose we utilize yearly updated unbalanced panel data set of EUROZONE countries during the period from 2005 to 2013 and we employ Dynamic Panel Generalized Method of Moments (DPGMM) approaches. Our research innovates in the sense that it explores energy efficiency targets of Europe 2020 strategy within a dynamic framework. Particularly, on the one hand we analyse data from the EUROZONE, exploring the effect of various energy efficiency indicators, such as the share of renewable energy in gross final energy consumption, the electricity generated from renewable sources of gross electricity consumption and energy saving from primary energy consumption, on four different environmental pollutants, Sulphur Oxides (SO_2), Nitrogen Oxides (NO_X), Non-methane volatile organic compounds (NMVOC) and Greenhouse Gas Emissions (CO_2 equivalent, GGE). On the other hand, we utilize Dynamic Panel approaches such as SYS and DIF – GMM methodologies to examine clustered patterns of energy pollutants and economic growth[3].

The empirical results reveal a positive monotonic relationship between economic growth and pollution. They also show a very important issue, that is, the dependence among the main components of energy policy mixture within EUROZONE. Particularly, the use of renewable sources of energy negatively affects environmental pollutants. The more the renewable energy we use the less the air pollution. However, energy saving and energy intensity contribute to more air pollution. Therefore, the empirical results in this paper reveal a very critical point for further elaboration: do all EU member states use energy efficiently at all stages of the energy chain from its production to its final consumption or European Commission (EC) has to reconsider the energy saving indicator for monitoring more adequately the progress towards European energy strategies against pollution?

The remainder of this paper is organized in the following way. Section 2 presents the empirical model and the methods of estimation and Section 3 presents the data under scrutiny. Section

[2] See Kuznets (1995) for the traditional Kuznets Curve hypothesis.

[3] Lopez Menendez et al. (2014) examine energy sources as explanatory variables in the empirical models within a static environment. See also Mazur et al. (2015).

4 provides the empirical results and Section 5 discusses them and concludes, providing some policy implications that emerge from the empirical analysis.

2. Empirical model and methods of estimation

2.1 Empirical model

Eq. 1 is the empirical model of this paper (Richmond and Kaufmann, 2006; Stern, 2014):

$$\log E_{i,t} = \alpha_i + \beta \log E_{i,t-1} + \beta_1 I_{i,t} + \beta_2 I_{i,t}^2 + \beta_3 I_{i.t}^3 + \beta_4 \log X_{i,t} + \varepsilon_{i,t} \tag{1}$$

Following standard notation *t* stands for the period (9 years) and *i* stands for the countries under scrutiny (19 EUROZONE countries)[4]. Log $E_{i,t}$ denotes the vector of the environmental pollutants (log $SO_{2,t}$, log $NO_{X,t}$, log $NMVOC_t$, log GGE_t) at period *t* and log $E_{i,t-1}$ denotes the vector of the environmental pollutants at period *t-1*. Log SO_2 is the natural logarithm of sulphur oxides emissions, log NO_X is the natural logarithm of nitrogen oxides emissions, log *NMVOC* is the natural logarithm of non-methane volatile organic compounds emissions and log GGE_t is the natural logarithm of total greenhouse gas emissions (CO_2 equivalent).

$I_{i,t}$ is the percentage ratio of real GDP growth rate and log $X_{i,t}$ denotes the vector of control variables (log *MI*, log *RENEWS*, log *RENEWG*, log *ES*) that influence environmental degradation. Particularly, log *MI* denotes the natural logarithm of energy intensity, log *RENEWS* denotes the natural logarithm of the share of renewable energy in gross final energy consumption, log *RENEWG* denotes the natural logarithm of electricity generated from renewable sources (% of gross electricity consumption) and log *ES* denotes the natural logarithm of the energy saving indicator for monitoring progress towards energy efficiency targets of Europe 2020 strategy. As usual, $\varepsilon_{i,t}$ is the error term[5].

The variable *RENEWS* may be considered as an estimate of the indicator described in Directive 2009/28/EC (OJ L 140)[6]. The variable *RENEWG* (the ratio between the electricity produced from renewable energy sources and the gross national electricity consumption plus electricity imports, minus exports) measures the contribution of electricity produced from renewable energy sources to the national electricity consumption. The variable *ES* is implemented by Directive 2012/27/EU on energy efficiency (OJ L 315)[7]. Under the Directive, all EU member states are required to use energy more efficiently at all stages of the energy chain from its production to its final consumption. The indicator of *MI* is the ratio between the gross inland consumption of energy and the GDP and measures the energy consumption of an economy and its overall energy efficiency.

Real GDP growth rate is the final result of the production activity of resident producer units. The squared real GDP growth rate is a measure that aims to capture the changes in environmental indicators trend across national economies (Fotis et al. 2017, p 75). It is defined as the value of all goods and services produced less the value of any goods or services used in their creation. In this paper we use the percentage ratio of real GDP growth rate rather than other measures of income utilised in previous literature since it allows comparisons of the dynamics of economic development both over time and between economies of different sizes and the

[4] The country specific terms α_i in Eq. 1 captures all fixed effects inherent in each member state national economy which are either not considered in the empirical model or not directly observed. The error term $\varepsilon_{i,t}$ encompasses random effects which are not considered in the empirical model.

[5] All the variables are measured in MWh at 2005 constant prices for all the countries under scrutiny and are deflated by the annual average rate of change of Harmonised Index of Consumer Prices (HICP).

[6] Directive 2009/28/EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC.

[7] Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC.

computed volume changes are imposed on the level of a reference year and therefore growth rate is not inflated by price movements[8].

2.2 Method of estimation

In order to allow for the dynamic aspects in our empirical models we investigate our main research questions by using dynamic panel data techniques such as PGMM estimators attributed to Arellano and Bond (1991)[9] and Arellano and Bover (1995)/Blundell and Bond (1998)[10]. The DPGMM estimator by Arellano and Bond (1991) is also known as a two – step difference GMM (DIF-GMM) where the lagged levels of the regressors are instruments for the equations in first differences. The DPGMM estimator by Arellano and Bover (1995)/Blundell and Bond (1998) is also known as the System GMM estimator (SYS-GMM), since it combines regression in first differences with the original equation, included by further instrumental variables (Polemis, 2016). Both estimators (DIF-GMM & SYS-GMM) are designed to deal with small T and large N panels, that is, few time periods and many individual units (cross sections). Recall that in this paper we deal with a short T dynamic panel data ($T = 9$ and $N = 19$).

According to Arellano and Bond (1991) and Arellano and Bover (1995)/Blundell and Bond (1998) α_i and $\varepsilon_{i,t}$ are independently distributed across i, $\varepsilon_{i,t}$ has zero mean and it is independent over t and i. Also, it is assumed that $E(E_{i,1,}\varepsilon_{i,t}) = 0$ for $i = 1 \ldots N$ and $t = 2 \ldots T$. The last assumption concerning the initial conditions of environmental indicators in conjunction with the assumptions regarding α_i and $\varepsilon_{i,t}$ suffice for a consistent estimation of Eq. 1 using DPGMM estimators for $T \geq 3$.

3. Data

In this paper we use data from 2005 to 2013 to estimate, except from the growth effect, the pure effect of "20-20-20" targets on environmental pollution. The econometric estimations are based on pooled time-series cross-section yearly (panel) data sets for EU19 countries (EUROZONE) (T = 9, N = 19) covering the above-mentioned period. Each of the series corresponds to Eurozone countries and are from the Eurostat database (http://ec.europa.eu/eurostat/web/energy/data). The reason for using panel data sets so as to investigate possible cointegrating vectors instead of time series analysis is that residual based cointegration tests are known to have low power and are subject to normalization problems. Since economic time series are typically short and there are difficulties in obtaining reliable time-series data of sufficient length, it is desirable to exploit panel data in order to draw sharper inferences (Fotis et al. 2017; Polemis and Dragoumas, 2013). Besides, cross-section data suffers from assuming that the same characteristics (i.e. structure of the markets, degree of regulation, etc.) apply to all national economies. Table 1 provides the main statistics for the dependent and the independent variables in Eq. 1.

4. Empirical results

4.1 Stationarity and cointegration of the variables

Given the relatively short span of the cross section element (n = 9), all the commonly used unit root tests separately to each country may have low power, (Christopoulos and Tsionas, 2003). Thus our results for the stationarity properties of the data could be seriously misguided. An increase in the power of individual unit root tests can be achieved by pooling individual time series and performing panel unit root tests (Banerjee, 1999).

[8] See also Fotis et al. (2017).
[9] See, *inter alia*, Polemis and Fotis (2013).
[10] See also Holtz-Eakin et al. (1988).

Table 1. Main statistics of Environmental pollutants (in logs), Real Gross Domestic Product growth rate and Control variables (in logs): EUROZONE countries (2005 − 2013)

	Environmental pollutants					*Control variables*			*GDP Growth rate*
	SO_2	*NO_X*	*NMVOC*	*GGE*	*ES*	*RENEWS*	*RENEWG*	*MI*	*I*
Mean	4.70	5.14	5.00	4.73	1.17	0.97	1.11	2.27	1.23
St Dev	0.67	0.63	0.68	0.69	0.70	0.46	0.56	0.19	4.24
Min	3.10	3.56	3.41	3.47	-0.41	-0.72	-1	1.92	-14.67
Max	6.11	6.20	6.13	5.99	2.34	1.57	1.83	2.74	10.88
Variance	0.46	0.40	0.47	0.48	0.49	0.21	0.36	0.04	18.01
Skewness	-0.17	-0.05	-0.33	0.08	-0.18	-1.47	-1.34	0.76	-0.80
Kurtosis	2.50	2.27	2.72	1.94	2.40	6.18	2.59	2.89	5.12

Notes: SO_2: Sulphur oxides, *NO_X*: Nitrogen oxides, *NMVOC*: Non-methane volatile organic compounds, *GGE*: Greenhouse Gas Emissions (CO_2 equivalent), *MI*: Energy Intensity, *RENEWG*: The ratio between the electricity produced from renewable energy sources and the gross national electricity consumption (% of gross electricity consumption), *RENEWS*: Share of renewable energy in gross final energy consumption (%), *ES*: Energy saving from Primary Energy Consumption, *I*: Real GDP Growth Rate.
Source: Author's elaboration of data from European Commission, Eurostat, European Environment Agency (EEA), (http://ec.europa.eu/eurostat/web/energy/data).

To test for the existence of a unit root in a panel data setting, we have used various econometric tests, such as Breuting (2000) t-test, Im et al. (2003) W-test, Harris and Tzavalis (1999) and Fisher type tests (Maddala and Wu, 1999; Choi, 2001). In all the above tests the null hypothesis is that of a unit root. The W-test is based on the application of the ADF test to panel data, and allows for heterogeneity in both the constant and slope terms of the ADF regression. The Fisher type tests (ADF and PP tests) under the null hypothesis are distributed as χ^2 with degrees of freedom twice the number of cross-section units. From the estimated results we observe that the null-hypothesis of a unit root cannot be rejected at 5% critical value for all of the relevant variables. In other words they are integrated of order one including a deterministic component (intercept).

The next step is to examine if there is a cointegrated relationship between the non-stationary variables of the models. The reason for using cointegration techniques is that nonstationary time series result to spurious regressions and hence do not allow statistical interpretation of the estimations. For this purpose we apply the Fisher type test (Johansen, 1992; Madalla and Wu, 1999). This method allows us to examine whether there is a long-run co-movement of the variables. The maximum-likelihood eigenvalue statistics indicate that the null hypothesis (no cointegration) is rejected at 1% level for all the sample countries. The estimated results of the said tests and the estimated likelihood ratio tests depict that there is (at least) one cointegration vector for each model[11].

4.2 Empirical evidences from the EUROZONE

Table 2 presents the DIF-GMM and SYS-GMM parameter estimates of Eq. 1 regarding the EUROZONE. The parameter estimates of EKC hypothesis (*I, I^2 and I^3*) are almost all highly statistically significant and the whole estimates are robust given that Eq. 1 represents structural and not spurious long-run relation. Standard errors of GMM parameter estimates are asymptotically robust to heteroskedasticity and have been found to be more reliable for finite sample inference than GMM standard errors.

[11] The estimated results of the employed unit root tests and Fisher cointegration technique are given in Appendix A (Tables A1 and A2).

Table 2. Estimation results from the EUROZONE: DIF & SYS-GMM methodology[a] (2005 − 2013)

Ind. Var.[b]	*DIF – GMM* *Dep. Var.*[c]				*SYS – GMM* *Dep. Var.*[c]			
	SO_2	NO_X	*NMVOC*	*GGE*	SO_2	NO_X	*NMVOC*	*GGE*
c^d	1.37 (1.03)	3.32** (1.69)	0.67 (0.82)	-1.23*** (0.74)	-0.43 (0.56)	0.95 (0.81)	0.21*** (0.13)	-0.28 (0.26)
E_{t-1}	0.49* (0.09)	-0.02 (0.19)	0.71* (0.14)	0.38* (0.11)	0.92* (0.06)	0.31** (0.14)	0.90* (0.02)	0.65* (0.08)
E_{t-2}	-	0.19*** (0.10)	-	0.23** (0.11)	-	0.43* (0.06)	-	0.34* (0.08)
I	0.01* (0.00)	0.01*** (0.00)	0.01*** (0.00)	0.01* (0.00)	0.01* (0.00)	0.00 (0.00)	0.01* (0.00)	0.01* (0.00)
I^2	-0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)
I^3	-0.01* (0.00)	-0.00 (0.00)	-0.00 (0.00)	0.00 (0.00)	-0.01 (0.00)	-0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)
ES	0.25 (0.23)	0.20 (0.54)	0.24 (0.21)	0.54** (0.26)	0.06** (0.03)	0.23 (0.18)	0.10* (0.03)	-0.00 (0.06)
RENEWS	-0.09* (0.03)	0.01 (0.07)	0.01 (0.03)	-0.06** (0.03)	-0.03*** (0.02)	-0.04** (0.02)	0.01 (0.00)	-0.03 (0.03)
RENEWG	-0.01* (0.00)	-0.00 (0.00)	-0.00 (0.00)	-0.02* (0.00)	-0.00 (0.00)	-0.00 (0.00)	0.00*** (0.00)	-0.01* (0.00)
MI	0.41 (0.49)	0.36 (0.37)	0.21 (0.15)	1.04* (0.23)	0.04 (0.07)	0.09** (0.04)	0.06 (0.04)	0.13*** (0.07)
Wald chi^2	*646.11* (0.00)*	*273.05* (0,00)*	*106028* (0,00)*	*400.63* (0,00)*	*30310.46* (0.00)*	*8295.17* (0,00)*	*8487.07* (0,00)*	*5854.82* (0,00)*
No of Instruments	*86*	*79*	*36*	*32*	*117*	*107*	*117*	*60*
Max lags	3	*3*	*1*	*1*	*3*	*3*	*3*	*1*

Notes: [a] One step results in STATA13, [b] Independent variables (in logs) (except from Real GDP growth rate), [c] Dependent variables (in logs), [d] c denotes the constant term. The numbers in parentheses of the parameter estimations refer to the *Robust Standard Errors* (*heteroskedasticity consistent asymptotic standard errors*). The italic numbers in parentheses of the Wald chi^2 estimations refer to the p- values of the individually significance tests.
Significant at *1% **5% and ***10% respectively.
Source: Authors' elaboration of data from European Commission, Eurostat, European Environment Agency (EEA), (http://ec.europa.eu/eurostat/web/energy/data).

The empirical results from Table 2 reveal that within EUROZONE there exists a positive relationship between real per capita GDP growth rate and pollution. The non statistically significant parameter estimates of coefficients of income (I^2 and I^3) indicate that the EKC hypothesis does not exist in the EUROZONE during the period from 2005 to 2013.

The estimation of coefficient β in Eq. 1 (E_{t-1}) is always highly statistical significant and smaller than 1 for all the dependent variables employed within the EUROZONE. For instance, the highest significant estimate is 0.92 under DIF-GMM and 0.31 under SYS-GMM. We also estimate the dependent variable with two lags in the right hand side of Eq. 1, E_{t-2}, since it is found to be (highly) statistical significant in all the empirical models employed. This result strengthens the importance of the inclusion of the lagged dependent variable in the right hand side of Eq. 1[12]. Energy intensity (*MI*) positively affects all the environmental pollutants. The empirical results reveal that in EUROZONE energy intensity mostly affects GGE (CO_2 equivalent) emissions. For instance, an increase of energy intensity by 1% causes almost 0.1% increase of GGE (CO_2 equivalent) emissions (SYS-GMM), while under DIF-GMM the corresponding response of SO_2 emissions is almost the same.

Energy saving has also positive effect on environmental pollutants, revealing a negative effect on pollution. However, the empirical model, in which the parameter estimate of RENEWG is statistical significant (see the models with SO_2 and GGE dependent variables under DIF-GMM and SO_2 and NO_X dependent variables under SYS-GMM), emissions from almost all the environmental pollutants are eliminated by the increase of the share of renewable energy in gross final energy consumption (RENEWS) and by the effect of electricity generated from renewable sources of gross electricity consumption (RENEWG) on environmental pollutants.

5. Concluding remarks

The estimated results of this paper suggest the non existence of EKC hypothesis. The squared and cubic terms of economic growth are found to be not statistically significant and the obtained results suggest the existence of a positive monotonic pattern between pollution and real per capita GDP growth rate. These results are not surprising since they agree with the empirical investigations by Mazur et al. (2015), Baycan (2013), Iwata et al. (2011), Marrero (2010), Martínez-Zarzoso et al. (2007), Azomahou et al. (2006), who find increasing or non-inverted U patterns between economic growth and pollution.

The empirical findings also indicate that the use of renewable sources of energy negatively affects environmental pollutants. The more the renewable energy we use the less the air pollution. However, energy saving and energy intensity contribute to more air pollution. The share of electricity produced from renewable energy sources to the national electricity consumption contributes to the elimination of emissions, but a more pronounced effect is revealed by the contribution of the share of renewable energy in gross final energy consumption. Renewable energy should continue to be at the core of Europe's energy policy and the implementation of the recent update by the European Commission regarding the 30% energy efficiency target for 2030 must be the paradigm for the future.

Further research opportunities on this topic are essential for improving the estimated results. For this purpose new research should be directed towards the enlargement of the sample under examination. For instance, how our results differ if we analyse the effect of renewable energy use and economic growth on pollution within EU28 or EU34 member states? Do the expansion of EU affects the European energy policy and in which direction? Upon the empirical results how can we improve the policy mixture underlying European Commission's 30% energy efficiency target for 2030? Moreover, the discussion for the origin of the pollution (local or global

[12] However, when we estimate the dependent variable with more than 2 lags in the right hand side of Eq. 1 (E_{t-1}, $i \geq 3$), the estimated coefficients are found to be statistical insignificant in all the empirical models employed.

pollution) and the different amounts of CO_2 emitted across member states is a quite interesting research topic for the future. If pollution is transboundary problem cooperation among member states is needed for eliminating the greenhouse effect and improving the living standards of their people.

Since energy saving contributes to more air pollution this research also reveals a very critical point for further elaboration: do all EU member states use energy more efficiently at all stages of the energy chain from its production to its final consumption or EC has to reconsider the said indicator for monitoring more efficiently progress towards energy efficiency targets of Europe 2020 and 2030 strategies?

Last but not least, disaggregated results for each country of the EUROZONE are of great importance for policy makers. Therefore, time-series analysis should be in the future agenda of the researchers in order to disaggregate the effect of national environmental policies on pollution.

References

Ajmi, A.N., Hammoudeh, S., Nguyen, K.N. and Sato, J.R. (2015) A new look at the relationships between CO2 emissions, energy consumption and income in G7 countries: the importance of time variations, *Energy Economics*, 49, 629–638.

Anastasia, V. (2015) The casual relationship between GDP, exports, energy consumption and CO2in Tayland and Malaysia, *International Journal of Economic Perspectives*, 9(4), 37-48.

Apergis, N. (2016) Environmental Kuznets Curves: New evidence on both panel and country-level CO_2 emissions, *Energy Economics*, 54, 263-271.

Arellano, M. and Bond, S. (1991) Some Tests of Specification for Panel Data: Monte Carlo Evidence and an Application to Employment Equations, *Review of Economic Studies*, 58, 277-297.

Arellano, M. and Bover, O. (1995) Another look at the Instrumental variable estimation of Error Component Models, *Journal of Econometrics*, 68, 29-51.

Azomahou, T., Laisney, F. and Van Phu, N. (2006) Economic development and CO_2 emissions: a nonparametric panel approach, *Journal of Public Economics*, 90, 1347–1363.

Baltagi, H.B. and Kao, C. (2001) Nonst*ationary Panels*, *Cointegration in Panels and Dynamic Panels: A Survey*, in Baltagi, B.H., Fomby, T.B. and Hill, R.C. (Eds.): Nonstationary Panels, Panel Cointegration, and Dynamic Panels. Volume 15, Emerald Insight, pp. 7-51.

Banerjee, A. (1999) Panel Unit Root Tests and Cointegration: An Overview, *Oxford Bulletin of Economics and Statistics*, 61, 607-629.

Baycan, O.I. (2013 Air Pollution, Economic Growth, and the European Union Enlargement, *International Journal of Economics and Finance*, 5(12), 121-126.

Bernard, J-T., Gavin, M. Khalaf, L. and Voia, M. (2014) Environmental Kuznets Curve: Tipping Points, Uncertainty and Weak Identification, *Environmental and Resource Economics*, 60(2), 285-315.

Blundell, R. and Bond, S. (1998) Initial restrictions and moment rstrictions in dynamic panel data models, *Journal of Econometrics*, 87, 115-143.

Breitung, J. (2000) *The Local Power of Some Unit Root Tests for Panel Data*, in B. Baltagi (ed.), Nonstationary Panels, Panel Cointegration, and Dynamic Panels, Advances in Econometrics, Vol. 15, Amsterdam, 161-178.

Choi, I. (2001) Unit root tests for panel data, *Journal of International Money and Finance*, 20(2), 249-272.

Christopoulos, D.K. and Tsionas, E.G. (2003) A Reassessment of Balance of Payments Constrained Growth: Results from Panel Unit Root and Panel Cointegration tests, *International Economic Journal*, 7, 39 – 54.

Dinda, S. (2004) Environmental Kuznets Curve Hypothesis: A Survey, *Ecological Economics*. 49, 431-455.

Fotis, P., Karkalakos, S. and Asteriou, D. (2017). The relationship between energy demand and real GDP growth rate: the role of price asymmetries and spatial externalities within 34 countries across the globe, *Energy Economics*, 66, 69-84.

Galeotti, M., Manera, M. and Lanza, A. (2009) On the Robustness of Robustness Checks of the Environmental Kuznets Curve Hypothesis, *Environmental and Resource Economics*, 42, 551-574.

Grossman, G.M. and Krueger, A.B. (1995) Economic Growth and the Environment, *Quarterly Journal of Economics*, 110, 353-377.

Harris, D.F. Tzavalis, E. (1999) Inferences for unit roots for dynamic panels where the time dimension is fixed, *Journal of Econometrics*, 91(2), 201-226.

Holtz-Eakin, D. and Selten, T.M. (1995) Stoking the fires: CO_2 emissions and Economic Growth, *Journal of Public Economics*, 57, 85-101.

Im, K. Pesaran, M.H. Shin, Y. (2003) Testing for Unit Roots in Heterogeneous Panels, *Journal of Econometrics*, 115, 53-74.

Istaiteyeh, R.M.S. (2016) Casuality Analysis between Electricity consumption and Real GDP: Evidence from Jordan, *International Journal of Economic Perspectives*, 10(4), 526-540.

Iwata, H., Okada, K. and Samreth, S. (2011) A note on the Environmental Kuznets Curve for CO_2: a pooled mean group approach, *Applied Energy*, 88, 1986–1996

Johansen, S. (1992) Cointegration in partial systems and the efficiency of single-equation analysis, *Journal of Econometrics*, 52, 389-402.

Kalaysi, S. and Koksal, C. (2015) The relationship between China's Airway Freight in Terms of Carbon-Dioxide Emission and Export Volume, *International Journal of Economic Perspectives*, 9(4), 60-68.

Kapusuzoglou, A. (2014) Casuality relationships between carbon dioxide emissions and economic growth: Results from a multi-country study, *International Journal of Economic Perspectives*, 8(2), 5-15.

Kuznets, S. (1955) Economic growth and income inequality, *American Economic Review*, 45(1), 1–28.

López-Menéndez, A., Pérez, R. and Moreno, B. (2014) Environmental costs and renewable energy: Re-visiting the Environmental Kuznets Curve, *Journal of Environmental Management*, 145, 368-373.

Maddala, G.S. and Wu, S. (1999) A Comparative Study of Unit Root Tests With Panel Data and a New Simple Test, *Oxford Bulletin of Economics and Statistics*, 61, 631–652.

Markandya, A., Golub, A. and Pedroso-Galinato, S. (2006) Empirical Analysis of National Income and SO_2 Emissions in Selected European Countries, *Environmental and Resource Economics*, 35, 221-257.

Martínez-Zarzoso, I., Bengochea-Morancho, A. and Morales-Lage, R. (2007) The impact of population on CO2 emissions: evidence from European countries, *Environmental and Resource Economics*, 38, 597-512.

Mazur, A., Phutkaradze, Z. and Phutkaradze, J. (2015) Economic Growth and Environmental Quality in the European Union Countries – Is there Evidence for the Environmental Kuznets Curve?, *International Journal of Management and Economics*, 45, 108-126.

Marrero, A.G. (2010) Greenhouse gases emissions, growth and the Energy mix in Europe, *Energy Economics*, 32, 1356-1363.

Panayotou, T. (2000) *Economic Growth and the Environment*, CID Working Paper No. 56, Cambridge, MA: Center for International Development at Harvard University.

Panayotou, T. (1995) Environmental degradation at Different stages of Economic Development, in Iftikhar, A. and Doeleman, A.J. (Eds.): B*eyond Rio: The Environmental Crisis* *and Sustainable livelihoods in the Third World*, ILO Study Series New York: St. Martin's Press, 13-36.

Polemis, L.M. (2016) New evidence on the impact of structural reforms on electricity sector performance, *Energy Policy*, 92, 420-431.

Polemis, L.M. and Dagoumas, S.A. (2013) The Electricity Consumption and Economic Growth Nexus: Evidence from Greece, *Energy Policy*, 62, 798-808.

Polemis, L.M. and Fotis, P. (2013) Do gasoline prices respond asymmetrically in the euro zone area? Evidence from cointegrated panel data analysis, *Energy Policy*, 56, 425-433.

Richmond, A. and Kaufmann, R. (2006) Is there a turning point in the relationship between income and energy use and/or carbon emissions?, *Ecological Economics*, 56, 176–189.

Rodriguez, M., Pena-Boguete, Y. and Pardo-Fernardez, J.C. (2016). Revisiting Environmental Kuznets Curves through the energy price lens, *Energy* Policy, 95, 32-41.

Sephton, P. and Mann, J. (2016) Compelling Evidence of an Environmental Kuznets Curve in the United Kingdom, *Environmental and Resource Economics*, 64(2), 301–315.

Sephton, P. and Mann, J. (2013) Further evidence of the environmental Kuznets curve in Spain, *Energy Economics*, 36, 177–181.

Stern, D.I. (2014) The environmental Kuznets curve: A primer, *Centre for Climate Economic & Policy*, Working Paper, 1404.

Appendix A
Supplementary tables

Table A1. Panel unit root test results

	Breuting-t test[a]	*Im, Pesaran and Shin W-test*[a]	*Harris & Tzavalis*[b]	*ADF–Fisher Chi-square*[a]	*PP–Fisher Chi-square*[a]
Variable[c]					*Levels*
SO_2	0.34	0.69	0.82	42.24	53.63
NO_X	-0.83	-0.30	0.60	36.21	63.33
NMVOC	2.24	0.61	0.84	65.88	76.40
GGE	-0.16	-0.73	0.64	56.40	66.57
ES[d]	1.14	-0.60	0.57	86.02	74.93
RENEWS	1.45	4.09	0.96	23.26	28.74
RENEWG	3.80	-0.11	1.02	22.29	26.03
MI	-1.31	-0.38	0.64	78.63	84.74
I	0.26	-0.38	-[e]	68.62	69.34[c]
Variable			*First differences*		
$\Delta(SO_2)$	-3.73^*	-4.36^*	-0.09^*	126.77^*	160.48^*
$\Delta(NO_X)$	-5.70^*	-6.01^*	-0.56^*	155.90^*	238.30^*
Δ(NMVOC)	-2.83^*	-4.20^*	-0.06^*	123.27^*	134.08^*
Δ(GGE)	-5.04^*	-6.38^*	-0.23^*	162.62^*	249.98^*
Δ(ES)	-6.94^*	-9.52^*	-0.57^*	224.41^*	381.44^*
Δ(RENEWS)	-6.94^*	-7.20^*	-0.00^*	171.02^*	212.58^*
Δ(RENEWG)	-6.01^*	-5.24^*	0.11^*	141.62^*	182.65^*
Δ(MI)	-2.60^*	-5.74^*	-0.21^*	161.86^*	102.05^*
Δ(I)	-7.37^*	-5.45^*	-[e]	147.47^*	98.87^*

Notes: [a]The lag lengths were selected by using Akaike, Schwarz & Modified Hannan-Quinn criteria with an individual intercept as an exogenous regressor, [b]Small sample adjusted to T without time trend, [c]In logs except from real GDP growth rate, [d]The lag lengths were selected by using Modified Akaike Criterion, [e]Harris & Tzavalis unit root test applies only in strongly balanced panel data sets. The real per capita GDP growth rate for the EUROZONE sample set contains 170 instead of 171 (n=19, T=9) observations since the data for Lithuania in 2005 is not available. Therefore, the unit root test for *I* (*Real GDP Growth Rate*) couldn't be estimated.
Significant at *1%.
SO_2: Sulphur oxides (Total sectors of emissions for the national territory - Tonnes), *NO_X*: Nitrogen oxides (Total sectors of emissions for the national territory - Tonnes), *NMVOC*: Non-methane volatile organic compounds (Total sectors of emissions for the national territory - Tonnes), *GGE*: Greenhouse Gas Emissions (CO_2 equivalent - All sectors and indirect CO_2 - Thousand tonnes), *MI*: Energy Intensity (the ratio between the gross inland consumption of energy and the GDP - in kgoe per 1 000 EUR), *RENEWG*: The ratio between the electricity produced from renewable energy sources and the gross national electricity consumption (% of gross electricity consumption), *RENEWS*: Share of renewable energy in gross final energy consumption (%), *ES*: Energy saving from Primary Energy Consumption (million tonnes of oil equivalent, TOE), *I* (*Real GDP Growth Rate*): Annual growth rate of GDP volume (percentage change on previous year).
Source: Authors' elaboration of data from European Commission, Eurostat, European Environment Agency (EEA), (http://ec.europa.eu/eurostat/web/energy/data).

Table A2. Johansen Fisher panel cointegration test results[a]

	Johansen Fisher Panel Cointegration Test	
Series	*Trace statistic*	*Maximum eigenvalues*
SO_2 - I	392.2^* [r=0], 145.5^* [r=1]	368.5^* [r=0], 145.5^* [r=1]
$SO_2 – I^2$	414.9^* [r=0], 145.1^* [r=1]	397.1^* [r=0], 145.1^* [r=1]
$SO_2 – I^3$	344.5^* [r=0], 131.0^* [r=1]	315.2^* [r=0], 131.0^* [r=1]
SO_2 - ES	398.2^* [r=0], 159.4^* [r=1]	369.4^* [r=0], 159.4^* [r=1]
SO_2 - RENWES	435.7^* [r=0], 142.9^* [r=1]	407.5^* [r=0], 142.9^* [r=1]
SO_2 - RENWEG	314.9^* [r=0], 138.2^* [r=1]	272.5^* [r=0], 138.2^* [r=1]
SO_2 - MI	411.8^* [r=0], 193.8^* [r=1]	361.5^* [r=0], 193.8^* [r=1]
NO_X - I	317.9^* [r=0], 104.0^* [r=1]	300.7^* [r=0], 104.0^* [r=1]
$NO_X – I^2$	337.1^* [r=0], 143.7^* [r=1]	353.3^* [r=0], 143.7^* [r=1]

$NO_X – I^3$	259.0* [r=0], 100.8* [r=1]	242.2* [r=0], 100.8* [r=1]
NO_X - ES	388.6* [r=0], 114.4* [r=1]	375.9* [r=0], 114.4* [r=1]
NO_X - RENWES	291.5* [r=0], 101.6* [r=1]	289.4* [r=0], 101.6* [r=1]
NO_X - RENWEG	194.8* [r=0], 90.27*, b [r=1]	169.5* [r=0], 90.27* [r=1]
NO_X - MI	213.5* [r=0], 110.4* [r=1]	181.7* [r=0], 110.4* [r=1]
NMVOC - I	412.3* [r=0], 147.7* [r=1]	387.2* [r=0], 147.7* [r=1]
NMVOC – I^2	408.8*, c [r=0], 112.0*, c [r=1]	397.4*, c [r=0], 112.0*, c [r=1]
NMVOC – I^3	292.1* [r=0], 120.3* [r=1]	226.2* [r=0], 120.3* [r=1]
NMVOC - ES	292.4* [r=0], 176.1* [r=1]	229.0* [r=0], 176.1* [r=1]
NMVOC - RENWES	4232.* [r=0], 177.7* [r=1]	312.8* [r=0], 177.7* [r=1]
NMVOC - RENWEG	2657.* [r=0], 147.3* [r=1]	207.8* [r=0], 147.3* [r=1]
NMVOC - MI	4232.* [r=0], 164.8* [r=1]	312.8* [r=0], 164.8* [r=1]
GGE - I	369.2*, c [r=0], 95.51*, c [r=1]	359.4*, c [r=0], 95.51*, c [r=1]
GGE – I^2	315.4*, c [r=0], 111.2*, c [r=1]	297.5*, c [r=0], 111.2*, c [r=1]
GGE – I^3	4493.* [r=0], 215.7* [r=1]	328.4* [r=0], 215.7* [r=1]
GGE - ES	4234.* [r=0], 190.3* [r=1]	314.1* [r=0], 190.3* [r=1]
GGE - RENWES	3708.* [r=0], 176.9* [r=1]	278.7* [r=0], 176.9* [r=1]
GGE - RENWEG	4230.* [r=0], 166.2* [r=1]	310.0* [r=0], 166.2* [r=1]
GGE - MI	5018.* [r=0], 196.0* [r=1]	363.9* [r=0], 196.0* [r=1]
SO_2 - NO_X	4758.* [r=0], 156.8* [r=1]	348.2* [r=0], 156.8* [r=1]
SO_2 - NMVOC	2924.* [r=0], 154.3* [r=1]	229.0* [r=0], 154.3* [r=1]
SO_2 - GGE	3972.* [r=0], 207.4* [r=1]	297.1* [r=0], 207.4* [r=1]
NO_X - NMVOC	3972.* [r=0], 161.1* [r=1]	297.1* [r=0], 161.1* [r=1]
NO_X - GGE	2662.* [r=0], 220.0* [r=1]	211.9* [r=0], 220.0* [r=1]
NMVOC - GGE	3972.* [r=0], 136.3* [r=1]	297.1* [r=0], 136.3* [r=1]
$I – I^2$	3446.* [r=0], 178.3* [r=1]	261.6* [r=0], 178.3* [r=1]
$I – I^3$	4232.* [r=0], 256.3* [r=1]	312.8* [r=0], 256.3* [r=1]
$I^2 – I^3$	3446.* [r=0], 260.4* [r=1]	261.6* [r=0], 260.4* [r=1]
I – ES	5018.* [r=0], 167.0* [r=1]	363.9* [r=0], 167.0* [r=1]
I – RENWES	2921.* [r=0], 206.2* [r=1]	226.2* [r=0], 206.2* [r=1]
I – RENWEG	3966.* [r=0], 138.2* [r=1]	291.6* [r=0], 138.2* [r=1]
I – MI	3184.* [r=0], 182.8* [r=1]	244.6* [r=0], 182.8* [r=1]
ES - RENEWS	4494.* [r=0], 159.2* [r=1]	329.8* [r=0], 159.2* [r=1]
ES - RENEWG	5016.* [r=0], 122.5* [r=1]	361.1* [r=0], 122.5* [r=1]
ES - MI	4759.* [r=0], 357.1* [r=1]	349.6* [r=0], 357.1* [r=1]
RENEWS - RENEWG	4230.* [r=0], 213.9* [r=1]	310.0* [r=0], 213.9* [r=1]
RENEWS - MI	3708.* [r=0], 157.0* [r=1]	278.7* [r=0], 157.0* [r=1]
RENEWG - MI	4754.* [r=0], 144.6* [r=1]	344.0* [r=0], 144.6* [r=1]

Notes: [a] Null hypothesis implies absence of cointegration, while r denotes the number of cointegrating equations with intercept and deterministic trend in CE, no deterministic trend in VAR, [b] No intercept or trend in CE or VAR, [c] Intercept (no trend) in CE or VAR. Significant at *1%.

SO_2: Sulphur oxides (Total sectors of emissions for the national territory - Tonnes), *NO_X*: Nitrogen oxides (Total sectors of emissions for the national territory - Tonnes), *NMVOC*: Non-methane volatile organic compounds (Total sectors of emissions for the national territory - Tonnes), *GGE*: Greenhouse Gas Emissions (CO_2 equivalent - All sectors and indirect CO_2 - Thousand tonnes), *MI*: Energy Intensity (the ratio between the gross inland consumption of energy and the GDP - in kgoe per 1 000 EUR), *RENEWG*: The ratio between the electricity produced from renewable energy sources and the gross national electricity consumption (% of gross electricity consumption), *RENEWS*: Share of renewable energy in gross final energy consumption (%), *ES*: Energy saving from Primary Energy Consumption (million tonnes of oil equivalent, TOE), *I* (*Real GDP Growth Rate*): Annual growth rate of GDP volume (percentage change on previous year).

Source: Authors' elaboration of data from European Commission, Eurostat, European Environment Agency (EEA), (http://ec.europa.eu/eurostat/web/energy/data).