Sustainable development, environmental policy and renewable energy use: A dynamic panel data approach

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Sustainable development, environmental policy and renewable energy use: A dynamic panel data approach

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Abstract

The aim of this paper is to cast light on the relationship between sustainable development environmental policy and renewable energy use. We utilize a dynamic GMM approach over a panel of 34 European Union (EU) countries spanning the period 2005-2013. Our findings reveal a positive monotonic relationship between development and pollution. Energy saving positively affects environmental degradation, while energy intensity increases air pollution. Our findings imply important policy implications to policy makers toward sustainability. Despite the fact that the Europe "*20-20-20*" climate and energy package strategy seems to be achieved, the recently adopted Energy Roadmap 2050 must be updated on regular basis in order to be effectively implemented and monitored by government officials and firms' stakeholders. Therefore, we argue that EU countries must increase the use of new technology and renewable energy capacity in order to align environmental policies towards more efficient energy use and sustainable development among the EU periphery.

Keywords: Sustainable Development; Environmental Policy; Renewable Energy Sources; Dynamic Panel Data Analysis

JEL classification C23; L16; O11; Q56

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1 Introduction

In 2007 all EU member states adopted a new law intended to reduce at least 20% greenhouse gas emissions and to achieve 20% share of renewable energies in EU energy consumption by 2020. Within this framework, the European Commission (EC) aims to achieve the "20-20-20" targets, including a 20% reduction in EU greenhouse gas emissions from 1990 levels, a raise in the share of EU energy consumption produced from renewable resources to 20% and a 20% improvement in the EU's energy efficiency.

The motivation of this paper stems from the relationship between sustainable development and enviromental policy regarding pollution. It is mainly based on the Environmental Kuznets Curve hypothesis (Kuznets 1955; Shafik and Bandyopandhyay 1992; Grossman and Krueger 1995; Holtz-Eakin and Selten 1995)[2], which states that pollution rises with income at low income levels (*degradation of environmental quality*), but at a higher income level a turning point is reached and further development leads to lower pollution (Panayotou, 1995). An opposite line of reasoning states that the relationship between pollution and development is monotonically rising (Cole, 1999).

This paper empirically explores the relationship between environmental pollution, development and renewable energy consumption. It also explores the effect of environmental efficient indicators on environmental pollutants and draws valuable policy implications towards energy efficiency targets of Europe "20-20-20" strategy.[3] For these purposes we utilize two pooled time-series cross-section yearly (panel) data sets for EU34 countries (EU28, 5 candidates and Norway) and EU28 countries

[2] See also, inter alia, Dinda (2004), Richmond and Kaufmann (2006), Lopez-Menendez et al. (2014).
[3] In 2014 EU presented the new key achievements of its energy and climate policy framework (EU Energy Roadmap 2050, COM 2014, 15 final, p. 2). In this paper we focus on the "20-20-20" strategy on environmental pollution and growth.

covering the period from 2005 to 2013 and we employ Dynamic Panel Generalized Method of Moments (DPGMM) approaches to examine clustered patterns of environmental policy and sustainable development.

This paper contributes to the existing literature through various channels. On the one hand we extent the literature by exploring the effect of various energy efficiency indicators, such as the share of renewable energy in gross final energy consumption (RENWES), the electricity generated from renewable sources of gross electricity consumption (RENWEG) and energy saving from primary energy consumption (ES), 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.[4]

The empirical results reveal that development and environmental pollution exhibit a positive monotonic relationship, while renewable sources of energy negatively affects environmental policy towards pollution. The more the renewable energy we use the less the air pollution. Energy saving positively affects pollution, while energy intensity contributes to more air pollution.

The remainder of this paper is organized as follows. Section 2 reviews the literature and section 3 presents the data and descriptive statistics of the employed variables. Section 4 presents the empirical models and the used methodology and section 5 reports the empirical results. Lastly, section 6 discusses the empirical results and section 7 concludes and provides some policy implications that emerge from the empirical analysis.

[4] Lopez Menendez et al. (2014) examine the effect of energy efficient indicators on environmental pollutants by including renewable energy sources as explanatory variables in the empirical models within a static environment (panel data models with fixed and random effects).

2 Literature Review

The effect of energy efficient indicators and development on environmental pollutants has been studied for the European Union and its subsequent members.[5] The empirical results show a considerable heterogeneity between environmental and economic development variables. The main source of the divergence may be linked to the rate of productivity and nations' specific characteristics.

Particularly, at the EU level,[6] Alvarez, Marrero and Puch (2005) analyze EU15 countries, between 1990 and 2000 and reveal that air pollution, NO_X & SO_2, decreased in the 1990's in most EU countries. However, the empirical results concerning CO_2 reveal that income development does not play a critical role in environmental pollution. Richmond and Kaufmann (2006) state a positive monotonic relationship between development and carbon emissions, but there exists an inverted U-shaped relationship between the two of them if the effects of energy mix are included in the econometric model. Markandya et al., (2006) examine 12 Western European countries over a period of more than 150 years (1850-2001) and find an inverted U-shaped relationship between environmental pollution and income development. However, when they incorporate into their analysis environmental regulation (1972 - 2001) the empirical results show a less pronounced inverted U-shaped relationship between the two variables.

Coondoo and Dinda (2008) explore the relationship between the inter-country income inequality and CO_2 emissions for a sample of 88 (22 EU) countries over the period 1960 – 1990. The empirical results confirm that inter country income

[5] In this paper we focus on the presentation of literature review concerning the research within the EU. For a survey of the literature on an empirical and theoretical perspective see Bernard et al. (2014). For relevant studies prior to 2010 see Lopez-Menendez et al. (2014), Markandya et al., (2006), Galeotti et al. (2009), Kukla-Gryz (2006), Dinda (2004) and Stern (2004) Dögl and Behnam (2015). Panayotou (2000) has also given a critical overview of the research done from 1992 to 2000.
[6] See also Table A1 in the APPENDIX.

inequality has a significant effect on the mean emission for all the sample countries. Also, evidences in favour of existence of EKC hypothesis have been found for EU for the period 1966 onwards. Lee at al. (2009) explores the validity of EKC hypothesis for a sample of, *inter alia*, 19 EU countries over the period 1960 – 2000. They find evidence of the EKC hypothesis for CO_2 emissions in a global data set, middle-income, American and European countries. Atici (2009) confirms the existence of EKC relationship in Bulgaria, Hungary, Romania and Turkey, since CO_2 emissions per capita decrease from 1980 to 2002 as the per capita GDP increases. The author also states that energy use positively affects environmental pollution, while international openness of the economies has not facilitated the degree of it.

Marrero (2010) uses data on EU24 countries over the period from 1990 to 2006 and concludes that the EKC hypothesis does not hold for the EU24 countries. Acaravci and Ozturk (2010) examine EU19 countries over the period from 1965 to 2005 and state that the validity of EKC hypothesis holds only for Denmark and Italy. Jaunky (2011) uses the Blundell–Bond system generalized methods of moments (GMM) to test the EKC hypothesis for 36 high-developed (income) countries for the period 1980–2005 The author supports the existence of the EKC hypothesis for Malta, Oman, Portugal and the United Kingdom.

Iwata et al. (2011) explore a panel data analysis of 28 countries (17 EU countries) over the period 1960 – 2003 and show that CO_2 emissions increase monotonically in all countries under scrutiny, the effects of nuclear energy on CO_2 emissions are significantly negative and CO_2 emissions decrease and increase with income in OECD and non-OECD countries respectively. Donfouet et al. (2013) use data from EU countries over the period of 1961-2009 and present evidences regarding spatial EKC hypothesis. The authors find evidence of an inverted U-shaped relationship between

CO_2 emissions and development (per capita income) after controlling for spatial interdependence. Danaeifar (2014) uses spatial panel data model for 30 EU countries over the period of 1992-2008. The results confirm the existence of an inverse U-shaped relationship between development, global CO_2 emissions and local aerosols pollutants. Baycan (2013) examines the EKC relationship in EU25 countries over the period from 1995 to 2005. The empirical results show a statistically significant U-shaped EKC relationship between each of the air pollutants employed and per capita income development for EU15 and EU25 member countries.

Lopez-Menendez et al. (2014) explore EU27 countries over the period from 1996 – 2010. They use fixed and random effects panel models with additional explanatory variables related to the high renewable energy intensity (the proportion of electricity generated from renewable sources) in order to investigate the relationship between CO_2 emissions and development (per capita GPD). The empirical results show evidences of inverted-N shaped curve for the EU27 countries. 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. Chang et al. (2014) show that increased carbon emissions resulting from economic development cannot be outweighed by technological improves in environmental protection at different levels of economic development. The authors also state that industrial structure of economies under scrutiny plays a crucial role in lowering the degree of carbon emissions. Since this is associated with international activity and energy use, policy makers should evaluate all of them together in order to reduce environmental pollution.

Mazur et al. (2015) also use fixed and random effects panel models in order to explore the EKC hypothesis for a panel data on EU28 countries during the period 1992–2010. The empirical results do not support strong evidences in favor of EKC hypothesis within EU28 countries. However, they find evidences in favor of an inverted U-shaped relationship for EU18 countries. Ajmi et al. (2015) consider annual data from 1960 to 2010 on per capita for energy consumption, economic development (real GDP per capita) and CO_2 emissions for the G7 countries excluding Germany and claim 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. Apergis (2016) uses panel and time-series based methods of cointegration for a dataset of EU13 countries from 1960 to 2013. The empirical results are mixed both under panel or time-series techniques. However, when quantile cointegration is used the results support the validity of EKC hypothesis in the majority of the countries. Rodriguez et al. (2016) analyses a balanced panel data of EU13 countries, Japan and US over the period 1979-2004. They find a positive, but marginal decreasing relationship between CO_2 emissions and development (GDP per capita) and a relative decoupling between two variables.[7]

Halkos and Polemis (2017), argue that local (NO_X per capita emissions) and global (CO_2 per capita emissions) pollutants redefine the EKC hypothesis when financial development indicators are taken into consideration. They find that in the case of global pollution an N-shape relationship is evident both in static and dynamic framework with a very slow adjustment. Fotis and Pekka (2017) show that economic growth positively affects environmental pollutants within Eurozone. In a recent study Morse (2018) explores the relationship among environmental performance, as

[7] Table A2 in APPENDIX presents the main research regarding the effect of energy efficient indicators and Growth on environmental pollutants at the country level within EU.

represented by Environmental Performance Index (EPI2016) [8] , development (GDP/capita) and income inequality (Gini coefficient) over the period from 1995 to 2014. In general, the empirical results suggest that environmental performance increases with increasing development and declining Gini coefficients (less inequality).

3 Data and sample statistics

In this paper we use data from 2005 to 2013 to estimate the pure effects of "20-20-20" targets and development on environmental pollution. The econometric estimations are based on two pooled time-series cross-section yearly (panel) data sets for EU34 countries (EU28, 5 candidates and Norway) (T = 9, N = 34) and EU28 countries (T = 9, N = 28) covering the above mentioned period. The samples are from the Eurostat database.

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, it is desirable to exploit panel data in order to draw sharper inferences (Christopoulos and Tsionas, 2003, 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, while there are difficulties in obtaining reliable time-series data of sufficient length.

Proxies of Pollution, which is the dependent variable of this study, are presented by SO_2, NO_X and NMVOC, that is, Sulphur Oxides, Nitrogen Oxides and non-methane volatile organic compounds correspondingly. GGE presents Greenhouse Gas

[8] Mukherjee and Chakraborty (2013) use Environmental Performance Index (EPI2008) to explore the relationships among environmental quality, human and economic development and political and governance regimes through a cross-country framework of 146 countries in 2008.

Emissions (CO_2 equivalent). The energy efficiency targets are the share of renewable energy in gross final energy consumption ($RENEWS$), which denotes an indicator calculated on the basis of data covered by Regulation (EC) No 1099/2008 (OJ L 304, 14.11.2008).[9] This indicator may be considered as an estimate of the indicator described in Directive 2009/28/EC (OJ L 140, 5.6.2009, p. 16–62).[10] The indicator of electricity generated from renewable sources as a percentage of gross electricity consumption ($RENEWG$) is the ratio between the electricity produced from renewable energy sources (electricity generation from hydro plants, excluding pumping, wind, solar, geothermal and electricity from biomass/wastes) and the gross national electricity consumption (total gross national electricity generation from all fuels (including autoproduction), plus electricity imports, minus exports) for a given calendar year. It measures the contribution of electricity produced from renewable energy sources to the national electricity consumption.

The indicator of energy saving for monitoring progress towards "20-20-20" targets ($\log ES$) is implemented by Directive 2012/27/EU on energy efficiency (OJ L 315, 14.11.2012, p. 1–56).[11] The latter establishes a set of measures to help the EU reach its 20% energy efficiency target by 2020. 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 energy intensity (MI) is the ratio between the gross inland consumption of energy (the sum of the gross inland consumption of five energy types: coal, electricity, oil, natural gas and renewable

[9] Regulation (EC) No 1099/2008 of the European Parliament and of the Council of 22 October 2008 on energy statistics.
[10] 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.
[11] 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.

energy sources) and the Gross Domestic Product (GDP)[12] for a given calendar year. It is measured in kgoe per 1 000 EUR and measures the energy consumption of an economy and its overall energy efficiency (Shahbaz et al. 2013; Martínez-Zarzoso et al. 2007).[13]

Real GDP growth rate represents development. It is the final result of the production activity of resident producer units. It is defined as the value of all goods and services produced less the value of any goods or services used in their creation. The squared real GDP growth rate is a measure that aims to capture the changes in environmental indicators trend across national economies. It captures changes in production and consumption patterns which affect the impact of potential real GDP growth rate on environmental and comprises a measure of the economic activity. We use the percentage ratio of real GDP growth rate rather than other measures of income utilised in previous literature (such as income in physical units) since it allows comparisons of the dynamics of economic development both over time and between economies of different sizes and the computed volume changes are imposed on the level of a reference year and therefore development rate is not inflated by price movements (Table 1).[14]

[Insert Table 1 about here]

Figures 1 and 2 present mixed evidences concerning the relationship between environmental pollutants and development rate for the EU34 and EU28 countries during the period 2005-2013. Visual inspection of all figures supports a monotonic relationship between the variables under scrutiny. The majority of the sample countries exhibit high and low levels of positive development rate with low or at least

[12] The GDP figures are taken at chain linked volumes with reference year 2005.
[13] All the environmental pollutants and control variables consist of emissions from all sectors of the country's territory under scrutiny.
[14] See Fotis et al. (2017).

modest levels of environmental pollutants. These countries are Belgium, Czech Republic, Denmark, Estonia, Ireland, Croatia, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, Malta, Austria, Slovenia, Slovakia, Finland, Sweden, the UK and Norway.

[Insert Figure 1 about here]

However, there exist a group of countries which exhibit a positive monotonic relationship between environmental pollutants with respect to development rate. The group of these countries is divided into two samples: the first sample consists of countries associated with high levels of development such as Poland, Bulgaria and Romania and the second group of countries consists of countries associated with low levels of economic growth such as Germany, Netherlands, France and Spain.

Lastly, there exist 3 countries (Greece, Portugal and Italy) which exhibit negative real GDP growthdevelopment rates. Greece shows an almost double level of environmental pollutants with respect to the average level of EU34 countries and Italy exhibits the same level of environmental pollutants with the corresponding average level. On the contrary, Portugal exhibits low level of environmental pollutants with respect to the corresponding average value, but its development rate is much higher than the corresponding level in Italy and Greece.

[Insert Figure 2 about here]

The aforementioned figures 1 and 2 reveal that for some sample countries pollution shows a stable path with respect to their economic development. In other words, pollution increases in the initial level of growth, but remains at the same levels as growth continues to increase. For other countries pollution increases in the initial levels of growth and continues to increase as growth increases. Besides, we cannot find any point of return as the research in favor of EKC hypothesis claims.

Figure 3 presents the relationship between energy intensity (MI) and devlopment rate. It is evident from the aforementioned figure that there exist a group of countries that exhibit a positive monotonic relationship between MI and development, but also there exist a group of countries which reveal stable levels of energy intensity as development rate changes. This latter group of countries shows lower levels of economic growth than the former group of countries.

[Insert Figure 3 about here]

Four countries with the highest levels of development (Bulgaria, Czech Republic, Poland and Romania) exhibit high levels of energy intensity. As a matter of fact all of them show higher levels of MI than the corresponding mean level of EU34 and EU28 countries, while Bulgaria exhibits the highest level of energy intensity among all the countries under scrutiny.

4 Empirical framework and methodology

4.1 Empirical framework

Most of the researchers explore the relationship between pollution, development and energy efficiency indicators by estimating reduced-form models between per capita pollutant emissions, per capita real GDP and the squared-cubic values of per capita real GDP (Richmond and Kaufmann, 2006; Stern, 2014; Morse 2018), and per capita indicators of energy efficiency. An example of a cubic function is the semi - logarithm equation 1:

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

Following standard notation t stands for the period and i stands for the countries under scrutiny. $LogE_{i,t} = \begin{bmatrix} \log SO_{2,t} \\ \log NO_{X,t} \\ \log NMVOC_t \\ \log GGE_t \end{bmatrix}$ denotes the vector of the environmental pollutants at period t (the dependent variables of the empirical models) and $LogE_{i,t-1} = \begin{bmatrix} \log SO_{2,t-1} \\ \log NO_{X,t-1} \\ \log NMVOC_{t-1} \\ \log GGE_{t-1} \end{bmatrix}$ denotes the vector of the environmental pollutants at period *t-1*. $LogSO_2$ 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 $\log GGE$ is the natural logarithm of total greenhouse gas emissions (CO_2 equivalent).

$I_{i,t}$ denotes development and $\log X_{i,t} = \begin{bmatrix} \log MI \\ \log RENEWS \\ \log RENEWG \\ \log ES \end{bmatrix}$ denotes the vector of control variables 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 indicator of energy saving for monitoring progress towards "20-20-20" targets. As usual $\varepsilon_{i,t}$ is the error term. 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*).

Following Marrero (2010) the country specific terms α_i in equation 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.

4.2 Dynamic Panel GMM (DPGMM) method of estimations

Arellano (1989) argues that for dynamic error components models, the estimator that uses differences rather than levels for instruments has a singularity point and very large variances over a significant range of parameter values (Baltagi 2005, p. 136). Therefore, 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 DPGMM estimators attributed to Arellano and Bond (1991)[15] and Arellano and Bover (1995)/Blundell and Bond (1998).[16]

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 (see also Polemis, 2016). The SYS-GMM estimator uses lagged first differences of the variables as instruments in the level equations. 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 short T dynamic panel data sets (T = 9 and N = 34 or 28).

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[15] See, *inter alia*, Polemis and Fotis (2013), p. 428.

[16] See also Holtz-Eakin et al. (1988).

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 $i = 1......N$ and $t = 2.....T$. 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 equation 1 using DPGMM estimators for $T \geq 3$.

4.3 Empirical results

4.3.1 Panel unit root and cointegration results

To test for the existence of a unit root in a panel data setting, we have used various econometric tests (Im, Pesaran and Shin W-test, Fisher type tests, Levin, Lin and Chu–t test).[17] In all the above mentioned tests the null hypothesis is that of a unit root.

Particularly, the W-test is based on the application of the ADF test to panel data, and allows heterogeneity in both the constant and slope terms of the ADF regression (Polemis and Fotis, 2013). It tests the null hypothesis that all panels have a unit root against the alternative that some of the panels are stationary. It also allows for cross sectional dependence. The ADF and PP tests are distributed as χ^2 with degrees of freedom twice the number of cross-section units (2N), under the null hypothesis. This test has the advantage over the W-test that its value does not depend on different lag lengths in the individual ADF regressions. Moreover, Baltagi and Kao (2000) report that Fisher type tests such as ADF and PP are superior to the aforementioned one in terms of size-adjusted power.

[17] The residual-based Lagrange multiplier stationary test by Hadri (2000) is used to test the null hypothesis of stationarity. This panel stationarity test extends the univariate KPSS test of Kwaitkowski et al (1992) and is particularly well suited for panel datasets in which T is large and N is moderate. However, in this paper we do not perform the said test since the panel data set under scrutiny is not strongly balanced.

The results in Table B1 of Appendix indicate that all the variables under scrutiny are integrated of order one. Also, the Johansen test for the existence of a cointegrated relationship between the non-stationary variables of the models depicts that there is (at least) one cointegration vector for each model (Table B2 of the Appendix).

4.3.2 Empirical results from DPGMM estimations

Tables 2 and 3 present the DIF-GMM and SYS-GMM parameter estimates of equation 1 respectively regarding the EU34 and EU28 countries. The said estimates are almost all highly statistically significant and robust given that equation 1 represents structural and not spurious long-run relation. GMM parameter estimates are shown for the one-step GMM estimator case with standard errors that are asymptotically robust to heteroskedasticity and have been found to be more reliable for finite sample inference than the GMM standard errors. Notice that in the majority of empirical models employed the SYS-GMM estimate of β_1 in equation 1, that is the estimated coefficient of development rate (I), is bigger in magnitude than the corresponding estimate of DIF-GMM, as predicted by the theory when instruments are weak in the latter case and the SYS-GMM alternative helps to overcome this problem.

[Insert Table 2 about here]

The estimation of β in equation 1 (E_{t-1}) is always highly statistical significant and smaller than 1 for all the dependent variables employed within the EU34 countries. For instance, the highest estimate is 0.77 for EU34 under DIF-GMM and 0.75 for EU34 under SYS-GMM. This result reveals the importance of the inclusion of the lagged dependent variable in the right hand side of equation 1.

Under EU34 countries and DIF-GMM method the coefficient of development is statistical significant and positive, except from the growth coefficient in the empirical model with NMVOC dependent variable. Under EU34 countries and SYS-GMM method the development coefficient is always highly statistical significant and positive. However, the square and cube growth coefficients for both DIF and SYS-GMM methods are not always statistical significant. For instance, under DIF-GMM method within the EU34 countries (Table 2) the cube growth coefficients are always statistical insignificant and in the cases where the square growth coefficients are statistical significant, either they exhibit a positive effect of growth rate on environmental pollutant (see *i.e.* the empirical model with SO_2 dependent variable) or they exhibit a negative effect between the two variables (see *i.e.* the empirical model with GGE dependent variable).

Under SYS-GMM method (Table 3) the square growth coefficients are always statistical insignificant and in the cases where the cube growth coefficients are statistical significant the estimated coefficients are almost zero (see *i.e.* the empirical models with SO_2 and NMVOC dependent variables). These results show a positive relationship between environmental pollutants and development rate and minimal or zero evidence for the EKC hypothesis in the EU34 countries for the time period in question.

Within EU28 countries the effect of development on environmental pollutants is less pronounced than within EU34 countries. Even thought it continues to exist a positive relationship between the two variables the effect of real per capita GDP growth rate on all the environmental pollutants employed is quite close to zero. However, the non statistically significant parameter estimates of square and cube coefficients of income indicate that the EKC hypothesis does not exist in the EU28 countries for the time period in question, which coincides with the discussion made for the EU34 countries.[18]

In terms of the effect of control variables of equation 1 on environmental pollutants it is evident that energy intensity (*MI*) positively affects all the environmental pollutants (the parameter estimates of coefficient *MI* under all empirical models employed within EU28 is statistically significant except from the estimated parameter in the empirical model with GGE dependent variable under SYS-GMM method).[19]

[Insert Table 3 about here]

The empirical results reveal that within EU28 countries energy intensity positively affects SO_2 emissions. For instance, an increase of energy intensity by 1% causes almost half increase of SO_2 emissions (SYS-GMM), while under DIF-GMM the corresponding response of SO_2 emissions is almost 80%. The magnitude of this effect is less pronounced within EU34 countries.

When we deal with the effect of energy saving on environmental pollutants an interesting remark emerges. Under all models and methodologies employed the effect of energy saving on environmental pollutants is positive. This effect reveals an inefficient way of energy use within EU. Different technological or regulatory aspects within EU countries may be critical factors affecting the way they use energy saving towards monitoring EU's energy policy.

However, emissions from all the environmental pollutants are eliminated by the increase of the share of renewable energy in gross final energy consumption increases. This result reveals that the more the renewable energy we use the less the pollution.

[18] As in the case of EU34 countries the estimation of β in equation 1 (E_{t-1}) is always highly statistical significant and smaller than 1 for all the dependent variables employed within the EU28 countries. For instance, the highest estimate is 0.89 under SYS-GMM and 0.32 under DIF-GMM.
[1919] See also figure 4 in section 3.2.

The same could be said for the effect of electricity generated from renewable sources of gross electricity consumption (RENEWG) on environmental pollutants, at least in most of the models employed which the parameter estimate of RENEWG is statistical significant.

5 Results and discussion

The estimated parameters of the empirical models employed in this paper suggest the existence of a monotonic pattern between environmental pollutants and real per capita GDP growth rate, since the square and cubic coefficients of economic growth in equation 1 are found to be not statistically significant. These results are not surprising since they agree with the empirical results by Morse (2018), Mazur et al. (2015), Change t al. (2014), Baycan (2013), Iwata et al. (2011), Marrero (2010), Martínez-Zarzoso et al., (2007), Azomahou et al. (2006), who also find increasing or non-inverted U patterns (see also Tables A1 and A2 in APPENDIX).

The inclusion of the renewable energy intensity indicators (RENEWS & RENEWG) as explanatory variables in equation 1 improve the empirical models. For both quantitative indicators significant negative coefficients are estimated for almost all the dependent variables (SO_2, NO_X, NMVOC and GGE, CO_2 equivalent), as is showed in Tables 2 and 3. The share of electricity produced from renewable energy sources to the national electricity consumption (RENEWG) 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 ($RENEWS$). Therefore, Europe's energy policy within EU should be strengthened towards more installed renewable energy and the recent update by the EC of a new 30% energy efficiency target for 2030 verifies this.

The empirical results derived from the indicator of energy saving (ES) suggest that EU energy policy should be also strengthened towards a more efficient use of energy at all stages of the energy chain. A convergence of environmental policies towards more efficient energy use among EU countries should be in the merit of Europe's energy policy the next years. For this purpose the adoption of new technology plays crucial role in determining the level of emissions.[20]

Energy intensity positively affects environmental pollutants (Morse 2018).[21] Even though energy intensity of the EU countries has reduced by 24% between 1995 and 2011, it seems that this endeavor must be reinforced in the future. As in the case of the renewable energy intensity indicators the recent update by the EU of a new 30% energy efficiency target for 2030 will certainly improve more the elimination of emissions. However, energy intensity flows must be kept up more closely in nowadays since the empirical effects regarding MI continue to be against EU's energy roadmap 2050.

The role of firms' stakeholders on the reduction of pollution is of great importance. Firms should use technological improved techniques and renewable sources of energy in order to enhance environmental quality. The adverse effect of energy saving indicator on pollution highlights this priority and firms' stakeholders should follow a more environmental friendly strategy. Stakeholders' engagement in favour of environment, foremost, helps them to improve the products or services they supply to the consumers.

[20] Makridou et al. (2016) have stated that technology change is primarily responsible for the energy improvements achieved in most sectors of the economy for 23 EU countries.

[21] A similar result regarding Carbon Dioxide Emissions (CO_2) has been reported in the literature by Martínez-Zarzoso et al., (2007).

6 Conclusions and policy implications

In this paper we empirically explore the effect of development and various energy efficiency indicators on environmental pollutants. For these purposes we utilize Dynamic Panel data methodologies (SYS and DIF – DPGMM) to examine clustered patterns of energy pollutants.

The empirical findings indicate that sustainable development positively affects environmental pollutants. The results also reveal that the use of renewable sources of energy negatively affects environmental pollutants. The more the renewable energy we use the less the air pollution. Energy saving positively affects pollution, while energy intensity contributes to more air pollution.

Technological improvements and stakeholders' engagement in favour of environment are also two important tools against pollution. Stakeholders should adopt technologically improved lines of production at regular intervals so as to keep up their technology with environmental needs. For this purpose, the majority of stakeholders, at least the ones that own multinationals firms, must commit to reduce energy consumption from non-renewable sources and replace obsolete technology with environmental friendly one. National governments should encourage private sector to adopt innovations which improve the quality of products/services produced, balancing the costs of R&D expenditures against the generated firms' profits.

The persistence of pollution with high levels of development indicates once again the important role of governmental policies in favour of renewable energy use. Governments should enforce their endeavor against pollution and in favour of economic development. Financial contribution of firms along with the reduction of bureaucratic procedures for the adoption of cleaner technologies of production will reinforce the important role of energy saving on the reduction of environmental pollution.

National tax policy consists of another tool against pollution.[22] Since demand for a cleaner environment increases with development level, the sooner the adoption of taxes against environmentally harmful industries, the cleaner the environment. However, this scenario is not always easy to be adopted across different tax regimes. Therefore, environmental policy across member states should be carefully designed in order to address the basic needs against pollution of each member state. A flat environmental strategy against pollution across member states will probably result in the adoption of new technology that is not suitable for all the member states.

Even though Energy Roadmap 2050 seems to be satisfied, policy implications should be strengthened towards more installed renewable energy, a convergence of environmental policies towards more efficient energy use among EU countries and energy intensity flows must be kept up more closely in nowadays since the empirical results point out its substantially positive contribution on air pollution. The recent adopted 30% energy efficiency target for the year of 2030 by EC aims to implement such policies. This target must be updated at regular intervals in order that to be monitored effectively.

[22] As soon as population increases the demand for energy increases as well as the public concern related to harmful effects of pollution (scale effect). Government taxation focuses on abating emissions and merely compensating part of the scale effect (Ansuategi 2003). Following Smulders et al. (2011) this is called "*the alarm phase*".

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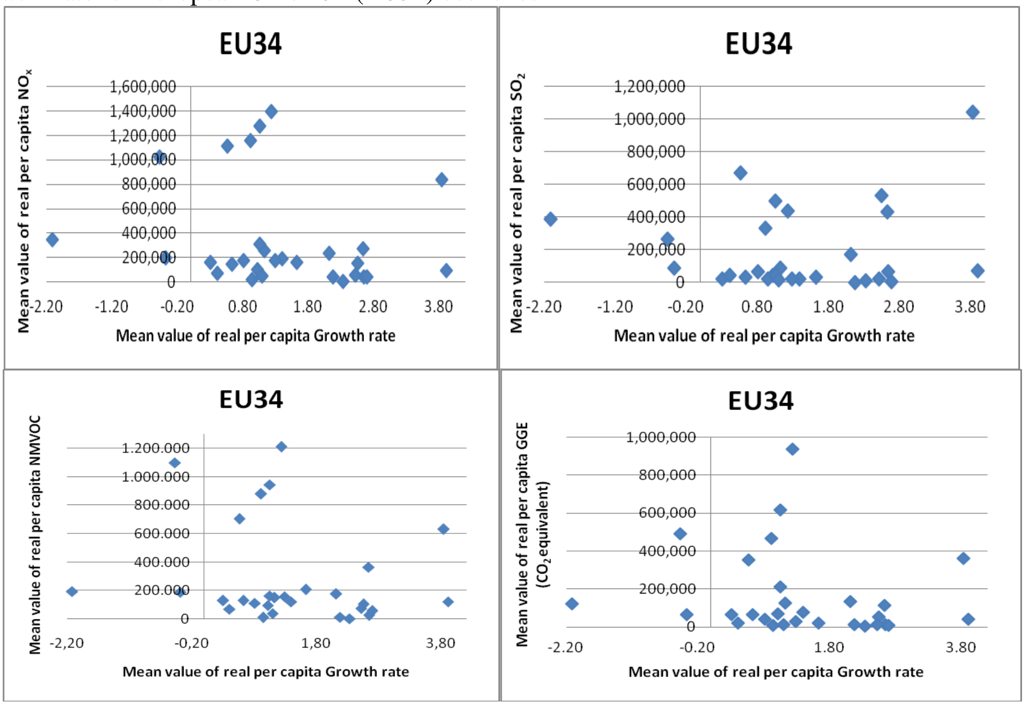
List of Figures and Tables

Figure 1: The relationship between the Environmental pollutants and the Real Gross Domestic Product Growth Rate for European Union 34 (EU34) countries



Notes:

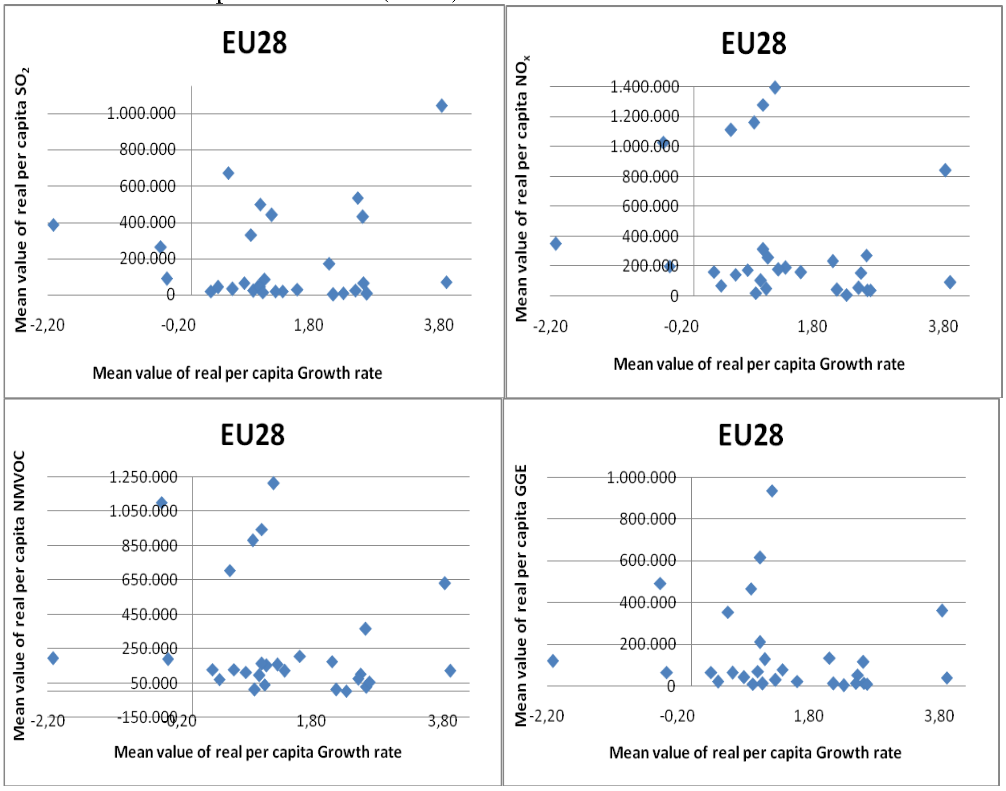
For all the graphs the horizontal axis depicts the Real GDP Growth Rate at 2005 constant prices and the vertical axis depicts the average (2005 – 2013) environmental pollutant per capita at 2005 constant prices.

The explanation of the variables is given in Table 3.

Source:

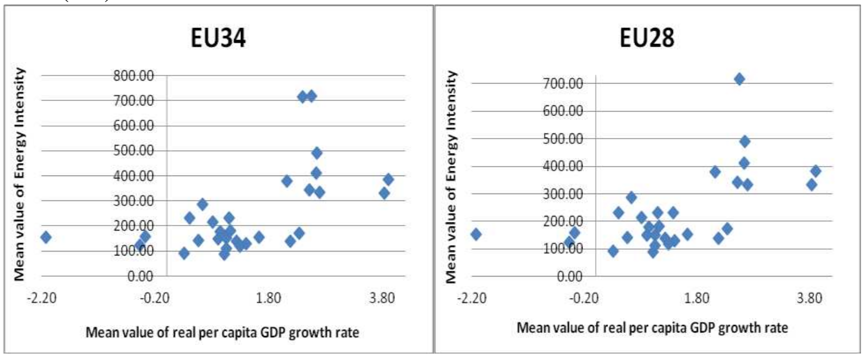
Author's elaboration of data from European Commission, Eurostat, European Environment Agency (EEA), (http://ec.europa.eu/-eurostat/web/energy/data).

Figure 2: The relationship between the Environmental pollutants and the Real Gross Domestic Product Growth Rate for European Union 28 (EU28) countries: 2005 – 2013



Notes:
For all the graphs the horizontal axis depicts the Real GDP Growth Rate at 2005 constant prices and the vertical axis depicts the average (2005 – 2013) environmental pollutant per capita at 2005 constant prices.
The explanation of the variables is given in Table 3.
Source:
Author's elaboration of data from European Commission, Eurostat, European Environment Agency (EEA), (http://ec.europa.eu/-eurostat/web/energy/data).

Figure 3: The relationship between the Energy Intensity and the Real per capita GDP Growth Rate for European Union (EU) 34 –28 countries



Notes:

For all the graphs the horizontal axis depicts the Real GDP Growth Rate at 2005 constant prices and the vertical axis depicts the average (2005 – 2013) environmental pollutant per capita at 2005 constant prices.

The explanation of the variables is given in Table 3.

Source:

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

Table 1: Summary statistics

	Environmental pollutants				Control variables				GDP Growth rate
	SO_2	***NO_X***	***NMVOC***	***GGE***	***ES***	***RENEWS***	***RENEWG***	***MI***	***I***
					EU34				
Mean	4.87	5.24	5.14	4.81	1.15	1.03	1.16	2.36	1.41
Standard Deviation	0.73	0.57	0.61	0.63	0.66	0.45	0.47	0.41	3.90
Min	3.10	3.56	3.41	3.47	-0.41	-0.72	-1	1.92	-14.67
Max	6.41	6.21	6.13	5.99	2.34	1.82	2.02	7.87	10.88
Variance	0.53	0.32	0.38	0.40	0.44	0.20	0.28	0.17	15.21
Skewness	0.50	-0.23	-0.60	-0.04	-0.25	-1.17	-1.30	8.37	-0.81
Kurtosis	2.43	2.68	3.38	2.14	2.50	5.80	1.67	11.13	5.19
					EU28				
Mean	4.84	5.22	5.11	4.80	1.24	1.01	1.13	2.31	1.37
Standard Deviation	0.69	0.57	0.62	0.64	0.62	0,43	0.44	0.23	3.99
Min	3.10	3.56	3.41	3.47	-0.41	0.72	-1	1.92	-14.67
Max	6.12	6.21	6.13	5.99	2.34	1.71	1.83	2.93	10.88
Variance	0.47	0.33	0.38	0.38	0.39	0.18	0.25	0.05	15.88
Skewness	-0.14	-0.18	-0.57	-0.57	-0.32	-1.35	-1.40	0.53	-0.80
Kurtosis	2.39	2.67	3.35	3.35	2.92	6.25	2.01	2.53	5.05

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).

Table 2: Estimation results (DIFF-GMM)

Ind. Var.	EU34				EU28			
	Dep. Var.[b]				**Dep. Var.**[b]			
	SO_2	**NO_X**	**NMVOC**	**GGE**	**SO_2**	**NO_X**	**NMVOC**	**GGE**
c [c]	62.15*** (35.49)	0.91* (16.16)	-70.39* (23.31)	-75.38 (24.21)	-0.13 (0.88)	1.54* (0.39)	1.40* (0.52)	0.81 (0.63)
E_{t-1} [d]	0.44* (0.11)	0.71* (0.09)	0.77* (0.08)	0.53* (0.08)	0.52* (0.10)	0.48* (0.09)	0.59* (0.09)	0.32* (0.08)
I	0.74* (0.24)	0.30*** (0.15)	0.13 (0.12)	0.51* (0.15)	0.01* (0.00)	0.01** (0.00)	0.00*** (0.00)	0.02** (0.00)
I²	0.05** (0.25)	-0.01 (0.02)	-0.00 (0.02)	-0.03**(0.02)	0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)	-0.00 (0.00)
I³	-0.00 (0.00)	-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 (0.00)
ES [d]	0.39*(0.11)	0.79* (0.11)	0.57* (0.13)	0.75* (0.09)	0.62** (0.25)	0.63* (0.10)	0.36* (0.10)	0.72*(0.22)
RENEWS [d]	-0.12* (0.01)	-0.03* (0.01)	0.00 (0.01)	-0.03** (0.01)	-0.23** (0.10)	-0.15** (0.06)	-0.04 (0.04)	0.04 (0.04)
RENEWG [d]	-0.18* (0.09)	0.81 (0.04)	0.02 (0.04)	0.09** (0.04)	-0.00 (0.00)	0.00 (0.00)	-0.00 (0.00)	0.00 (0.00)
MI [d]	0.08 (0.07)	0.10*** (0.05)	0.01 (0.07)	0.12*** (0.07)	0.85** (0.40)	0.22*** (0.13)	0.13** (0.06)	0.63* (0.20)
Wald chi²	*407.90* (0,00)*	*923.59* (0,00)*	*695. 91* (0,00)*	*258.45* (0,00)*	*368.19* (0,00)*	*1495.52* (0,00)*	*513.90* (0,00)*	*411.82* (0,00)*
No of Instruments	*33*	*33*	*33*	*33*	*33*	*178*	*91*	*120*
Max lags	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*

Notes: [a] One step results, [b] Dependent variables (in logs), [c] c denotes the constant term [d] in logs. 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 chi² estimations refer to the p- values of the individually significance tests.

Significant at *1% **5% and ***10% respectively.

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

Table 3: Estimation results (SYS-GMM)

Ind. Var.[b]	EU34				EU28			
	Dep. Var.[b]				Dep. Var.[b]			
	SO_2	NO_X	NMVOC	GGE	SO_2	NO_X	NMVOC	GGE
c [c]	18.47 (18.37)	-9.25 (16.48)	8.28 (18.15)	4.31 (24.56)	-0.40 (0.37)	0.57** (0.24)	0.22* (0.07)	0.46 (0.30)
E_{t-1}	0.75* (0.08)	0.72* (0.07)	0.70* (0.06)	0.60* (0.14)	0.78* (0.07)	0.80* (0.07)	0.89* (0.02)	0.85* (0.08)
I	0.64* (0.25)	0.46** (0.20)	0.34* (0.13)	0.52** (0.22)	0.01* (0.00)	0.01** (0.00)	0.01** (0.00)	0.01* (0.00)
I^2	0.00 (0.02)	-0.02 (0.02)	-0.01 (0.02)	-0.02 (0.02)	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 (0.003)	-0.00 (0.00)	-0.00 (0.00)	-0.00* (0.00)	-0.00* (0.00)
ES [d]	0.21*(0.07)	0.41* (0.09)	0.26* (0.06)	0.39*(0.15)	0.28*(0.10)	0.21* (0.07)	0.10* (0.02)	0.14 (0.10)
RENEWS [d]	-0.13* (0.02)	-0.06* (0.02)	-0.01 (0.01)	-0.05* (0.02)	-0.05 (0.10)	-0.01 (0.03)	0.00 (0.02)	-0.01 (0.06)
RENEWG [d]	0.01 (0.07)	-0.05 (0.04)	-0.06*** (0.03)	0.02 (0.04)	-0.00 (0.00)	-0.00*** (0.00)	0.00 (0.00)	0.00 (0.00)
MI [d]	0.15* (0.05)	0.04 (0.03)	-0.02 (0.05)	0.1(0.06)	0.51* (0.19)	0.10** (0.05)	0.07* (0.02)	0.04 (0.08)
Wald chi²	*1076.82* (0.00)*	*631.90* (0,00)*	*953.25* (0,00)*	*698.36* (0,00)*	*1058.19* (0,00)*	*14129.45* (0,00)*	*16779.01* (0,00)*	*33910.11* (0,00)*
No of Instruments	*40*	*40*	*40*	*40*	*40*	*216*	*246*	*140*
Max lags	*5*	*5*	*5*	*5*	*5*	*5*	*5*	*5*

Notes: [a] One step results, [b] Dependent variables (in logs), [c] c denotes the constant term [d] in logs. 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 chi² estimations refer to the p- values of the individually significance tests.

Significant at *1% **5% and ***10% respectively.

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

APPENDIX

Table A1: Main empirical studies and findings – group of countries

Study	Period	Pollutants	Number of countries	Methodology	Results
Rodriguez et al. (2016)	1979 - 2004	CO_2	13	Fixed – effects	Non – existence of inverted U-shape
Apergis (2016)	1960 - 2013	CO_2	13	CCE & CUP models	Mixed results
Ajmi et al. (2015)	1960 - 2010	CO_2	3	VAR model	Non – existence of inverted U-shape (N-shaped & inverted N-shaped)
Mazur et al. (2015)	1992 - 2010	CO_2	28	Fixed and Random effects	Non – existence of inverted U-shape
Lopez-Menendez et al. (2014)	1996 - 2010	CO_2	27	Fixed and Random effects	Existence of inverted U-shape only for Cyprus, Greece, Slovenia and Spain
Danaeifar (2014)	1992 - 2008	CO_2	30	Spatial panel data econometric techniques	Existence of (spatial) inverted U-shape
Wang Y-C (2013)	1870 - 2001	SO_2 & CO_2	19**	OLS, Fixed and Random effects	Existence of inverted U-shape
Baycan (2013)	1995 - 2005	SPM, NO_x, SO_2, CO_2	25	Fixed and Random effects	Non – existence of inverted U-shape (U-shaped)
Donfouet et al. (2013)	1961 - 2009	CO_2	43	Spatial econometric techniques	Existence of (spatial) EKC
Jaunky (2011)	1980 - 2005	CO_2	36	SYS GMM in a VECM	Existence of inverted U-shape only for Portugal and the UK
Iwata et al. (2011)	1960 - 2003	CO_2	17	ARDL model	Non – existence of inverted U-shape
Acaravci and Ozturk (2010)	1965 - 2005	CO_2	19	ARDL model	Existence of EKC only for Denmark and Italy
Marrero (2010)	1990 - 2006	GGE*	24	DIF & SYS GMM	Non – existence of inverted U-shape
Lee et al. (2009)	1960 - 2000	CO_2	19	Fixed, Random effects and DIF GMM	Existence of inverted U-shape
Coondoo and Dinda (2008)	1960 - 1990	CO_2	22	Fixed and Random effect econometric models	Existence of inverted U-shape
Wagner M. (2007)	1950 - 2000	SO_2 & CO_2	100**	DOLS, FM-OLS, 2-STEP LS	Non – existence of inverted U-shape
Azomahou et al. (2006)	1960 - 1996	CO_2	21	Non - Parametric	Non – existence of inverted U-shape (positive effects)
Markandya et al., (2006)	1850-2001	SO_2,	12	Fixed and Random effects	Existence of inverted U-shape
	1973 - 1997	CO_2	16	Random Coefficient Estimation	Mixed results
	1990 - 2000	NO_x, SO_2, CO_2	15	Fixed – effects & Cross - section estimations	Mixed results (positive & negative effects)
	1985, 1987-1992	SO_2	21	Fixed – effects	Non – existence of inverted U-shape (negative effects)
Zaim and Taskin (2000)	1980 - 1990	CO_2	18	Common, Fixed and Random effects	Existence of inverted U-shape

Notes: *Greenhouse Gas Emissions; **among other OECD countries
Source: Author's elaboration of data.

Table A2: Main empirical studies and findings – single countries

Papers	Period	Pollutants	Number of countries	Methodology	Results
Yang et al. (2017)	1998 - 2013	GHG*	Russia	-	Existence of inverted U-shape
Wang et al. (2017)	2000 - 2013	CO_2	China	Semi-parametric panel fixed effect	Mixed results per industrial sector
Sephton and Mann (2016)	1830 - 2003 1850 - 2002	SO_2 & CO_2	UK	Threshold Cointegration Techniques	Existence of EKC
Zhang & Zhao (2014)	1995 - 2010	CO_2	China	Fixed Effect, FGLS, PCSE, etc, techniques	Mixed results per region
Shahbaz et al. (2013)	1970 - 2010	CO_2	Turkey	VECM Granger causality approach	Existence of inverted U-shape
Sephton and Mann (2013)	1857 - 2007	CO2	Spain	Threshold Cointegration Techniques	Existence of inverted U-shape
Fosten et al.(2012)	1830 - 2003 1850 - 2002	SO_2 & CO_2	UK	Threshold Cointegration Techniques	Existence of inverted U-shape
Esteve and Tamarit (2012)	1857 - 2007	CO_2	Spain	Two-regime threshold cointegration model	Existence of inverted U-shape
Wang et al. (2012)	1997 - 2010	CO_2	Beijing City, China	Partial least square regression	Non – existence of inverted U-shape
Akbostanci et al. (2009)	1992 - 2001 1968 - 2003	CO_2	Turkey	VAR model GLS model	Non – existence of inverted U-shape Positive monotonic/N-shaped
Soytas and Sari (2009)	1960 - 2000	CO_2	Turkey	VAR model	Non – existence of EKC
Brannlund & Ghalwash (2008)	1984, 1988, 1996	SO_2, CO_2 NO_x	Sweden	Seemingly Unrelated Regressions (SURE)	Positive (concave) relationship
Kunnas and Myllyntaus (2007)	1800 - 2003	SO_2, CO_2 NO_x	Finland	OLS	Existence of EKC for SO_2 and NO_x
Johansson & Kriström (2007)	1900-2002	SO_2	Sweden	OLS – AR(2) process	Non – existence of inverted U-shape
Lise (2006)	1980 - 2003	CO_2	Turkey	OLS	Non – existence of inverted U-shape Linear (positive) relationship
Friedl and Getzner (2003)	1960 - 1999	CO_2	Austria	OLS with structural break	Non – existence of inverted U-shape (N-shaped)

Notes: *Greenhouse Gas Emissions
Source: Author's elaboration of data.

Table B1: Panel unit root test results

	Breuting-t test[a]	*Im, Pesaran and Shin W-test*[a]	*ADF–Fisher Chi-square*[a]	*PP–Fisher Chi-square*[a]
Variable [c]	***Levels***			
SO_2	0.34	0.69	42.24	
NO_X	-0.83	-0.30	36.21	63.33
NMVOC	2.24	0.61	65.88	76.40
GGE	-0.16	-0.73	56.40	66.57
ES [d]	1.14	-0.60	86.02	74.93
RENEWS	1.45	4.09	23.26	28.74
RENEWG	3.80	-0.11	22.29	26.03
MI	-1.31	-0.38	78.63	84.74
I	0.26	-0.38	68.62	69.34[c]
Variable	***First differences***			
$\Delta(SO_2)$	-3.73*	-4.36*	126.77*	160.48*
$\Delta(NO_X)$	-5.70*	-6.01*	155.90*	238.30*
Δ(NMVOC)	-2.83*	-4.20*	123.27*	134.08*
Δ(GGE)	-5.04*	-6.38*	162.62*	249.98*
Δ(ES)	-6.94*	-9.52*	224.41*	381.44*
Δ(RENEWS)	-6.94*	-7.20*	171.02*	212.58*
Δ(RENEWG)	-6.01*	-5.24*	141.62*	182.65*
Δ(MI)	-2.60*	-5.74*	161.86*	102.05*
Δ(I)	-7.37*	-5.45*	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 (only for EUROZONE sample countries), [c]*In logs*, [d]The lag lengths were selected by using Modified Akaike Criterion. 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: Author's elaboration of data from European Commission, Eurostat, European Environment Agency (EEA) (http://ec.europa.eu/eurostat/web/energy/data).

Table B2: Johansen Fisher panel cointegration testing

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