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Output, renewable and non-renewable energy production, and international trade: Evidence from EU-15 countries

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Abstract

This research presents first empirical evidence on the dynamic relationship between output, renewable and non-renewable energy production, international trade, capital and labour in the case of the EU-15 countries over the period of 1980-2015 for individual countries as well as a group. A simple production function of capital and labour is extended as such that it incorporates the impact of renewable and non-renewable energy inputs, and international trade on output level. Econometric estimations of the extended production equations are carried out via ARDL approach to cointegration for individual country cases and panel GMM econometric technique for the entire EU-15. The ARDL empirical results indicate the existence of cointegration relationships amongst the variables in the case of seven countries of the EU-15, in addition to the GMM based, long-run relationship for the entire EU-15 as a panel. The ARDL procedure suggests that the relative impact of renewable and non-renewable energy inputs on output levels vary considerably for individual countries. The GMM results demonstrate the existence of the relative importance of renewable and non-renewable energy inputs along with international trade on output in the EU-15 countries. This paper also discusses policy implications of the empirical results, as well as offering policy recommendations.

Keywords: Output, International trade, renewable and non-renewable energy, Cointegration, EU-15 countries.
JEL Classifications: F14, F18, C22, C33, Q43

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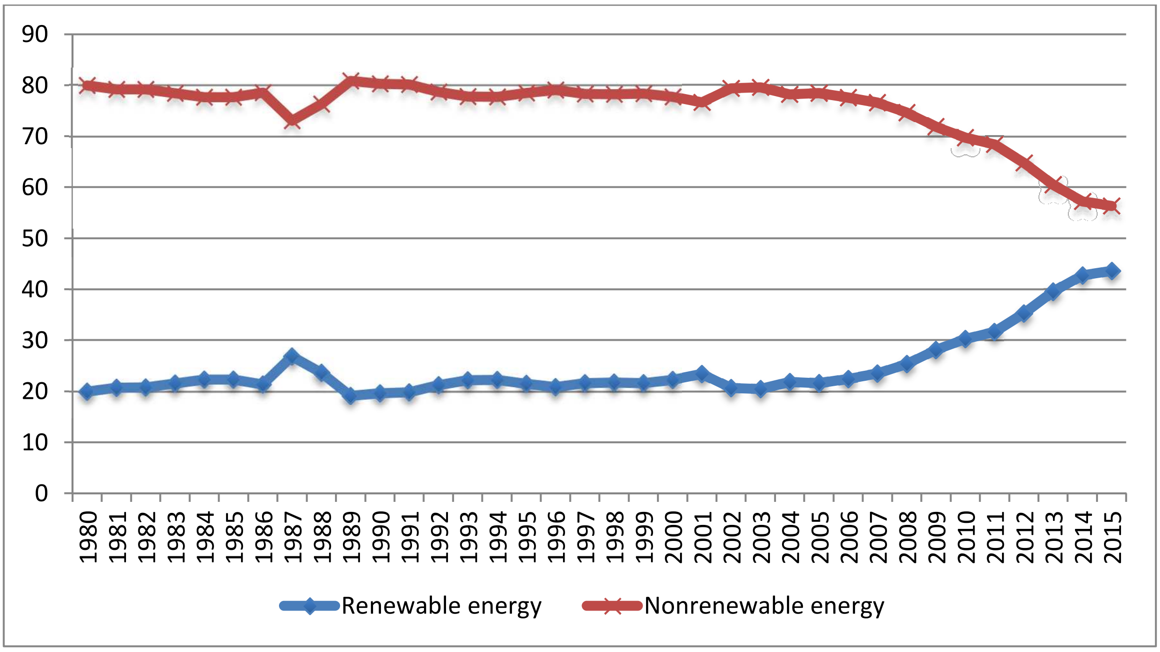
1. Introduction

Environmental degradation, especially in the form of GHGs (Green House Gases), has been giving concern to the entire world, especially in the last three decades. By and large, the international community seems to be united to curb several pollutants, including carbon dioxide (CO_2) emissions, which are deemed to be causing severe depletion of the ozone layer. According to the World Resources Institute (WRI, 2015), global GHGs emissions rose considerably from 32414 to 46049 M_tCO_2e (million metric tons of carbon dioxide equivalent) over the period 1990-2012. The WRI reports that the amount of CO_2 emissions constitutes around 60% of GHGs. Fossil energy sources, such as coal and oil, are blamed for environmental degradation but they are also being used as the primary energy inputs for economic growth, as discussed in Halicioglu and Ketenci (2016).

The European Union (EU) has been particularly active in tackling global warming in regards to engaging international climate change agreements, as well as setting out clear targets to curb environmental pollutants. To this extent, the EU has been a signatory part of several climate action agreements and has set clear, long-term targets for reducing GHGs. The EU signed the global charter of the United Nations Framework Convention on Climate Change (UNFCCC) in 1992, which aims to limit global warming to below 2^o C. The 1997 Kyoto protocol, which emerged from the UNFCCC, was also signed by the EU and mandated that the signatory countries would cut down their GHGs by on average 5.2% by 2012, compared with the 1990 level. The EU was amongst a few countries which met the first phase of the Kyoto targets. The EU has adopted the second of phase of the Kyoto agreement which runs from 2013 to 2020. During the second phase of the Kyoto protocol, by 2020 the EU aims to reduce its GHGs emissions by 20% in comparison to the 1990 levels. Finally, the EU has been spearheading the implementation of the legally binding Paris agreement (also known as '*the 21st Conference of the Parties*' in short COP21) on climate change, which was signed by 195 countries in 2015, which will come into effect in 2020. Even though this agreement, unlike the previous ones, does not set out any detailed timetable or country specific goals for GHGs, the agreement set a goal of limiting global warming to 1.5^o C which requires zero emissions sometime between 2030 and 2050. The EU not only complies with the Paris agreement on climate change, but it also sets out more ambitious targets to reduce the GHGS at the same time. For example, the EU aims at reducing GHGs by at least 40% by 2030 compared with 1990. By 2050, the EU wishes to achieve 80-95% reduction in GHGs compared with 1990. In order to achieve these targets, the EU promotes clean energy production by substituting non-renewable energy production with renewable energy production. The EU targeted that the share of renewable energy in production will be at least 27% by 2030. Graph 1 plots the shares of the renewable and non-renewable energy in total energy productions over the period 1980-2015. Graph 1 emphasizes that from 2002 onwards the share of non-renewable energy in energy production started to increase steadily in the EU-15 countries thanks to generous investment incentives in the energy sector. Thus, the EU is likely to meet or exceed its targets on renewable energy consumptions.

Graph 1. **Share of renewable and nonrenewable energies in total energy production, EU15**



Source: Authors' calculations based on WDI data.

In order to finance the climate change and reduce the burden of developing countries on implementing low carbon economic measurements, the EU is committed to allocate 20% of its budget by 2020, as reported in EU (2017). The strong commitment of the EU towards reducing the GHGs emissions appears to be working since the share of the EU-15 countries in total CO_2 emissions has been almost halved to 7.66% in 2013, in comparison with its peak point of 14.4% in 1991, according to World Development Indicators (WDI, 2016).

The main motivation of this research is to measure the impact of green energy policy commitments on the output levels of the EU-15 countries[1]. The choice of EU-15 is imposed on us due to practical and data restrictions on econometric models we employed in this study. However, the EU-15 is still a good statistical representation of the entire EU, which currently consists of 28 countries because the share of the GDP (gross domestic product) of the EU-15 composes 91.4% of the EU-28's GDP (Eurostat, 2017).

The dynamic relations between output, the inputs of renewable and non-renewable energy, international trade, capital and labour are analysed from different perspectives in the literature. These interlinkages in the literature usually miss one or more variables from the afore-mentioned, except the study of Jebli and Youssef (2015) which uses all variables. Thus, encompassing all of these variables in a production function may provide a better insight to understand between these dynamic relationships and it may also alleviate the elimination of the potential problem of omitted variable bias.

This research tries to identify the relative importance of renewable and non-renewable energy inputs along with international trade, capital and labour on production functions of the EU-15 countries. As far as this study is concerned, there exists no previous empirical study particularly researching the relative importance of renewable and non-renewable energy inputs on economic output in the case of the EU-15 countries. This study aims to measure the relative importance of renewable and non-renewable energy inputs on economic output, along with other major production inputs such as capital and labour. Finally, the relative importance of international trade on economic output is considered to be an important factor due to its essential role in open economies, such as the EU-15 countries, Rainer (1994), Frankel and Homer (1999), Silberberger and Koniger (2016). European countries are not well endowed with non-renewable sources of energy, such as oil and gas; therefore it is important to investigate relationships of renewable and non-renewable energy consumption and economic growth in the most advanced framework, which will reveal details for further policy implication, Salim *et al*. (2012), Jebli and Youssef (2015), Narayan and Doytch (2017). This research may also help policy makers adopt more appropriate policies for a cleaner environment and prolonged economic growth in the EU.

This research utilizes the econometric procedures of the ARDL (Auto Regressive Distributed Lag) approach to cointegration, to measure the relative impact of renewable and

[1] Information on employed variables and the list of countries is presented in the Appendix.

non-renewable energy economic growth at country level of the EU-15, in addition to testing the same impact from the panel of the EU-15 by using the GMM (Generalized Methods of Estimation) technique.

The rest of the paper is organized as follows: the next section provides a brief literature review on the relationships between the inputs of economic output concentrating particularly on energy inputs, international trade, labour and capital. Section three explains the adopted cointegration methodologies. The fourth section reports and discusses the obtained empirical results, and finally, the last section concerns the concluding remarks and policy recommendations.

2. A Brief Literature Review

The empirical studies on energy and economic growth are reviewed by several authors. Out of these surveys, the studies of Payne (2008), Omri (2014) and Csereklyel *et al*. (2016) provide very comprehensive reviews on different aspects of energy and economic growth. The empirical studies of energy and economic growth tend to test the well-known hypotheses and therefore they complement their econometric results with some sort of causality test. Nevertheless, results appear to be rather inconclusive due to different econometric methodologies being used or the variations in time span of data. Naturally, drawing plausible inferences is not easy from these studies.

Csereklyel *et al*. (2016) points out that due to the structural change of economies, the relative importance of fossil energy sources are falling at all income levels over recent decades. This finding implies that fossil energy resources are substituted with renewable energy resources, in addition to the implication of rising energy efficiencies on production lines. In order to highlight the rising level of renewable energy usage in production, the focus of the literature review here is based on the studies that reveal the impact of renewable energy on economic growth. Sebri (2015) conducts a meta-analysis of renewable energy and economic growth relation to identify different aspects of the hypotheses being tested in the literature. Chien and Hu (2007) utilized the data envelopment analysis (DAE) to measure technical efficiency during the 2001-2002 period for 45 countries and stated that compared to non-OECD economies, OECD economies have higher technical efficiency due to a higher share of renewable energy. The study of Apergis and Payne (2011) estimates a production function using heterogeneous panel cointegration technique for six Central American countries, using data from 1980 to 2006. The production function includes GDP, renewable energy, capital and labour variables, and the econometric results indicate a positive impact of renewable energy on output. Another study of Apergis and Payne (2010) concentrates on a simple production function with 13 countries within Eurasia over the period 1992-2007. The heterogeneous panel cointegration results suggest the existence of a long-run equilibrium between the variables of GDP, renewable energy consumption, capital and labour. Moreover, the impact of renewable energy consumption on output is recorded positively. Fang (2011) estimated Cobb-Douglas type of production function by OLS in China from 1978-2008 in order to test the impact of renewable energy consumption and concluded that a 1% increase in renewable energy consumption increases GDP by 0.12%. Another study in this manner conducted by Inglesi-Lotz (2016) finds evidence from panel data and states that the impact of renewable energy consumption on economic welfare is positive.

Menegaki (2011) tests the role of renewable energy on GDP in both the short run and the long run for the panel of 27 European countries. The empirical results state that, taking into account the shortage of non-renewable energy sources in Europe, it is important to implement new policies to improve energy efficiency that would leave the neutrality of renewable energy sources in the past. Sebri and Ben-Salha (2014) employed ARDL bounds testing approach to test the relationship between economic growth, renewable energy consumption, CO_2 emissions and trade openness for BRICS countries. Empirical results indicate the positive impact of renewable energy on output. Bhattacharya *et al.* (2016) selects 38 top countries to measure the relative importance of renewable and non-renewable energies along with capital and labour force on aggregate output. Their study uses panel cointegration technique with data running from 1991 to 2012 and concludes that renewable energy has a positive impact on the output for 57% of the sample countries. Armenau *et al.* (2017) employed panel cointegration econometric techniques to test the impact of different renewable energy resources such as hydroelectric, wind, and solar on the economic growth of the EU-28 countries over the period 2003-2014. The findings of their study indicate the existence of a positive impact of renewable energy on output. However, it should be noted that the results are derived from a production function.

By using a dynamic simultaneous-equation panel technique, Amri (2017) demonstrated that renewable energy, along with international trade, has a positive impact on the output of 72 developing and developed countries during the 1990-2012 period.

Finally, the study of Jebli and Youssef (2015), which utilizes the variables of output, renewable and non-renewable energies, international trade, capital and labour in a simple production function, is notable. Their study employs panel cointegration technique for the data of 69 countries over the period 1980-2010 and concludes that the relative impact of renewable energy on output is substantially higher. Their study includes 18 European countries, consisting of 11 countries in the EU-15. The study of Jebli and Youssef (2015) investigates general casual relationships between selected variables taking as an example wide sample of 69 countries of different development levels in the panel.

Thus, there is no specific study containing the EU-15 members as a panel with a production function including the variables of output, renewable and nonrenewable energy, international trade, capital and labour. This study is distinct from the above research in terms of the longer time span of data. In addition the present study focuses on the long-run impacts of selected variables on the output of individual European countries and on the panel of the EU-15.

3. Model and Econometric Methodology

Following the existing literature see for example, Apergis and Payne (2010) and Jebli and Youssef (2015), we extend the conventional neo-classical Cobb-Douglas aggregate production function by incorporating renewable and non-renewable energy consumption and international trade openness as additional inputs.

The empirical literature relating to the dynamic relationships between output and the inputs of renewable and non-renewable energy production, international trade, capital and labour dictate a simple augmented production function in the form below:

$$Y_{it} = f(RE_{it}, NRE_{it}, O_{it}, K_{it}, L_{it}) \qquad (1)$$

where Y_{it} is output proxied by GDP (Gross Domestic Product), RE_{it} denotes renewable electricity production, NRE_{it} stands for the non-renewable energy production, O_{it} is the trade openness ratio which is a simple ratio of exports plus imports over GDP and it is being used as a proxy for international trade, K_{it} and L_{it} represent the capital and labour inputs, respectively[2].

The long-run relationship of equation (1) can be expressed econometrically in double logarithmic form as follows:

[2] The conventional Cobb-Douglas production function is represented by the following equation $Y = AK^{\alpha}L^{\beta}$ where Y , K, and are represented output, capital and labour, respectively. Whereas A, α and β stand for efficiency, and input marginal productivity parameters.

$$y_{it} = a_0 + a_1 re_{it} + a_2 nre_{it} + a_3 o_{it} + a_4\, k_{it} + a_5\, l_{it} + u_{it} \qquad (2)$$

where u_{it} is the stochastic error term. The lower case letters in equation (2) demonstrate that all variables are in their natural logarithms. Naturally, all expected signs are positive from this extended production equation.

In order to measure the dynamic relative impacts of renewable and non-renewable energy inputs along with other variables on economic output, equation (2) can be expressed in the ARDL approach to cointegration of Pesaran *et al*. (2001)[3].

$$\Delta y_{it} = b_0 + \sum_{j=1}^{n1} b_{1i}\Delta y_{t-j} + \sum_{j=0}^{n2} b_{2i}\Delta re_{t-j} + \sum_{j=0}^{n3} b_{3i}\Delta nre_{t-j} + \sum_{j=0}^{n4} b_{4i}\Delta o_{t-j} + \sum_{j=0}^{n5} b_{5i}\Delta k_t + \sum_{j=0}^{n6} b_{6i}\Delta l_{t-j}$$
$$b_7 y_{it-1} + b_8 re_{it-1} + b_9 nre_{it-1} + b_{10} o_{it-1} + b_{11} k_{it-1} + b_{12} l_{it-1} + v_t \qquad (3)$$

An error correction model of the ARDL technique can be formulated as follows:

$$\Delta y_{it} = b_0 + \sum_{j=1}^{n1} b_{1i}\Delta y_{t-j} + \sum_{j=0}^{n2} b_{2i}\Delta re_{t-j} + \sum_{j=0}^{n3} b_{3i}\Delta nre_{t-j} + \sum_{j=0}^{n4} b_{4i}\Delta o_{t-j} + \sum_{j=0}^{n5} b_{5i}\Delta k_t + \sum_{j=0}^{n6} b_{6i}\Delta l_{t-j}$$
$$\lambda EC_{it-1} + \mu_t \qquad (4)$$

where EC_{it-1} is the lagged error correction term which is obtained from the long-run relationship. The most important econometric convenience of this procedure is that the combination of level stationary, $I(0)$ and first difference stationary, $I(1)$ variables are allowed to be used together in the long-run estimations. This method is implemented in two separate stages. In the first stage, the existence of long-run relationships is checked on the basis of bounds testing procedures which requires the F or Wald test procedures. In the second stage, equation (2) and equation (3) are estimated simultaneously. Autocorrelation and endogeneity problems are avoided with the ARDL procedure. The ARDL approach to cointegration is a single cointegration technique and its other advantages are well documented in the literature: see, for example, Narayan (2005). As a passing note, it should be highlighted that the first stage of the ARDL procedure is very sensitive to lag length selection process as discussed in Bahmani-Oskooee *et al*. (2005) and Bahmani-Oskooee and Gelan (2005). Therefore, it is possible to implement another way of establishing the cointegration between the variables of

[3] This section heavily relies on Andres e*t al*. (2011), Andres and Halicioglu (2010), Halicioglu and Yolac (2015), Dell'Anno and Halicioglu (2010) and Halicioglu (2009, 2011, 2012).

equation (1), if the pre-testing stage of the ARDL approach to cointegration fails. In this situation, according to Kremers *et al.* (1992) and Benarjee *et al.* (1998), the statistical significance of the lagged error correction term is an indication of cointegration between the variables in question. One of most important reasons of choosing the ARDL approach in this study is its superior advantage in small sample sizes, where the ARDL technique provides better results compare to other techniques, Pesaran et al. (2001).

The ARDL approach to cointegration is convenient to measure the dynamic relations set out in equations (2, 3 and 4) for each individual country of the EU-15. However, if one wishes to test the dynamic relationship set out in equation (1) as a panel, the ARDL approach cannot be used. In this case, the GMM technique which was introduced by Hansen (1982) seems to be a good choice econometrically. The GMM[4] is based on an inclusion to the regression of lagged endogenous variables as instrumental variables. One of the important advantages of the GMM is that many estimators like Ordinary Least Squares (OLS) and instrumental variables are considered as special cases, making the GMM flexible in use. The superiority of the GMM test is in the avoidance of heteroskedasticity and autocorrelation by allowing a weighting matrix to account for them using orthogonality conditions. In order to check the validity of instrumental variables applied to the regression, the test for over-identifying restrictions developed by Sargan (1958) is employed. The GMM technique also requires the variables in question to be stationary.

Equation (1) can be rewritten in the following simple GMM form:

$$z_t = x'_t\beta_0 + \varepsilon_t \qquad (5)$$

where z_t corresponds to the dependent variable Y_{it} output, x'_t is an $Lx1$ vector of explanatory variables and which correspond to five variables of equation (1), which are renewable energy, non-renewable energy, international trade, capital and labour with the regression error term ε_t.

4. Empirical Results

Annual data over the period 1980-2015 were used to estimate the augmented Cobb-Douglas production function. Data definition and sources of data are cited in the Appendix.
The econometric procedures that are adopted in this study require checking time series and panel properties of the data being used in the analysis. Therefore, the ADF (Augmented

[4] See more on this technique Ketenci (2015) and Halicioglu and Ketenci (2016).

Dickey Fuller) unit root test of Dickey and Fuller (1979) and the PP unit test of Phillips and Perron (1988) were implemented for time series data. The results are presented for the variables through Tables 1A to 1F. The unit root test results demonstrate that the variables in question are in the form of $I(0)$ or $I(1)$ which warrant the implementation of the ARDL procedure.

Table 1A. Unit root tests

Variable *y*

	ADF	PP	ADF	PP
Country	Level		First Difference	
Austria	-0.74	-0.24	-3.68*	-4.46*
Belgium	-1.11	-1.49	-3.53*	-4.85*
Denmark	-1.32	-0.93	-3.66*	-4.86*
Finland	-1.91	-1.39	-3.33*	-3.40*
France	-1.46	-0.35	-3.09*	-3.70*
Germany	-2.23	-1.14	-4.35*	-4.76*
Greece	-1.75	-0.97	-3.22*	-3.35*
Ireland	-3.42	-1.94	-3.56*	-3.54*
Italy	-0.89	-0.45	-3.01*	-3.52*
Luxembourg	-1.83	-1.02	-3.29*	-4.58*
Netherlands	-0.98	-0.69	-3.02*	-4.26*
Portugal	-1.80	-0.85	-2.71	-3.61*
Spain	-2.45	-0.77	-2.70	-3.53*
Sweden	-2.28	-2.18	-3.99*	-4.49*
United Kingdom	-1.81	-1.28	-3.15*	-3.68*

Notes: * denotes the rejection of the null hypothesis at 5% level of significance. The critical values for ADF and the PP tests are obtained from MacKinnon (1996). Level regressions include intercept and trend but difference regressions contain intercept only.

Table 1B. Unit root tests

Variable *re*				
	ADF	PP	ADF	PP
Country	Level		First Difference	
Austria	-3.97*	-4.16*	-4.79*	-9.75*
Belgium	-0.88	-1.76	-3.14	-4.79*
Denmark	-3.11	-0.28	-3.61*	-4.73*
Finland	-2.75	-4.09*	-5.78*	-10.06*
France	-2.55	-3.26	-4.74*	-9.20*
Germany	-1.64	-1.15	-3.73*	-3.76*
Greece	-3.18	-2.50	-5.70*	-7.62*
Ireland	-1.32	-1.01	-3.62*	-7.25*
Italy	-1.23	-1.27	-3.79*	-5.70*
Luxembourg	-2.06	-1.67	-5.07*	-6.59*
Netherlands	-1.48	-4.87*	-4.90*	-9.03*
Portugal	-3.14	5.17*	-9.09*	-12.51*
Spain	-2.93	3.58	-3.40*	-11.58*
Sweden	-2.58	-1.86	-3.76*	-3.92*
United Kingdom	-2.22	-1.50	-5.73*	-5.91*

Notes: * denotes the rejection of the null hypothesis at 5% level of significance. The critical values for ADF and the PP tests are obtained from MacKinnon (1996). Level regressions include intercept and trend but difference regressions contain intercept only.

Table 1C. Unit root tests

Variable *nre*				
	ADF	PP	ADF	PP
Country	Level		First Difference	
Austria	-2.01	-1.39	-4.09*	-5.00*
Belgium	-1.53	-2.53	-4.45*	-4.18*
Denmark	-0.44	-0.28	-4.80*	-7.15*
Finland	-0.45	-2.15	-5.12*	-7.37*
France	-2.52	-2.88	-4.19*	-6.26*
Germany	-1.65	-2.63	-4.09*	-7.32*
Greece	-2.48	-2.12	-2.87	-4.82*
Ireland	-1.06	-0.64	-4.43*	-5.20*
Italy	-0.31	-0.16	-3.80*	-4.28*
Luxembourg	-1.83	-2.08	-3.14*	-3.41*
Netherlands	-2.45	-1.70	-4.25*	-4.94*
Portugal	-2.00	-1.78	-5.34*	-7.42*
Spain	-1.62	-1.77	-3.82*	-6.64*
Sweden	-2.26	-3.12	-4.26*	-7.20*
United Kingdom	-2.12*	-1.81	-2.98*	-3.58*

Notes: * denotes the rejection of the null hypothesis at 5% level of significance. The critical values for ADF and the PP tests are obtained from MacKinnon (1996). Level regressions include intercept and trend but difference regressions contain intercept only.

Table 1D. Unit root tests

Variable *o*				
	ADF	PP	ADF	PP
Country	Level		First Difference	
Austria	-3.30	-2.70	-4.89*	-6.22*
Belgium	-3.94*	-2.72	-5.41*	-6.79*
Denmark	-4.34*	-1.85	-4.90*	-5.77*
Finland	-2.31	-2.36	-3.75*	-5.06*
France	-4.24*	-2.08	-5.02*	-5.77*
Germany	-2.95	-1.76	-4.28*	-5.20*
Greece	-2.79	-2.13	-4.25	-5.04*
Ireland	-2.41	-2.42	-3.52*	-4.68*
Italy	-4.43*	-2.35	-4.89*	-6.09*
Luxembourg	-2.58	-1.13	-3.06*	-4.54*
Netherlands	-4.67*	-2.17	-5.32*	-6.70*
Portugal	-3.00	-2.50	-4.95*	-6.32*
Spain	-2.45	-1.30	-4.47*	-5.00*
Sweden	-2.67	-2.00	-2.93	-4.75*
United Kingdom	-3.66*	-2.40	-3.39*	-5.94*

Notes: * denotes the rejection of the null hypothesis at 5% level of significance. The critical values for ADF and the PP tests are obtained from MacKinnon (1996). Level regressions include intercept and trend but difference regressions contain intercept only.

Table 1E. Unit root tests

Variable *k*				
	ADF	PP	ADF	PP
Country	Level		First Difference	
Austria	-3.31	-2.50	-4.27*	-5.57*
Belgium	-3.63*	-3.91*	-4.72*	-4.74*
Denmark	-2.62	-2.25	-4.47*	-4.69*
Finland	-2.54	-1.95	-3.73*	-2.95*
France	-2.72	-2.39	-3.50*	-2.97*
Germany	-2.70	-2.15	-3.58*	-4.00*
Greece	-1.13	-1.22	-3.23*	-5.05*
Ireland	-2.17	-2.11	-3.58*	-3.34*
Italy	-1.73	-1.90	-3.17*	-4.00*
Luxembourg	-6.06*	-3.27	-5.29*	-6.86*
Netherlands	-3.41	-2.10	-3.72*	-4.04*
Portugal	-2.69	-1.42	-3.75*	-3.69*
Spain	-2.67	-1.41	-3.63*	-4.07*
Sweden	-2.58	-1.86	-3.76*	-3.92*
United Kingdom	-4.01*	-2.26	-3.86*	-4.17*

Notes: * denotes the rejection of the null hypothesis at 5% level of significance. The critical values for ADF and the PP tests are obtained from MacKinnon (1996). Level regressions include intercept and trend but difference regressions contain intercept only.

Table 1F. Unit root tests

Variable *l*				
	ADF	PP	ADF	PP
Country	Level		First Difference	
Austria	-2.29	-2.69	-5.20*	-5.57*
Belgium	-3.69*	-2.96	-3.90*	-5.70*
Denmark	-2.74	-2.03	-3.78*	-5.79*
Finland	-2.75	-4.09*	-5.78*	-10.06*
France	-2.42	-2.75	-3.88*	-5.76*
Germany	-2.55	-3.66*	-3.43*	-3.41*
Greece	-2.16	-2.53	-3.56	-5.21*
Ireland	-1.70	-1.53	-2.48	-3.91*
Italy	-1.56	-1.90	-3.32*	-6.48*
Luxembourg	-2.12	-2.92	-3.62*	-4.78*
Netherlands	-1.62	-0.21	-3.91*	-5.72*
Portugal	-0.97	-1.99	-3.36*	-5.38*
Spain	-1.23	-2.48	-3.08*	-5.45*
Sweden	-1.09	-1.60	-3.92*	-5.47*
United Kingdom	-2.20	-2.13	-3.65*	-4.97*

Notes: * denotes the rejection of the null hypothesis at 5% level of significance. The critical values for ADF and the PP tests are obtained from MacKinnon (1996). Level regressions include intercept and trend but difference regressions contain intercept only.

In the same manner, the panel data properties were checked using different panel root tests such as Im, Pesaran, and Shin (IPS, 2003) test; Fisher- type Augment-Dickey Fuller (F-ADF) of Maddala and Wu (1999); Fisher-type Phillips-Perron (F-PP) of Choi (2001); and Hadri (2000) which is the panel application of KPSS test of Kwiatkowski *et al*. (1992). The results of panel unit root tests are displayed in Table 2 which states that the panel variables are stationary in their first difference.

Table 2. Panel unit root tests

	Level				First Difference			
Variables	IPS	F-ADF	F-PP	Hadri	IPS	F-ADF	F-PP	Hadri
y	0.19	24.52	19.53	13.48*	-7.74*	119.69*	143.98*	0.96
re	5.55	19.66	27.12	12.68*	-15.03*	247.96*	416.01*	5.84*
nre	-0.83	33.59	40.65	7.39*	-9.36*	154.85*	288.19*	-0.01
o	3.59	7.08	6.08	12.04*	-13.26*	216.29*	331.64*	0.31
k	3.71*	65.37*	37.81	6.34*	-9.36*	144.78*	192.48*	-0.98
1	2.52*	68.99*	99.45*	10.05*	-10.76*	171.21*	307.39*	0.17

Notes: * denotes the rejection of the null hypothesis at 1% level of significance.

On implementing the first stage of the ARDL procedure, the cointegration relations were tested using both the F-test procedure and the statistical significance of the lagged error term. The lag selection procedure on differenced equations was implemented using AIC (Akaike Information Criterion) with lag length being set as two in order to minimize the loss of degrees of freedom. The summary results, along with some other diagnostics, such as LM test of autocorrelation, Ramsey's RESET test of mis-specification and stability tests of CUSUM and CUSUMSQ, are displayed in Table 3.

Table 3. ARDL approach to cointegration summary diagnostics

	Cointegration Tests			Short-run model diagnostic test statistics		Stability Tests
Countries	F-statistic	EC_{t-1}	t-statistic for EC_{t-1}	LM	RESET	CUSM ($CUSM^2$)
Austria	2.75	-0.12	1.76	0.22	1.05	S(S)
Belgium	2.28	-0.06	1.14	0.42	22.05	S(S)
Denmark	2.93	-0.37*	2.78	2.79	0.46	S(S)
Finland	3.41	-0.14*	3.06	1.34	3.75	S(NS)
France	6.92*	-0.09*	4.93*	5.35	0.03	S(S)
Germany	3.79*	-0.17*	3.87	0.07	0.29	S(S)
Greece	1.82	-0.49*	5.51*	0.04	NA	S(S)
Ireland	3.82*	-0.31**	1.99	0.04	1.22	S(NS)
Italy	3.78*	-0.37*	2.69	0.75	6.66	S(S)
Luxembourg	1.54	-0.05	1.53	0.73	13.78	S(S)
Netherlands	2.93	-0.45*	5.97*	0.69	0.77	S(S)
Portugal	3.77*	-0.37*	4.22	0.13	4.27	S(S)
Spain	1.24	-0.01	0.54	0.10	NA	S(S)
Sweden	1.39	-0.06	1.61	1.43	4.67	S(NS)
United Kingdom	1.25	-0.14*	2.16	0.08	0.14	S(S)

Notes: a. Numbers inside the parentheses are absolute value of t-ratios. *, ** indicate significance at the 5% and 10% levels respectively.

b. The upper bound critical value of the F-test for cointegration when there are five exogenous variables is 3.39 at the 5% level of significance. This comes from Pesaran *et al*. (2001, Table CI, Case III, p. 300).

c. The critical values for significance of ECM_{t-1} with five exogenous explanatory variables is -5.04 (-4.43) at the 5% (10%) level of significance. These come from Benarjee *et al*. (1998, Table I, with sample size less than 50. p. 276).

d. LM is the Lagrange Multiplier statistic to test for autocorrelation. It is distributed as χ^2 with one degree of freedom. The critical value is 3.84 at the 5% level and 2.70 at the 10% level.

e. RESET is Ramsey's test for misspecification. It is distributed as χ^2 with one degree of freedom. The critical value is 3.84 at the 5% level and 2.70 at the 10% level.

f. CUSUM and $CUSM^2$ stand for two alternative stability tests of Brown *et al*. (1975). S denotes stability and NS indicates non-stability.

In a close inspection of Table 3, it is clear that, based on the F-test procedure, only five countries of the EU-15 are qualified to have cointegrating regression equations since the reported F-statistics exceed the boundary critical values. These countries are France, Germany, Ireland, Italy and Portugal. Relying on the statistical significance of the lagged error correction term, which is based on the t-statistical significance of EC_{t-1}, it was possible to increase the number of cointegrating relationships by two more countries, namely Greece and the Netherlands, as their error correction equations produced statistically significant lagged error correction coefficients. These results imply that we are able to estimate the cointegrating relationships only seven countries of the EU-15. Diagnostic tests of the selected seven countries are, by and large, statistically satisfactory. In the second stage of the ARDL procedure, the cointegrating relationships of seven countries of the EU-15 were estimated and the results are presented in Table 4.

Table 4. ARDL approach to cointegration summary long-run results

	Estimated coefficients					
Countries	Constant	*re*	*nre*	*o*	*k*	*l*
France	58.45	-0.23	-0.28	0.69	0.14	-5.01
	(7.83)*	(1.95)**	(4.21)*	(4.40)*	(0.48)	(3.58)*
Germany	37.20	-0.09	-0.79	0.46	0.01	3.22
	(2.43)**	(1.55)	(1.58)	(2.39)**	(0.05)	(6.04)*
Greece	9.62	0.27	0.43	0.04	0.38	0.35
	(6.88)*	(5.27)*	(12.8)*	(0.39)	(5.26)*	(0.79)
Ireland	-11.79	0.07	1.13	-0.49	-0.24	3.00
	(2.76)**	(0.73)	(5.01)*	(1.39)	(0.78)	(1.53)
Italy	11.84	0.02	0.52	0.12	0.52	1.12
	(3.84)*	(0.23)	(9.40)*	(1.13)	(2.57)**	(1.62)
Netherlands	13.92	-0.02	0.09	0.47	0.03	2.21
	(6.55)*	(1.74)***	(0.81)	(6.75)*	(0.34)	(9.38)*
Portugal	10.34	0.15	0.34	0.21	0.04	0.69
	(8.33)*	(3.98)*	(17.9)*	(1.89)**	(0.54)	(1.72)***

Notes: *, ** and *** indicate, 1%, 5% and 10% significance levels, respectively. The absolute t-ratios are presented in parentheses. The order of optimum lags is based on the specified ARDL model.

According to Table 4, only three countries of the EU-15 appear to have all the correct signs of the estimated production function: Greece, Italy and Portugal. The sign expectations have failed in other countries either by one variable such as the Netherlands, or more variables such as Germany, France and Ireland. Regarding the relative impacts of renewable and non-renewable energy on output level, it seemed that the relative impact of non-renewable energy on output levels is higher during the estimation period which indicates that these countries are still heavily dependent on fossil energy input for their production. For example, Greece is able to increase its output level by 1% if non-renewable energy input is raised by 0.43% whilst other production factors remain constant. The relative impact of renewable energy input on output is the lowest in Italy and highest in Greece. As for the impact of international trade on output, it has the lowest magnitude in Greece but it has the highest impact in Portugal, which indicates more international trade reliance of Portugal for its economic growth. Results are similar to findings of Alper and Oguz (2016) where renewable energy has significant but relatively low impact on economic growth in new EU member countries. The effect of trade is found with positive sign as well but slightly higher in the panel of South East European countries by Fetahi-Vehapi *et al*. (2015).

The GMM estimation results are displayed in Table 5, which suggests that the sign expectations on the estimated parameters are fully realized.

Table 5. GMM Results

Estimated Coefficients						
re	*nre*	*o*	*k*	*l*	NI	ST
0.15	0.33	0.40	0.53	1.37	4	0.23
(12.41)*	(7.79)*	(7.60)*	(9.64)*	(3.47)*		

Notes: The absolute t-ratios are presented in parentheses. NI refers to the for number of instruments and ST (Sargan *p* values) are reported in last two columns.

The GMM results also reveal that the dynamic relations of output, renewable and non-renewable energy inputs along with international trade, capital and labour exist as a panel group of the EU-15 during the estimation period. The magnitude of the estimated coefficients indicates the relative importance. For example, the estimated parameter of renewable energy variable is less than half of the non-renewable energy variable, which suggests that the EU-15 has still a long way to go to transform its production function in regards to energy inputs, the similar results are found by Jebli and Youssef (2015), Tugcu *et al*. (2012), where the impact of non-renewable energy on output significantly exceeds the impact of renewable energy. Considering that the EU set out to reduce fossil energy consumption substantially in order to meet its GHGs emission by 2030 or by 2050, the estimation of this production function in the future may produce more favorable results in terms of the relative impact of energy inputs on output, as the EU gets close to meeting its key targets on climate change. The impact of international trade is also substantially noticeable on output level which proves that the EU-15 countries benefit considerably from international trade.

5. Concluding Remarks

This research has tried to explore the impact of renewable energy, non-renewable energy, international trade, capital and labour on output level in the case of the EU-15 countries over the period of 1980-2015. To this end, an extended production function, which uses capital and labour along with renewable energy and non-renewable energy inputs and international trade, was formed and was estimated econometrically with two different procedures, including time-series and panel econometric techniques. Even though the energy economics literature is rather abundant with different aspects of these relationships, it is the first time that this study presented empirical evidence on production functions of the EU-15 countries from time series econometric techniques as well as panel econometric procedures.

The econometric results obtained from the ARDL procedure proved the existence of the cointegration relationships in only seven of the EU-15 countries. Out of these seven countries, the production functions of Greece, Italy and Portugal fulfilled the sign expectations fully. Thus, the inferences drawn from these results should be treated with caution. However, the results of the GMM estimations on the same production appeared to be more satisfactory in regards to the sign expectations of the extended production function. Moreover, in relating to the key targets of the EU on climate change for 2030 and 2050, it is safe to infer that the EU-15 countries are going in the right direction to transform their production function as such that more renewable energy inputs compared to non-renewable energy inputs will be used in the near future. As the EU seems to be very committed to achieve the reduction of the GHGs back to the 1990 levels, it is naturally expected that the share of fossil energy consumption will decline sharply in the future. Promoting the increase of usage of renewable energy production and consumption requires considerable tax incentives, special credit schemes, and political willpower to meet the heavy cost of this transition period. To this end, the EU is well prepared and more determined than any single nation at present. The EU has also a moral responsibility to help those developing nations in tackling the cost of climate change as their limited resources cannot cope with the cost of substituting renewable energy sources with non-renewable energy sources. Therefore, the EU should provide further international trade incentives to these developing countries. The international trade incentives in the form of reducing production costs or allowing special export deals will be more beneficial for both parties as the EU has already been enjoying the impact of international trade on output.

Nevertheless, the impact of all these positive policy changes on environmental quality will be limited due to the fact that there are limits to substitution and technological change. Innovations that reduce one type of hazardous emission (for example, flare gas desulfurization) often produce a different type of waste that must be disposed of, as well as other disruption required to implement the technology, as put forward by Stern (2004).

Dependency on fossil energy sources also creates a dilemma because the economic growth dependent on energy inputs, which are currently largely provided by fossil energy sources, are not easily replaceable currently, and by nature they face extinction in the foreseeable future. Therefore, it is crystal clear that production function should be redefined with new inputs of energy such as renewable resources of hydroelectricity, wind energy, solar energy, etc.

As for the shortcomings of this study, it should be noted that this research has just concentrated on the relative importance of renewable and non-renewable energy use on output and neglected the role of nuclear energy on output. Some members of the EU-15 countries, notably France, Germany and the UK, are heavily reliant on nuclear energy. Nuclear energy is not considered to be environmentally friendly and to be potentially dangerous for human beings. Therefore, its use as an energy input in production has been declining world-wide. Our econometric results may suffer due to the omission of nuclear energy consumption particularly in those countries, which are heavily dependent on this form of energy input in their production. In the energy economics literature, there is a special strand of literature on nuclear energy and economic growth nexus; see for example, Mbarek, *et al*. (2017).

Appendix

Data definition and sources

Annual data of 1980-2015 are used for the estimations and they come from International Financial Statistics of the International Monetary Fund (IMF) and World Development Indicators of the World Bank (WB). The EU-15 countries consist of Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Sweden and United Kingdom.

y is GDP in constant 2010 US$. Source: WB

re is electricity production from renewable sources such as hydroelectricity, solar, wind in kWh. Source: WB.

nre is electricity production from non-renewable energy source such as oil, gas and coal sources in kWh. Source: WB

o is trade openness ratio defined as export and import as % of GDP. Source: IMF

k is gross fixed capital formation as % of GDP. Source: WB.

l is labour force participation rate as of % of total population aged 15+. Source: WB.

All variables are in their natural logarithms in econometric estimations.

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