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Effects of renewable energy sector development on electricity consumption – Growth nexus in the European Union

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ABSTRACT

The aim of this study is to assess the effect of renewable energy sector development on the relationships between electricity consumption and economic growth in the European Union countries in the period between 1995 and 2015. A panel vector autoregressive model is used for testing Granger causality and estimating impulse-response functions. The results indicate that the relationships between economic growth and electricity consumption depend on the level of renewable energy sector development. The greater the share of the renewable energy sector in the economy is, the more noticeable the mutual dependence between the economic growth and renewable electricity consumption is. In countries with relatively well-developed renewable energy sectors renewable electricity consumption boosts the economy and vice versa. In the remaining countries economic growth and electricity consumption are independent. Empirical findings suggest that policymakers should develop strategies to implement clean energy policy aimed at stimulating the development of the renewable energy sector to support economic growth.

1. Introduction

In November 2016 the European Commission published a set of eight legislative acts entitled “Clean energy for all Europeans”, also called the Winter Package, regarding the update of its energy policy framework for the years 2020–2030. The package is a continuation of the 2020 Climate and Energy Package issued with a target of 20% of RES in 2020 (Directive 2009/28/EC). In December 2018, the new Renewables Energy Directive (2018/2001/EC) [1] entered into force establishing a new binding renewable energy target for the EU for 2030 of at least 32%, with a clause for a possible upwards revision by 2023. And in November 2018 the European Commission adopted a strategic long-term vision for a prosperous, modern, competitive and climate neutral economy by 2050: A Clean Planet for all.

The political pressure to develop the renewable energy sector may not be neutral for economy. One the one hand, energy obtained from ‘new’ renewables significantly boosts economic activity and employment in manufacturing and services [2–5] and promotes R&D by means of innovation, patents and technology. In the longer term, renewable energy increases energy security, which improves the overall business environment, supports the transition to a low-carbon future, improves the environment and reduces the amount of harmful dust (smog) and greenhouse gases. On the other hand, replacing fossil fuel (conventional) energy with renewable energy may have a negative impact on economic growth, as it leads to changes in the employment structures, such as a reduction of employment in the fossil fuel energy sector in particular regions Renn and Marshall [6].

The relationships between renewable energy consumption and economic growth are of interest to researchers. Most studies focus on European countries that occupy a leading position in the use of renewable energy sources. Rafindadi and Ozturk [7] reveal a positive impact of renewable energy consumption on economic growth in Germany, the leader in renewable energy consumption in Europe. The results obtained for other countries in Europe are not so clear-cut. In Menegaki's [8] analysis of European countries, no relationship is found between economic growth and renewable energy consumption, which is explained by an unevenly distributed and inadequate exploitation of renewable energy sources in Europe. Majority papers, however, concentrate on four hypotheses (the conservation, feedback, growth and neutrality hypotheses) when analysing the renewable energy consumption-growth nexus. The results are ambiguous. Most studies confirm the growth hypothesis (energy consumption affects economic

Abbreviations: TPES, total primary energy supply; IRF, impulse response function; EU, European Union; GDP, gross domestic product; WDI, world development indicator; GMM, generalized method of moments; RES, renewable energy sources; PVAR, Panel Vector Autoregressive; MBIC, Bayesian information criterion; MAIC, Akaike information criterion; MQIC, Hannan and Quinn information criterion

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growth) [7,9–21]. Some studies provide empirical evidence for the opposite hypothesis, i.e., the conservation hypothesis [15,22–25]. The feedback hypothesis is confirmed in Refs. [19,26,27]. No relationship is found between economic growth and renewable energy consumption in Refs. [8,15,21,27,28].

The above-mentioned arguments concerning the economic, social and environmental benefits as well as threats resulting from the development of renewable energy sources are the essence of the ongoing policy debate (see e.g., Renewables Global Futures Report: Great debates towards 100% renewable energy [29]). What is more, the European Climate and Energy Package [30] imposes an obligation on Member States to increase the RES share regardless of the impact this will have on their economic growth.

This study focuses on the impact of renewable electricity consumption on economic growth. The choice of electricity (consumption) instead of energy consumption, most frequently considered so far, is motived by two reasons. First, the trend of electrification of economy (see Marques et al. [31]), makes the electricity consumption a "limiting factor to economic growth" [32]. Second, according to the World Economic Forum [33], electrification is critical for decarbonisation, thus electricity consumption is expected to increase.

As the development of renewable energy results mainly from the European Union's renewable energy policy, the analysis indirectly assesses the effect of this EU's policy on economic growth. In this sense, this study contributes to a discussion devoted to potential benefits of promoting the development of renewable energy sources in the European Union countries.

The aim of this study is to assess the effect of the development of the renewable energy sector on the relationships between electricity consumption and economic growth in the European Union countries in the period between 1995 and 2015. Bearing in mind the limitations listed in Menegaki [8], the analysed countries have been divided into two groups according to the development of their renewable energy sectors. This division has been obtained using a clustering method and the data provided by EurObserv'ER's [34] barometers, which cover employment, investment, and turnover.

The assumption adopted in the study states that the size of the renewable energy sector share of the economy determines its importance (that is, the greater the share, the greater the importance). The study verifies four hypotheses (the conservation, feedback, growth and neutrality hypotheses) for the electricity consumption-growth nexus, considering their significant implications for energy policy.

The analysis is performed in two stages. The objective of the first one is to identify the countries that differ with respect to the development of their renewable energy sectors. Clustering is conducted by k-means methods, assuming two groups of countries. In the second stage, the recent Panel Vector Autoregressive (PVAR) framework proposed by Abrigo and Love [35] is employed to investigate the relationships between renewable and non-renewable electricity consumption and economic growth in both groups of countries and in all countries together. The PVAR runs on a Generalized Method of Moment (GMM) framework and assumes that all the variables in the system are endogenous and allows for assessing the unobserved individual heterogeneity (fixed effects). The PVAR is applied for analysing Granger causality and the impulse response function (IRF), which helps to improve understanding of the direction of the electricity consumption-growth nexus.

The novel aspects of this study can be summarised as follows.

First, the empirical strategy on which the study is based divides the analysed countries into groups depending upon their renewable energy sectors' development and next investigates the electricity consumption-growth nexus. The division is crucial because the EU countries are greatly diversified in this respect, and previous studies have not addressed this issue directly. The results of the study are important in the context of implications for both energy policy and the scientific debate. The relationships between economic growth and renewable electricity consumption found in countries with well-developed renewable energy sectors can serve as practical guidelines for countries in which this sector is not so advanced.

Second, the model employed in the study, i.e., the panel VAR, has an advantage over other approaches used so far because it allows not only for testing Granger causality but also for studying the impulse response function. It is an important extension, as Granger causality does not necessarily imply causality (see Kilian and Lütkepohl [36], pp198) and does not provide information about the direction of the relationship. Both interpretations of the panel VAR in this approach complement each other and reveal the interaction between renewable electricity consumption and economic growth.

Finally, to the best of our knowledge, no previous studies have considered the development of the renewable energy sector in their analyses of linkages between renewable and non-renewable electricity consumption and economic growth in the EU member states.

The following sections can be found in the study. Section 2 reports the findings of other studies investigating the energy-growth nexus in the EU countries. Section 3 describes methodology, Section 4 reports the data, and Section 5 presents the empirical results with discussion. The paper ends with the conclusions and policy implications.

2. Literature review

The main research area has thus far focussed on linkages between economic growth and energy consumption. Considering discrepancies concerning the existence and direction of the dependencies, four hypotheses describing causal relationships between electricity consumption and economic growth are given in the literature: the conservation hypothesis, the feedback hypothesis, the growth hypothesis and the neutrality hypothesis Ozturk [32]. To verify these hypotheses, the authors use various methodological approaches (a detailed review of these methods can be found in, e.g., Smyth and Narayan [37]). Of these surveys, the studies Ozturk [32], Payne [38], Omri [14], Serbi [39], and Adewuyi and Awodumi [40] provide very comprehensive reviews on different aspects of energy and economic growth. An extensive review of the literature devoted to relationships between energy, environment and economic growth can be found in Tiba and Omri [41]. The article offers listings (1978–2014) of causal relationships between energy use variables and the environment and documents economic growth for both individual countries and groups of countries. In general, the articles report conflicting results, which might stem from the fact that their analyses are based on different databases, countries and variables and follow different methodological approaches. The electrification of the economy noticed in recent years has given rise to articles investigating the relationships between electricity consumption and economic growth.

The literature review covers only those articles whose authors analysed European countries. Table 1 offers an overview of articles focussing on energy and electricity consumption and economic growth in European countries.

Most studies investigating individual countries confirm the effect of energy consumption on GDP [42,44,46,47][83] or the effect of electricity consumption on GDP [13,16,31,66]. Turkey is the only country in which the studies mentioned above do not find any relationships between GDP and energy consumption Soytas and Sari [38]. The results obtained when analysing groups of countries are not clear-cut. The analyses of dependencies between energy consumption and GDP most frequently confirm the neutrality hypothesis Menegaki and Ozturk [49], Śmiech and Papież [50]. Only Menegaki et al. [54] and Shahbaz et al. [52] confirm the feedback hypothesis. However, a different picture is revealed when renewable and non-renewable energy consumption and their effect on GDP are considered separately; in this case, either the feedback hypothesis [9,56,61] or the growth hypothesis [11,12,18,64] is usually confirmed. Only Menegaki [8] confirms the neutrality hypothesis, which implies a lack of causal relationship between renewable energy consumption and GDP in 27 EU member

Table 1
Overview of the main studies in the area.

Study/source	Period	Country	Conclusions	Methodology
the energy consumption (EC)-growth (GDP) nexus for country-specific studies				
Soytas and Sari [42]	1960–2000	Turkey	GDP ≠ EC	Toda-Yamamoto causality test
Tsani [43]	1960–2006	Greece	EC= > GDP	Granger causality test
Apergis and Danuletiu [44]	2000–2011	Romania	EC = > GDP	Panel Error Correction Model
Fuinhas and Margues [45]	1965–2009	Portugal, Italy, Greece, Spain and Turkey	EC ⇔ GDP	ARDL
Dergiades et al. [46]	1960–2008	Greece	EC= > GDP	Non-linear Granger causality
Magazzino [47]	1970–2007	Italy	EC = > GDP	Granger causality test
the energy consumption (EC)-growth (GDP) nexus for multi-country studies				
Acaravci and Ozturk [48]	1960–2005	19 EU countries	Results are mixed	ARDL
Ozturk and Acaravci [27]	1980–2006	Albania, Bulgaria, Hungary, Romania	Results are mixed	ARDL, VECM
Pirloge and Cicea [10]	1990–2010	Spain, Romania and European Union	EC= > GDP	Granger causality test
Menegaki and Ozturk [49]	1995–2009	26 European countries	GDP ≠ EC	Two-way fixed effects model
Śmiech and Papież [50]	1993–2011	25 EU countries	EC ≠ GDP	Bootstrap Granger panel causality
Caraiani et al. [51]	1980–2013	5 emerging countries (Bulgaria, Hungary, Poland, Romania and Turkey)	Results are mixed	Granger causality test
Shahbaz et al. [52]	1970–2015	BRICS	EC⇔GDP (short term)	NARDL
Streimikiene and Kasperowicz [53]	1995–2012	18 EU countries	EC= > GDP	DOLS, FMOLS
Menegeki et al. [54]	2000–2012	25 countries	EC⇔GDP	ARDL
Yasar [55]	1970–2015	119 countries	Results are mixed	VECM Granger causality
the renewable energy consumption (REC)-growth (GDP) nexus for country-specific or multi-country studies				
Apergis and Payne [56]	1992–2007	13 countries within Eurasia	REC⇔GDP	FMOLS, Panel ECM
Menegaki [8]	1997–2007	27 European countries	REC ≠ GDP	Random effect model
Tugcu et al. [28]	1980–2009	G7 countries	REC= > GDP	OLS
Bilgili and Ozturk [12]	1980–2009	G7 countries	REC= > GDP	OLS
Alper and Oguz [15]	1990–2009	8 new EU countries	REC= > GDP (Bulgaria) GDP ≠ REC (Cyprus, Estonia, Hungary, Poland and Slovenia) GDP= > REC (Czech Republic)	Asymmetric causality test ARDL
Fotourehchi [18]	1990–2012	42 developing countries	REC= > GDP	Granger causality tests
Koçak and Şarkgüneşi [19]	1990–2012	9 Black Sea and Balkan countries	REC= > GDP REC⇔GDP	DOLS, FMOLS, Heterogeneous panel causality
Mahmoodi [24]	2000–2014	11 developing countries	GDP= > REC	Panel cointegration tests, VECM causality, DOLS
Rafindadi and Ozturk [7].	1970–2013	Germany	REC= > GDP (+)	ARDL bound test, VECM Granger causality
Armeanu et al. [17]	2003–2014	European Union	GDP= > REC	VECM Granger causality
Marinaş et al. [21]	1990–2014	Central and Eastern Europe	Results are mixed	ARDL
Saad and Taleb [25]	1990–2014	12 EU countries	GDP= > REC	VECM Granger causality
Ozcan and Ozturk [57]	1990–2016	17 emerging countries	REC ≠ GDP dla 16 REC= > GDP (Poland)	Bootstrap Granger panel causality
the renewable and non-renewable energy consumption (REC, NEC)-growth (GDP) nexus for multi-country studies				
Marques and Fuinhas [9]	1990–2007	24 European countries	REC ⇔ GDP NEC ⇔ GDP	OLS
Vaona [58]	1861–2000	Italy	NEC ⇔ GDP	Granger non-causality tests
Okyay et al. [11]	1990–2011	EU-15 countries	NEC = > GDP	Granger causality test
Omri et al. [59]	1990–2011	17 developed and developing countries	Results are mixed	OLS
Bhattacharya [60]	1991–2012	38 top renewable energy consuming countries	I group: REC = > GDP(+) II group: REC = > GDP(−) III group: REC ≠ GDP	DOLS, FMOLS, panel causality test
Kahia et al. [61]	1980–2012	MENA NOEC	GDP = > REC (short-term) REC ⇔ GDP (long-term)	Panel ECM methodology, FMOLS
Halicioglu and Keten [62]	1980–2015	EU-15 countries	Results are mixed	ARDL
Tugcu and Topcu [63]	1980–2014	G7 countries	Results are mixed	NARDL
Gozgor et al. [64]	1990–2013	29 countries	REC = > GDP NEC = > GDP	ARDL, PQR,
the electricity consumption (EL)-growth (GDP) nexus for country-specific studies				
Shabhaz et al. [65]	1971–2009	Portugal	EL⇔GDP	ARDL bounds test, Johansen cointegration test, VECM Granger causality
Gurgul and Lach [66]	2000–2009	Poland	EL = > GDP	Toda-Yamamoto causality test
Tang et al. [67]	1974–2009	Portugal	EL⇔GDP	VECM Granger causality
Dogan [13]	1990–2012	Turkey	REL = > GDP NEL ⇔ GDP	Vector error correction model, Granger causality test
Bento et al. [22]	1960–2011	Italy	GDP = > REL	ARDL
Marques et al. [16]	2010–2014	France	REL = > GDP	ARDL bounds test
Furuoka [23]	1992–2011	Estonia, Latvia and Lithuania	GDP = > REL	panel unit root test, panel cointegration test, panel causality test
Marques et al. [31]	2003–2016	Spain	EL= > GDP	Toda-Yamamoto causality test, ARDL bounds test
the electricity consumption (EL)-growth (GDP) nexus for multi-country studies				
Acaravei and Oztruk [68]	1990–2006	transformation countries	EL ≠ GDP	Pedroni cointegration, VECM Granger causality
Ciarreta and Zarraga [69]	1970–2007	12 European countries	EL= > GDP	VECM Granger causality
Wolde-Rufael [70]	1975–2010	15 transformation countries	The results are mixed	Bootstrap panel Granger causality

(*continued on next page*)

Table 1 (*continued*)

Study/source	Period	Country	Conclusions	Methodology
Alfonso et al. [71]	2010–2015	Estonia, Sweden	REL= > GDP	ARDL
Costa-Campi et al. [72]	2007–2013	22 European countries	EL= > GDP	Fixed effect panel data techniques

Note: EC = > GDP means that causality runs from energy consumption to growth. GDP = > EC means that causality runs from growth to energy consumption. EC⇔GDP means that bi-directional causality exists between energy consumption and growth. EC≠GDP means that no causality exists between energy consumption and growth. EC: energy consumption, REC: renewable energy consumption, NEC: non-renewable energy consumption, EL: electricity consumption, REL: renewable electricity consumption, NEL: non-renewable electricity consumption.
Source: author's own conception.

states. Similarly, the analysis of linkages between electricity consumption and GDP in many countries does not yield consistent results Wolde-Rufael [70], although the growth hypothesis is confirmed for selected countries [69,71,72].

3. Methodology

3.1. Cluster analysis

Cluster analysis is used for finding groups of similar objects that differ from objects in other clusters in a given population. In this study, cluster analysis is used to divide the EU member states into groups with relatively low and high levels of renewable energy sector development. Clustering is conducted by k-means, which is one of the most popular methods. The k-means procedure utilises several steps in which relocation of objects into classes (whose number is given) is conducted. The procedure is interrupted and the groups are established if there are no further relocations of any object. In the study, the k-means procedure is repeated 500 times for different choices of seeds to make the result robust.

3.2. Panel VAR models

The panel VAR approach recently developed by Abrigo and Love [35] is applied in this study. There are two advantages of this approach: all variables in the model are treated as endogenous allowing for unobserved individual heterogeneity and the individual effects introduced in the model allow for better consistency of estimation.

An estimating panel VAR model requires pre-testing for unit root and cointegration. First, to analyse the non-stationarity of time series, the study uses the second-generation panel CIPS unit root test presented by Pesaran [73]. Next, to examine cointegration, the study uses Westerlund's panel cointegration test Westerlund [74]. Both tests consider cross-sectional dependence of panels. A reduced form of panel VAR of order p with a panel-specific fixed-effect model can be represented by the following system of linear equations:

$$Y_{it} = A_1 Y_{it-1} + A_2 Y_{it-2} + \dots + A_p Y_{it-p} + u_i + e_{it}, \text{ for } i \in \{1,2, ..N\},\ t \in \{1,2, .., T\} \tag{1}$$

where Y_{it} is a $(1xk)$vector of variables $(\Delta \ln GDP_{it}, \Delta \ln REL_{ti}, \Delta \ln NREL_{it}, \Delta \ln K_{it}, \Delta \ln L_{it})$, $u_i$is fixed effects, and e_{it} is idiosyncratic errors, while$A_1, A_2, \dots, A_p$ are (kxk) matrixes of model parameters to be estimated. It is assumed that innovations have the following characteristics: $E[e_{it}] = 0, E[e'_{it}e_{it}] = \Sigma$ and $E[e'_{it}e_{is}] = 0,\ \ t > s$.The last assumption indicates a model without dynamic interdependencies. Finally, it is assumed that VAR is stable, which means that all characteristic roots lie outside the unit circle Lütkepohl [75]. The use of fixed effects panel VAR raises correlation problems between the regressors. The Hermelet procedure proposed by Arellano and Bover [76] is applied to overcome this obstacle. The system of equations is estimated on the basis of a generalized method of moments (GMM) and with the regressors lagged as instrumental variables.

Two applications of panel VAR are used in the study. First, Granger causality, which utilises the Wald test, is implemented to uncover the relationships between electricity (renewable and non-renewable) consumption and economic growth. Second, the orthogonalised impulse-response function is used to illustrate the reaction of one variable to the shocks to another variable in the system. The standard Cholesky decomposition is adopted as the identification strategy.[1]

4. Data

The annual panel data are used to assess the effect of the development of the renewable energy sector on the relationship between renewable and non-renewable electricity consumption and economic growth. The analysis is conducted for 26 EU member states in the period between 1995 and 2015. Cyprus and Malta are omitted in the analysis because no data on the share of RE sources in TPSE in these countries are available. The two stages of the study use different sets of variables. The first one describes the level of renewable energy sector development, whereas the second one is used to analyse the relationship between renewable and non-renewable electricity consumption and economic growth.

The dataset used in the first stage illustrates the level of renewable energy sector development expressed in terms of socioeconomic variables, economic activity, and financial aspects. The first variable is the ratio of employment in the renewable energy sector to total employment (people aged from 15 to 64) in each EU member state (EMP).[2] The second variable is the ratio of combined turnover in the renewable energy sector to GDP (at current prices) in each EU member state (TURN). The third variable represents the GDP share of investment in the renewable energy sector (both at current prices) in each EU member state (INVEST). The data referring to employment, turnover and investment come from the EurObserv'ER's barometers (2011–2016) [34,77–81].[3] Because the data have been recorded since 2010, all

[1] We assume that current shocks to GDP per capita affect renewable and non-renewable electricity consumption per capita contemporaneously and with a lag; however, both electricity consumptions have an effect on the aggregate income only with a lag. In this approach the GDP per capita is treated as more exogenous, while electricity consumptions are treated as more endogenous.

[2] The variable covers jobs both directly and indirectly offered by this sector and expresses gross employment, i.e., does not consider job losses in other industrial sectors due to expenditure and investment in these sectors.

[3] To the best of our knowledge, the project "The state of renewable energy in Europe" which includes EurObserv'ER Report dataset is the only one to provide high-quality and comparable statistical data regarding the macroeconomic and financial activity of the renewable energy sectors in economies of all EU countries. This project is financed by the European Union under agreement No. ENER/C2/2016-487/SI2.742173. This report, in addition to the information concerning installed capacity and electricity production from renewable sources, this report includes three socio-economic indicators related to the renewable energy sector, i.e. employment and tuning, and investment. There is no additional information provided in this database. Thus, for example, the average salary in the renewable sector is not covered in this database.

Table 2
Summary statistics for average values in the period 2010–2015 (in %).

Variable	Mean	Min	Max	SD
EMP	0.57	0.22	1.60	0.37
TURN	1.32	0.22	4.12	0.85
INVEST	0.20	0.00	0.81	0.18

available records from the period between 2010 and 2015 are used,[4] and average values from this period are calculated to investigate the extent to which particular countries were engaged in the renewable industry. Table 2 contains a detailed description of these variables.

As Table 2 demonstrates, the renewable energy sectors are relatively small in comparison to their whole economies. What is important, the analysed countries differ significantly with respect to their share of employment in the renewable energy sector as a fraction of total employment (EMP). The average value of EMP (in the period 2010–2015) is 0.57%, with the maximum value 1.59% in Denmark and the minimum value 0.22% in Poland. Similar diversity is observed in the value of TURN. The average for the EU member states is 1.32%, in Denmark, 4.12%, and in Luxembourg, 0.22%. The greatest diversity among the analysed countries is observed in the GDP share of investments in the renewable energy sector (INVEST). With the average equalling 0.20%, there are countries in which INVEST in the observed period is very low (for example, Hungary – 0.05%, Czech Republic – 0.03%, Luxembourg – 0.02%, Latvia – 0.01%, and Slovenia – 0.01%), or non-existent (Croatia). Conversely, only in Bulgaria does the level of these investments exceeds 0.8%.

In the second stage of the study, the relationships between renewable and non-renewable electricity consumption and economic growth are analysed. Real gross domestic product per capita (variable: GDP) in constant 2010 U.S. dollars obtained from the World Development Indicators [82] is used as a measure of the economic output. Electricity consumption from renewable energy sources (REL) and electricity consumption from non-renewable energy sources (NREL) are defined as gross electricity generation from renewable (or non-renewable) sources expressed in terms of terawatt hours (TWh) per capita, respectively. These data are accessed from the European Commission websites.[5] In order to mitigate the problem of omitted variable bias, the electricity consumption–growth nexus is studied within an economic model - the Cobb-Douglas production function.[6] What is more, a given model specification follows Ozturk [32] recommendations, who suggests including additional information to the energy-growth nexus models. In consequence two additional variables have been added: real gross capital formation per capita (K) in constant 2010 U.S. dollars for the growth of capital stock and the labour force participation rate (% of total population aged 15+) (L), both of which are given by the WDI [82]. All variables are in natural logarithms.

5. Empirical results and discussion

5.1. Level of renewable energy sector development in economy

The aim of this part of the study is to find similarities between analysed countries within the area of the development of their renewable energy sectors. The groups are formed by comparing three variables: EMP, TURN and INVEST, all of which are initially standardised. The data cover the period 2010–2015. The *k*-means method is employed to find clusters in the EU member states related to share of the renewable energy sector. The results of the k-means method allow indicating two separate groups of countries with different levels of development of their renewable energy sectors. The first group (GROUP 1) includes countries with a relatively well-developed renewable sector; the second one (GROUP 2) includes countries with a not well-developed renewable sector.[7] The two groups are presented in Table 3. The statistics for the original variables across the groups are presented in Fig. 1.

The countries from the first group (GROUP 1) are characterised by the highest (compared with other groups) ratio of employment in the renewable energy sector as a fraction of total employment (EMP) (0.92% in comparison to 0.38%; see Fig. 1) and are much more diversified with respect to EMP (standard deviation equals 0.43% for the first group and 0.13% for the second group) than are countries from the other group. The minimum values are similar in both groups; in the first group, the minimum value is observed in Romania (0.22%), and in the second group, in Poland (0.21%), whereas the highest values can be found in Finland (1.49%) and Denmark (1.59%). The results are similar when the ratio of turnover in the renewable energy sector to GDP (TURN) is considered. The countries from GROUP 1 display significantly higher values of TURN than do the countries from GROUP 2, but their diversity is not as high as in the case of employment. TURN is high in Denmark (4.01%), whereas in Germany, it is one-third the value in Denmark (1.25%). The GDP share of investment in the renewable energy sector (INVEST) is characterised by smaller differences between the groups; both of them include countries with no INVEST, e.g., Latvia (GROUP 1) and Croatia (GROUP 2). The highest value of INVEST is observed in Bulgaria (1.00%). The first group is rather heterogeneous with respect to INVEST, with clear outlier values for Bulgaria and Romania (in which very low EMP is accompanied by high INVEST) and Denmark (with relatively low INVEST and the highest EMP and TURN).

The second group (GROUP 2) is far less diverse. The minimum value of EMP is similar in both groups, but the maximum value in the second group (in France – 0.69%) is lower than the average value calculated for the first group. The maximum value of TURN in the second group (the Czech Republic – 1.46%) reaches the minimum values of TURN in the first group, and the average value is twice as high (in GROUP 2, 0.85%, and in GROUP 1, 2.22%). Additionally, INVEST in GROUP 2 is on average lower than in the first group (0.12%), which is also true for diversity (0.10%), with the maximum value 0.32% in the United Kingdom.

To justify the clustering results, the countries from two group are compered according to the increase of the renewable energy share in the TPES in the period 1995–2015; see Fig. 2. The black colour indicates the countries from the first group; the grey colour indicates the countries from the second group. Most countries from the first group have the greatest renewable energy shares in the TPSE. The only exceptions are Bulgaria and Romania, which joined the EU in 2007 and 2013, respectively. Due to their high investments in renewable energy (mostly solar) in 2012, both of them belonged in 2015 to the group of five countries that met their renewable energy shares in TPES set for

[4] The problem we face is data availability. There are no comparable data for a longer period of time. Fortunately, the more intensive development of the "new" renewable energy (such as wind and solar) has only been observed in recent years.

[5] Energy datasheets: EU-28 countries https://ec.europa.eu/energy/en/data/energy-statistical-pocketbook https://ec.europa.eu/energy/en/data-analysis/country, accessed on 31.07.2018. Descriptive statistics are presented in Table A1.

[6] The Cobb-Douglas production function is frequently applied in studies devoted to the energy-growth nexus (e.g. Refs. [7,12,19,53,56,59–61,63,64]).

[7] Fig. A1 in Appendix shows the biplot, which displays the location of each country on the first two principal components. The loadings of the principal component are presented in Table A2. A relatively homogeneous group of countries with positive values of PC1 and moderate values of PC2 can be observed. The countries that belong to this group display a low share of the renewable energy sector. In the other countries at least one variable exceeds the average values; in other words, these countries develop their renewable energy sectors to the greatest extent.

Table 3
Groups of countries.

GROUP 1	Austria, Denmark, Bulgaria, Estonia, Finland, Germany, Latvia, Romania, Sweden
GROUP 2	Belgium, Croatia, the Czech Republic, France, Greece, Hungary, Italy, Ireland, Luxembourg, Lithuania, the Netherlands, Poland, Portugal, Slovenia, Slovakia, Spain, the United Kingdom

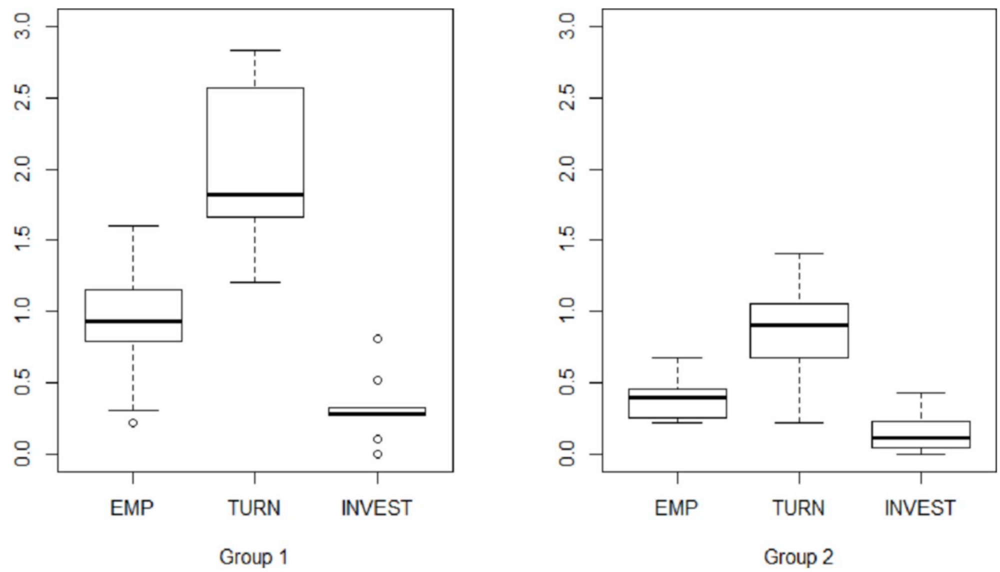


Fig. 1. Boxplot for variables representing countries' engagement in renewable energy.

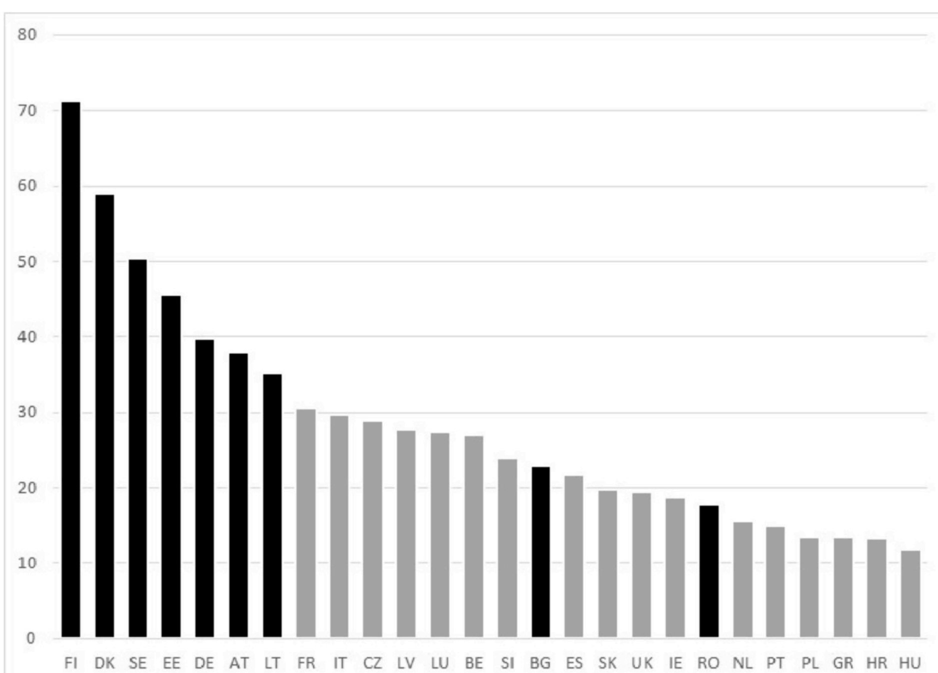


Fig. 2. Increase of renewable energy share in the TPES in the period 1995–2015.

2020; thus, they can be viewed as leaders in this field among other Central European Union member states. The importance of the last period (used in the clustering exercise) is crucial for the renewable energy sector in the European Union member states. The share of renewable energy sources in the total primary energy supply (TPES): from 5.1% in 1995 to 9.9% in 2010 (by 4.8 p.p. within 15 years) and almost the same increase (in the last 5 years) from 9.9% in 2010 to 13.0% in 2015. Also, their share of renewable energy sources in total electricity generation grew more in recent years: from 13.9% (in 1995) to 21.1% (in 2010) and to 29.9% (in 2015).

All the above points show that the clustering results obtained for the years 2010–2015 are highly correlated with the increase of renewable energy share in the TPSE in the period 1995–2015, which corresponds to the period of analysis adopted in the second stage of this study. Thus, it might be reasonably assumed that the clustering results obtained for the data expressing the share of the renewable energy sector in the

Table 4
Cross-sectional dependence tests (CD) (the null hypothesis: cross-sectional independence).

	lnGDP	lnNREL	lnREL	lnK	lnL
ALL	71.65***	30.31***	57.49***	49.79***	6.83***
GROUP 1	25.52***	3.34***	18.63***	20.02***	2.24***
GROUP 2	45.13***	29.10***	39.04***	29.87***	4.99***

Notes: ***, ** indicate statistical significance at 1 and 5% level of significance, respectively. The Stata "xtcd" command is used to calculate test.

period 1995–2015 would be similar to the results actually obtained for the period 2010–2015.

5.2. Causality analysis results

The analysis of the relationships between renewable and non-renewable electricity consumption and economic growth was performed for both groups separately (GROUP 1 and GROUP 2) and also as a robustness check for all EU member states (ALL).

5.2.1. Stochastic properties of the panel

First, cross-sectional dependence of the data is tested using Pesaran's [73] cross-sectional dependence (CD) test. Its results, provided in Table 4, confirm cross-sectional dependence, and the tests applied next incorporate this assumption. Consequently, the second-generation panel unit root tests proposed by Pesaran [73] and Westerlund's [74] panel cointegration test are used.

The results of Pesaran's [73] CIPS unit root test for all EU member states (ALL), which are presented in Table 5, demonstrate evidence for nonstationarity at this level. Having established nonstationarity of the time series, the study tests for the existence of a long-term relationship between economic growth and renewable and non-renewable electricity consumption.

Table 6 reports the results of Westerlund's [74] panel cointegration tests. To control for cross-sectional dependence, robust critical values are obtained through 1000 bootstrap replications. These results, obtained for lag length 1 and a constant and for all four statistics and different specifications (GROUP 1, GROUP 2 and ALL), reveal the lack of cointegration. Afonso et al. [20] draw similar conclusions with respect to economic growth and renewable and non-renewable energy consumption for 28 developed countries (including EU member states).

5.2.2. Panel VAR results

Considering the non-stationarity of the series and the lack of cointegration, the panel PVAR models for the first difference of the series are next analysed. Following Abrigo and Love [35], the PVAR model is estimated and Helmert transformation is used to address the orthogonality problem. Three criteria of lag selection, i.e. Bayesian information criterion (MBIC), Akaike information criterion (MAIC), and Hannan and Quinn information criterion (MQIC), indicate that the second-order PVAR models for all specifications (ALL, GROUP1, GROUP2) are preferred. The results of the PVAR model estimated by using "GMM-style" instruments for five variables {ΔlnGDP, ΔlnREL, ΔlnNREL, ΔlnK, ΔlnL} are reported in Table A3a-c. In order to check for robustness of the models, the stability condition of the estimated PVAR models is checked by computing the modulus of each eigenvalue. The results of the eigenvalues and modulus are shown in Fig. A2. All modulus are less than one, and all the eigenvalues stay inside the unit circle, so the PVAR estimates satisfy the stability condition. Following Abrigo and Love [35], this implies that the impulse response functions can be interpreted (Fig. 3a–c). Table 7 demonstrates the results of the Granger causality test, based on the Wald test [35], which cover the findings obtained for the first group (GROUP 1), the second group (GROUP 2) and all countries (ALL).

The results reported in Table 7 can be summarised in the following points. First, the results confirm the feedback hypothesis with respect to relationships between economic growth and renewable electricity consumption in the group of countries with relatively well-developed renewable energy sectors (GROUP 1). Second, the neutrality hypothesis is confirmed between economic growth and non-renewable electricity consumption for the countries in GROUP 1. Third, when the countries with not well-developed renewable sectors (GROUP 2) are considered, the results confirm the neutrality hypothesis between both renewable or non-renewable electricity consumption and economic growth. Changes in electricity consumption do not have an adverse effect on economic growth, and vice versa – changes in economic activity do not trigger changes in electricity consumption. Finally, the results (Table 7)

Table 6
Westerlund's [74] panel cointegration test statistics – values and robust p-values.

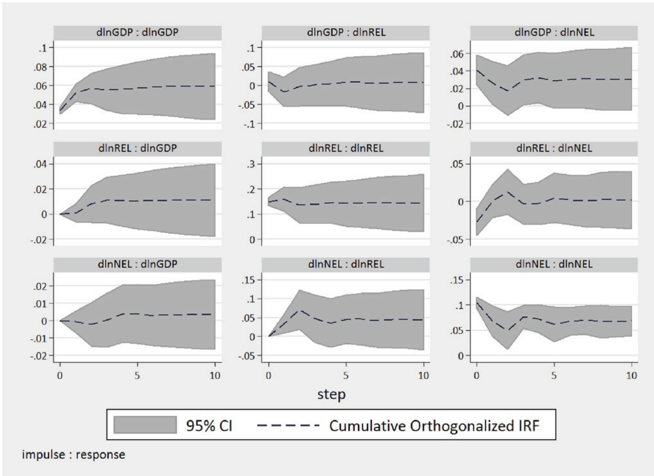
	ALL		GROUP 1		GROUP 2	
Statistics	Value	robust p-value	Value	robust p-value	Value	robust p-value
G_t	−0.927	0.988	−1.863	0.323	−0.432	1.000
G_a	−1.393	1.000	−1.886	0.888	−1.132	0.995
P_t	−2.277	0.978	−1.855	0.878	−1.524	0.985
P_a	−0.692	0.980	−0.777	0.888	−0.635	0.978

Notes: The null hypothesis: no cointegration. The Stata "xtwest" command is used to calculate Westerlund's [74] test.

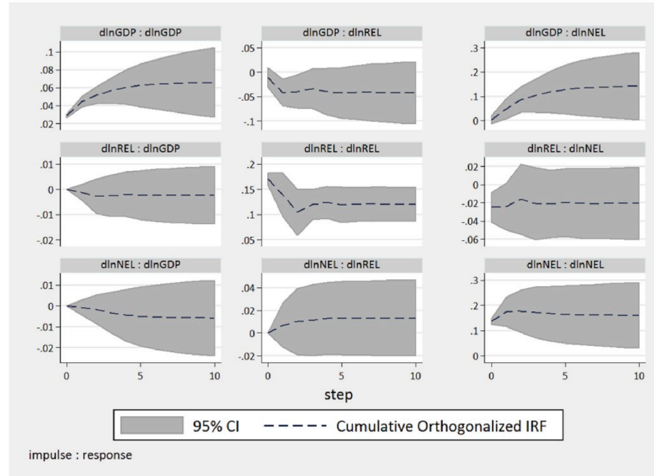
Table 5
Pesaran's (2007) CIPS panel unit root test results (the null hypothesis: unit roots for all cross-section units) for all European Union states (ALL).

Variables	Levels			First differences		
	CADF (0)	CADF (1)	CADF (2)	CADF (0)	CADF (1)	CADF (2)
(a) an intercept						
lnGDP	0.854	−2.610***	−2.482***	−3.533***	−2.458***	−2.176**
lnNREL	−0.017	0.046	0.911	−14.098***	−9.666***	−2.703***
lnREL	−4.783***	−4.215***	0.800	−14.751***	−10.234***	−3.507***
lnK	1.314	−1.967**	0.340	−10.072***	−8.293***	−5.244***
lnL	−0.713	−0.564	−0.149	−9.958***	−5.752***	−2.419***
(b) an intercept and a linear trend						
lnGDP	3.572	−2.444***	−1.482	−1.501*	0.863	1.695
lnNREL	−2.981***	−3.054***	2.204	−12.195***	−8.146***	−1.182
lnREL	−3.794***	−4.033***	0.986	−12.345***	−7.445***	−0.303
lnK	−0.100	−5.386***	−0.953	−7.599**	−5.117***	−2.212**
lnL	0.574	0.340	1.645	−9.023***	−5.093***	−1.352

Note: Lag order in brackets. ***, ** indicate statistical significance at 1 and 5% level of significance, respectively. The Stata "multipurt" command is used to calculate test.



a



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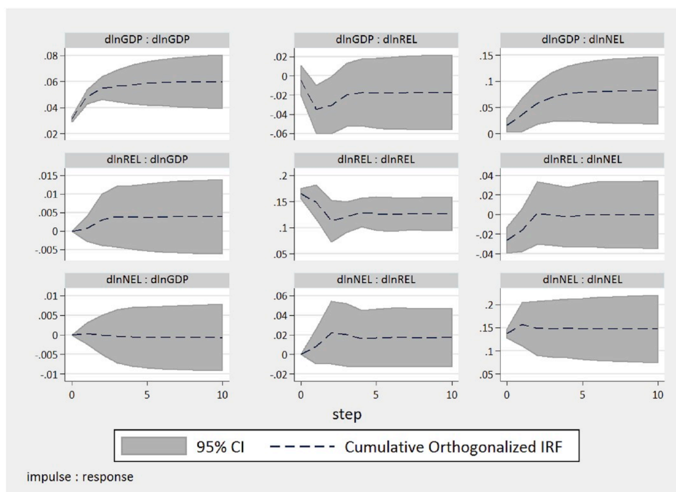

c

Fig. 3. a Impulse response functions for the countries belonging to GROUP 1. Fig. 3b Impulse response functions for the countries belonging to GROUP 2. Fig. 3c Impulse response functions for all European countries (ALL).

Table 7
The results of the panel Granger causality test.

Dependent variable	Source of causation (independent variables) – short term		
	Chi2 statistics		
	ΔlnGDP	ΔlnREL	ΔlnNREL
GROUP 1			
ΔlnGDP	–	**7.053****	0.639
ΔlnREL	**7.418****	–	9.910***
ΔlnNREL	1.716	4.116	–
GROUP 2			
ΔlnGDP	–	0.877	0.501
ΔlnREL	4.666	–	0.683
ΔlnNREL	2.626	1.431	–
ALL			
ΔlnGDP	–	1.754	0.272
ΔlnREL	**12.075*****	–	2.255
ΔlnNREL	**12.528*****	4.723	–

Notes: Δ is the first difference operator. The Stata "pvar" command is used to estimate the Panel VAR(2). ***, ** indicate statistical significance at 1 and 5% level, respectively.

confirm the conservation hypothesis between economic growth and both renewable or non-renewable electricity consumption for all European countries (ALL); therefore, the changes in renewable and non-renewable electricity consumption stem from the changes in economic activity in these countries (ALL).

5.2.3. *Impulse response functions*

To quantify the reaction of economic growth to electricity consumption and vice versa, the impulse response functions (IRF) are estimated. The Cholesky orthogonalisation procedure is used as an identification strategy. Monte Carlo simulation with 1000 iterations is used to estimate standard errors to generate the 95% confidence interval for the impulse response functions. The impulse response functions of non-renewable and renewable electricity consumption and economic growth to a one standard deviation shock in these variables are demonstrated in Fig. 3a–c.

The responses of renewable and non-renewable electricity consumption to one standard deviation shock to economic growth are presented in the first row of Fig. 3a–c. The first row of Fig. 3 a–c demonstrates a small positive and insignificant reaction of renewable electricity consumption to a shock to economic growth in the countries belonging to GROUP 1 (Fig. 3a). However, these relationships in the countries with not well-developed renewable energy sectors (GROUP 2) (Fig. 3b) and in all EU member states (ALL) (Fig. 3c) are negative but nevertheless insignificant. Conversely, the reaction of non-renewable electricity consumption to a shock to economic growth is statistically significantly positive in all groups (i.e., GROUP 1, GROUP 2 and ALL). However, in countries with relatively well-developed renewable energy sectors (GROUP 1), this positive reaction is statistically significant only in the first year. The second row of Fig. 3 a–c reveals a positive but insignificant reaction of economic growth to a renewable electricity consumption shock in the countries belonging to GROUP 1 and in all countries. The third row of Fig. 3 a–c illustrates the negative but insignificant reaction of economic growth to a shock to non-renewable electricity consumption in all EU countries and in countries belonging to GROUP 2.

5.3. Discussion

To summarise, this results indicate that the increase in economic growth exerts a minor, yet positive effect on renewable electricity consumption in the countries with relatively well-developed renewable energy sectors and a significant positive effect on non-renewable electricity consumption in countries in GROUP 2 and ALL. These results are not surprising because the fossil fuel share in total electricity generation is still meaningful. Between 1995 and 2016 the share of renewable energy sources in total electricity generation grew more than twofold – from 13.9% to 30.2%.

The most important results reveal that the development of the renewable electricity sector plays a substantial and positive role in economic activity in countries with relatively well-developed renewable energy sectors. When the renewable energy sector is insignificant, its effect on the economy is unlikely to be material. Moreover, if the level of renewable energy sector development is ignored, the results indicate that the changes in economic activity affect changes in electricity consumption, but neither conservative nor expansive electricity (renewable or non-renewable) consumption policies exert a noticeable effect on economic growth.

The comparison of this results with the one presented in previous studies is not straightforward. There are three reasons for that. First, the renewable and non-renewable electricity consumption – growth nexus for only EU countries (see Table 1) is investigated in a limited number of studies. Most analyses focus on either energy consumption (both renewable or non-renewable) or electricity consumption – growth nexus. Second, the majority of previous studies report the results of the Granger causality test, while in this paper it is complemented with the results of the impulse response function. Third, the groups of countries analysed in this study do not coincide with groups analysed in other studies, as they are identified following different criteria, so the samples in all the studies differ. Nevertheless, when we limit the comparison to the studies which investigate electricity (renewable) consumption – growth nexus, to some extent our findings are similar to the findings of previous studies. Aflonso et al. [72] report that renewable electricity consumption positively affects growth in Estonia and Sweden (both countries belong to the first group in our study), which is in line with our outcomes. Bento et al. [22] show that in Italy (which is in the second group in our study) renewable energy consumption does not impact economic growth.

There are, however, some differences. Marques et al. [16] reveal causality from renewable electricity to GDP in France, and Furuoka [23] finds an opposite relationship for Baltic States. The inconsistency between Furuoka [23] and our study can result from the fact that in this study Baltic states belong to two groups (EE, LT to the first group, while LV to the second group). The relationship found in Marques et al. [16] for France suggests that in this study it should belong to the group of well-developed countries. In fact, in France employment in the renewable energy sector is above the average (see Fig. A1), and the increase of the renewable energy share in the TPSE is also considerable (see Fig. 2). Nevertheless, the k-means method classified France to the second group.

6. Conclusions and policy implication

The results reveal two groups of countries which are greatly diversified in terms of the level of development of their renewable energy sectors. Renewable energy sectors in most EU countries are still relatively not well-developed, and only 9 countries have these sectors well-developed.

This study provides new insights into the literature on the electricity consumption – growth nexus, as it distinguishes groups of countries that differ in their level of development of the renewable energy sector. This distinction seems crucial because in most countries the renewable energy sector is still relatively not well-developed. This division allows for drawing the following conclusions. This study shows that the relationship between electricity consumption and economic growth depends on the level of development of the renewable energy sector. The greater the share of the renewable energy sector in the economy is, the more noticeable the relationships between economic growth and renewable electricity consumption are. New, original and the most important results of this study stem from analysing the countries with relatively well-developed renewable energy sectors. This study, in contrast to most previous papers based on Granger causality, finds that a rise in renewable electricity consumption boosts the economy. Conversely, renewable energy sectors in the remaining countries are not sufficiently large to play a substantial role in their economies. In addition, a worrying phenomenon can be observed in countries with a large share of the non-renewable energy sectors, as the increase in non-renewable electricity consumption may hamper economic development.

Two reservations of the study should be mentioned. First, in in most of the investigated countries, the “new” renewable energy is still at the initial phase. Thus, the results of the renewable electricity consumption–growth nexus obtained in this study should be related to an initial stage of renewable energy development. Second, the cost of power generation from wind and particularly the sun has been significantly reduced in recent years. This may indicate more gain in power generation from the same capital invested in the future and even more positive impact on economic growth.

Keeping this in mind, the results of this study obtained for these countries seem to be in line with the results of most recent studies in the field, which have confirmed the neutrality hypothesis (Menegaki [8], Acaravei and Oztruk [68], Ozcan and Otzurk [59]) for the more general renewable energy – growth nexus.

Consequently, our findings provide relevant policy implications, as they indicate that the promotion of renewable energy sources does not stifle economic growth, to say the least. In the future this promotion is likely to significantly boost economic growth. Therefore, apart from other important benefits resulting from the reduction of greenhouse gas emission or the increase of energy security, the development of renewable energy sources does not hamper economic growth. This suggestion supports the recommendation to develop renewable energy sectors in European countries and in countries outside the EU with similar conditions and similar levels of economic development. This message seems valuable, as in most EU countries (not to mention countries outside the EU) renewable energy is still not well-developed. This study contributes to the current debate on the promotion of renewable energy sources in the European Union countries [29]. This study delivers a clear message to policymakers that such development should be promoted because the risks of its negative effects on economic growth are low and the likelihood of potential benefits is high.

Our findings should be of interest to policymakers who are responsible for the implementation of energy policies, because they clearly demonstrate that promoting the production and consumption of green energy is a positive move. These policies should be aimed at stimulating economy sectors with low greenhouse gas emissions and reducing economy sectors with high greenhouse gas emissions.

Acknowledgement

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Appendix A

Table A.1
Descriptive statistics values in 1995 and 2015.

	GDP (constant 2010 US $ per capita)		REL (TWh per capita)		NREL (TWh per capita)	
	1995	2015	1995	2015	1995	2015
Mean	23667.447	34213.314	119.322	225.307	439.418	386.801
Min	3772.322	7586.440	0.557	32.617	41.931	77.452
Max	75325.212	110334.677	799.983	1046.743	879.886	705.828
SD	16867.412	22553.400	178.334	210.101	223.060	195.695

Table A.2
Principal component analysis – results.

	PC1	PC2	PC3
EMP	0.626	−0.459	0.629
INVEST	0.333	0.888	0.316
TURN	0.704	−0.012	−0.710
Cumulative variance	0.568	0.897	1.000

Notes: Approximately 90% of total variance is represented by the PC1 and the PC2.

Table A.3
a. Main results of a PVAR model for the countries belonging to GROUP 1

Independent variables	Dependent variables				
	ΔlnGDP (*t*)	ΔlnNREL (*t*)	ΔlnREL (*t*)	ΔlnK (*t*)	ΔlnL (*t*)
ΔlnGDP (*t*-1)	0.615***	−1.277***	0.135	1.319***	0.11***
	(0.119)	(0.473)	(0.386)	(0.383)	(0.036)
ΔlnGDP (*t*-2)	−0.034	0.877*	0.268	−0.753*	−0.052
	(0.127)	(0.494)	(0.28)	(0.399)	(0.034)
ΔlnREL (*t*-1)	0.003	0.129	0.114*	0.037	0.002
	(0.027)	(0.146)	(0.068)	(0.091)	(0.008)
ΔlnREL (*t*-2)	0.041**	−0.147	0.083	0.085	0.003
	(0.016)	(0.108)	(0.055)	(0.055)	(0.007)
ΔlnNREL (*t*-2)	−0.02	0.44***	−0.341**	−0.037	−0.014
	(0.026)	(0.151)	(0.132)	(0.089)	(0.01)
ΔlnNREL (*t*-1)	−0.009	0.332***	−0.353**	0.056	−0.009
	(0.03)	(0.124)	(0.15)	(0.111)	(0.009)
ΔlnK (*t*-1)	−0.016***	−0.003	−0.054***	0.135***	−0.006***
	(0.004)	(0.02)	(0.021)	(0.022)	(0.001)
ΔlnK (*t*-2)	−0.03***	−0.043**	−0.037***	−0.038***	−0.007***
	(0.004)	(0.017)	(0.013)	(0.012)	(0.002)
ΔlnL (*t*-1)	−0.37*	1.207	−0.966	−1.088	0.171
	(0.208)	(1.033)	(0.589)	(0.696)	(0.108)
ΔlnL (*t*-2)	−0.456***	0.333	0.131	−1.487**	0.056
	(0.176)	(1.097)	(0.562)	(0.645)	(0.069)

Note: ***, ** indicate statistical significance at 1 and 5% level of significance, respectively. Heteroskedasticity robust standard errors in parenthesis. The Stata “pvar” command is used to calculate test.

Table A.3
b Main results of a PVAR model for the countries belonging to GROUP 2

Independent variables	Dependent variables				
	ΔlnGDP (*t*)	ΔlnNREL (*t*)	ΔlnREL (*t*)	ΔlnK (*t*)	ΔlnL (*t*)
ΔlnGDP (*t*-1)	0.72***	−1.574**	1.188	1.9***	−0.074
	(0.14)	(0.752)	(0.928)	(0.39)	(0.051)
ΔlnGDP (*t*-2)	0.055	0.034	0.728	−0.439	0.041

(*continued on next page*)

Table A.3 (*continued*)

Independent variables	Dependent variables				
	ΔlnGDP (*t*)	ΔlnNREL (*t*)	ΔlnREL (*t*)	ΔlnK (*t*)	ΔlnL (*t*)
	(0.19)	(0.73)	(0.864)	(0.663)	(0.043)
ΔlnREL (*t*-1)	−0.008	−0.191	0.053	−0.035	−0.003
	(0.01)	(0.132)	(0.054)	(0.03)	(0.003)
ΔlnREL (*t*-2)	−0.009	−0.242***	0.054	−0.06	0.002
	(0.012)	(0.078)	(0.064)	(0.041)	(0.003)
ΔlnNREL (*t*-2)	−0.009	0.055	0.28	0.009	−0.005
	(0.013)	(0.079)	(0.217)	(0.043)	(0.006)
ΔlnNREL (*t*-1)	−0.001	0.026	−0.083	0.046	0
	(0.013)	(0.063)	(0.12)	(0.041)	(0.005)
ΔlnK (*t*-1)	−0.062	0.14	0.134	−0.231	0.03***
	(0.041)	(0.192)	(0.304)	(0.153)	(0.011)
ΔlnK (*t*-2)	−0.04	0.106	−0.197	−0.17	0.006
	(0.039)	(0.176)	(0.195)	(0.119)	(0.009)
ΔlnL (*t*-1)	0.088	1.953*	−1.212	0.667	0.169*
	(0.198)	(1.156)	(1.289)	(0.57)	(0.089)
ΔlnL (*t*-2)	0.196	−0.247	0.802	0.417	0.059
	(0.193)	(0.945)	(1.237)	(0.581)	(0.08)

Note: ***, ** indicate statistical significance at 1 and 5% level of significance, respectively. Heteroskedasticity robust standard errors in parenthesis. The Stata "pvar" command is used to calculate test.

Table A.3
c Main results of a PVAR model for all European countries (ALL)

Independent variables	Dependent variables				
	ΔlnGDP (*t*)	ΔlnNREL (*t*)	ΔlnREL (*t*)	ΔlnK (*t*)	ΔlnL (*t*)
ΔlnGDP (*t*-1)	0.607***	−1.067***	0.687*	1.166***	0.058**
	(0.072)	(0.314)	(0.406)	(0.281)	(0.025)
ΔlnGDP (*t*-2)	0.007	0.525	0.56	−0.721**	0.004
	(0.086)	(0.329)	(0.355)	(0.333)	(0.022)
ΔlnREL (*t*-1)	0.005	−0.097	0.091	0.024	0
	(0.011)	(0.097)	(0.056)	(0.036)	(0.004)
ΔlnREL (*t*-2)	0.013	−0.211***	0.085*	0.005	0.002
	(0.01)	(0.066)	(0.047)	(0.033)	(0.004)
ΔlnNREL (*t*-2)	0.001	0.063	0.146	0.059	−0.002
	(0.01)	(0.071)	(0.169)	(0.036)	(0.005)
ΔlnNREL (*t*-1)	−0.006	0.1	−0.096	0.03	−0.004
	(0.011)	(0.071)	(0.084)	(0.04)	(0.005)
ΔlnK (*t*-1)	−0.018**	0.009	−0.027	0.102**	−0.004
	(0.008)	(0.027)	(0.036)	(0.049)	(0.003)
ΔlnK (*t*-2)	−0.032***	−0.035	−0.032	−0.055*	−0.004**
	(0.006)	(0.023)	(0.021)	(0.033)	(0.002)
ΔlnL (*t*-1)	−0.143	1.475**	−1.423*	−0.193	0.155**
	(0.136)	(0.72)	(0.776)	(0.449)	(0.07)
ΔlnL (*t*-2)	−0.18	−0.238	0.886	−0.698*	0.045
	(0.126)	(0.704)	(0.766)	(0.419)	(0.053)

Note: ***, ** indicate statistical significance at 1 and 5% level of significance, respectively. Heteroskedasticity robust standard errors in parenthesis. The Stata "pvar" command is used to calculate test.

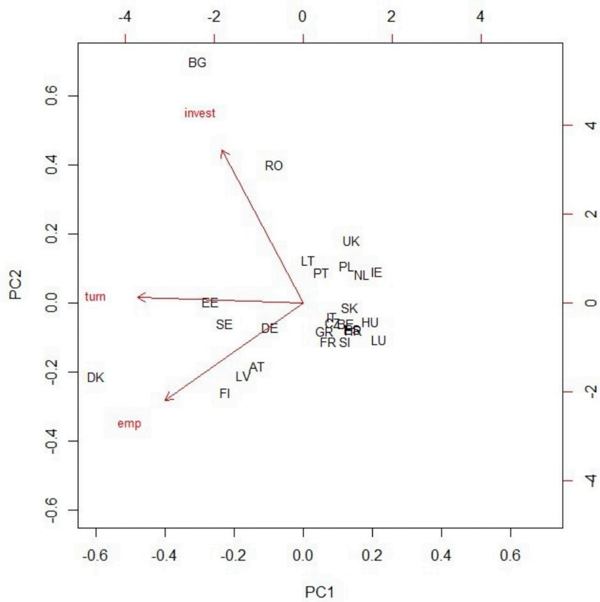

Fig. A.1. Biplot for variables representing countries' engagement in renewable energy.

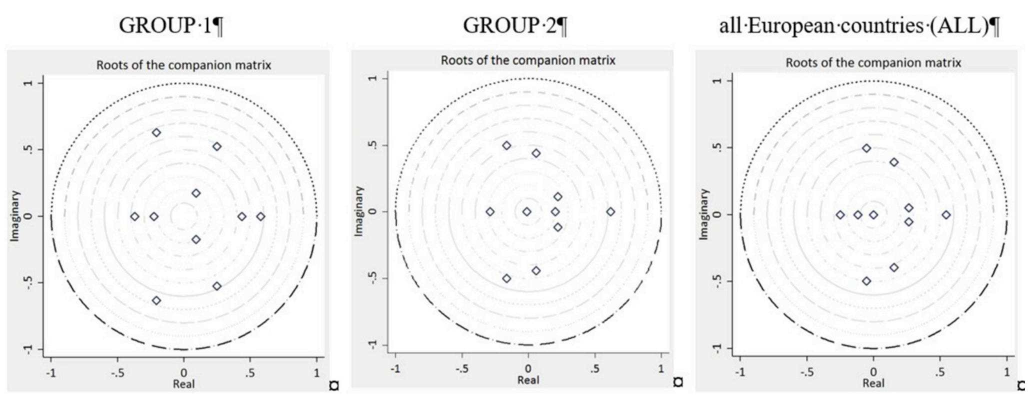

Fig. A.2. PVAR stability condition results -the unit circle results.

References

[1] Directive (EU. Of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (Text with EEA relevance). Official J European Union L vol. 328. 2018/2001. 21/12/2018.

[2] Mathiesen BV, Lund H, Karlsson K. 100% Renewable energy systems, climate mitigation and economic growth. Appl Energy 2011;88(2):488–501.

[3] Lehr U, Lutz C, Edler D. Green jobs? Economic impacts of renewable energy in Germany. Energy Policy 2012;47:358–64.

[4] Dvorak P, Martinat S, der Horst DV, Frantald B, Turečkova K. Renewable energy investment and job creation: a cross-sectoral assessment for the Czech Republic with reference to EU benchmark. Renew Sustain Energy Rev 2017;69:360–8.

[5] Garrett-Peltier H. Green versus brown: comparing the employment impacts of energy efficiency, renewable energy, and fossil fuels using an input-output model. Econ Modell 2017;61:439–47.

[6] Renn O, Marshall JP. Coal, nuclear and renewable energy policies in Germany: from the 1950s to the Energiewende. Energy Policy 2016;99:224–32.

[7] Rafindadi AA, Ozturk I. Impacts of renewable energy consumption on the German economic growth: evidence from combined cointegration test. Renew Sustain Energy Rev 2017;75:1130–41.

[8] Menegaki AN. Growth and renewable energy in Europe: a random effect model with evidence for neutrality hypothesis. Energy Econ 2011;33(2):257–63.

[9] Marques AC, Fuinhas JA. Is renewable energy effective in promoting growth? Energy Policy 2012;46:434–42.

[10] Pirlogea C, Cicea C. Econometric perspective of the energy consumption and economic growth relation in European Union. Renew Sustain Energy Rev 2012;16(8):5718–26.

[11] Okyay OCAN, Aricioglu E, Yucel F. Energy consumption and economic growth nexus: evidence from developed countries in Europe. Int J Energy Econ Policy 2014;4(3):411–9.

[12] Bilgili F, Ozturk I. Biomass energy and economic growth nexus in G7 countries: evidence from dynamic panel data. Renew Sustain Energy Rev 2015;49:132–8.

[13] Dogan E. The relationship between economic growth and electricity consumption from renewable and non-renewable sources: a study of Turkey. Renew Sustain Energy Rev 2015;52:534–46.

[14] Omri A. An international literature survey on energy-economic growth nexus: evidence from country specific studies. Renew Sustain Energy Rev 2014;38:951–9.

[15] Alper A, Oguz O. The role of renew able energy consumption in economic growth: evidence from asymmetric causality. Renew Sustain Energy Rev 2016;60:953–9.

[16] Marques AC, Fuinhas JA, Nunes AR. Electricity generation mix and economic growth: what role is being played by nuclear sources and carbon dioxide emissions in France? Energy Policy 2016;92:7–19.

[17] Armeanu DŞ, Vintilă G, Gherghina ŞC. Does renewable energy drive sustainable economic growth? multivariate panel data evidence for EU-28 countries. Energies 2017;10(3):381.

[18] Fotourehchi Z. Clean energy consumption and economic growth: a case study for developing countries. Int J Energy Econ Policy 2017;7(2):61–4.

[19] Koçak E, Şarkgüneşi A. The renewable energy and economic growth nexus in Black Sea and Balkan countries. Energy Policy 2017;100:51–7.

[20] Afonso TL, Marques AC, Fuinhas JA. Strategies to make renewable energy sources compatible with economic growth. Energy Strategy Rev 2017;18:121–6.

[21] Marinaș MC, Dinu M, Socol AG, Socol C. Renewable energy consumption and economic growth. Causality relationship in Central and Eastern European countries. PLoS One 2018;13(10):e0202951.

[22] Bento JPC, Moutinho V. CO 2 emissions, non-renewable and renewable electricity production, economic growth, and international trade in Italy. Renew Sustain Energy Rev 2016;55:142–55.

[23] Furuoka F. Renewable electricity consumption and economic development: new findings from the Baltic countries. Renew Sustain Energy Rev 2017;71:450–63.

[24] Mahmoodi M. The relationship between economic growth, renewable energy, and CO2 emissions: evidence from panel data approach. Int J Energy Econ Policy

2017;7(6):96–102.
[25] Saad W, Taleb A. The causal relationship between renewable energy consumption and economic growth: evidence from Europe. Clean Technol Environ Policy 2018;20(1):1–10.
[26] Apergis N, Payne JE. Renewable and non-renewable energy consumption-growth nexus: evidence from a panel error correction model. Energy Econ 2012;34(3):733–8.
[27] Ozturk I, Acaravci A. The causal relationship between energy consumption and GDP in Albania, Bulgaria, Hungary and Romania: evidence from ARDL bound testing approach. Appl Energy 2010;87:1938–43.
[28] Tugcu CT, Ozturk I, Aslan A. Renewable and non-renewable energy consumption and economic growth relationship revisited: evidence from G7 countries. Energy Econ 2012;34:1942–50.
[29] The renewables Energy Policy Network for the 21st Century. Renewables 2017 global status report. 2017http://www.ren21.net/wp-content/uploads/2017/06/17-8399_GSR_2017_Full_Report_0621_Opt.pdf, Accessed date: 7 January 2019.
[30] Directive 2009/28/EC 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. Official J European Union L 140/16. 2009. p. 5–6.
[31] Marques AC, Fuinhas JA, Neves SA. Ordinary and Special Regimes of electricity generation in Spain: how they interact with economic activity. Renew Sustain Energy Rev 2018;81:1226–40.
[32] Ozturk I. A literature survey on energy–growth nexus. Energy Policy 2010;38(1):340–9.
[33] How electrification can supercharge the energy transition .World Economic Forum. https://www.weforum.org/agenda/2019/04/electrification-energy-transition-decarbonization-climate-change/ (accessed June 11, 2019).
[34] EurObserv'ER. The state of renewable energies in Europe. 15th EurObserv'ER Report Available from: http://www.eurobserv-er.org/pdf/annual-overview-2015-en/; 2015, Accessed date: 7 January 2019 15.
[35] Abrigo MRM, Love I. Estimation of panel vector autoregression in stata. Stata J Promot Commun Stat Stata 2016;16:778–804.
[36] Kilian L, Lütkepohl H. Structural vector autoregressive analysis. Cambridge University Press; 2017.
[37] Smyth R, Narayan PK. Applied econometrics and implications for energy economics research. Energy Econ 2015;50:351–8.
[38] Payne JE. Survey of the international evidence on the causal relationship between energy consumption and growth. J Econ Stud 2010;37:53–95.
[39] Sebri M. Use renewables to be cleaner: meta-analysis of the renewable energy consumption–economic growth nexus. Renew Sustain Energy Rev 2015;42:657–65.
[40] Adewuyi AO, Awodumi OB. Renewable and non-renewable energy-growth-emissions linkages: review of emerging trends with policy implications. Renew Sustain Energy Rev 2017;69:275–91.
[41] Tiba S, Omri A. Literature survey on the relationships between energy, environment and economic growth. Renew Sustain Energy Rev 2017;69:1129–46.
[42] Soytas U, Sari R. Energy consumption, economic growth, and carbon emissions: challenges faced by an EU candidate member. Ecol Econ 2009;68(6):1667–75.
[43] Tsani SZ. Energy consumption and economic growth: a causality analysis for Greece. Energy Econ 2010;32(3):582–90.
[44] Apergis N, Danuletiu D. Energy consumption and growth in Romania: evidence from a panel error correction model. Int J Energy Econ Policy 2012;2(4):348–56.
[45] Fuinhas JA, Marque A. Energy consumption and economic growth nexus in Portugal, Italy, Greece, Spain and Turkey: an ARDL bounds test approach (1965–2009). Energy Econ 2012;34(2):511–7.
[46] Dergiades T, Martinopoulos G, Tsoulfidis L. Energy consumption and economic growth: parametric and non-parametric causality testing for the case of Greece. Energy Econ 2013;36:686–97.
[47] Magazzino C. Renewable energy consumption-economic growth nexus in Italy. Int J Energy Econ Policy 2017;7(6):119–27.
[48] Acaravci A, Ozturk I. On the relationship between energy consumption, CO2 emissions and economic growth in Europe. Energy 2010;35(12):5412–20.
[49] Menegaki AN, Ozturk I. Growth and energy nexus in Europe revisited: evidence from a fixed effects political economy model. Energy Policy 2013;61:881–7.
[50] Śmiech S, Papież M. Energy consumption and economic growth in the light of meeting the targets of energy policy in the EU: the bootstrap panel Granger causality approach. Energy Policy 2014;71:118–29.
[51] Caraiani C, Lungu CI, Dascălu C. Energy consumption and GDP causality: a three-step analysis for emerging European countries. Renew Sustain Energy Rev 2015;44:198–210.
[52] Shahbaz M, Shahzad SJH, Alam S, Apergis N. Globalisation, economic growth and energy consumption in the BRICS region: the importance of asymmetries. J Int Trade Econ Dev 2018;27(8):985–1009.
[53] Streimikiene D, Kasperowicz R. Review of economic growth and energy consumption: a panel cointegration analysis for EU countries. Renew Sustain Energy Rev 2016;59:1545–9.
[54] Menegaki AN, Marques AC, Fuinhas JA. Redefining the energy-growth nexus with an index for sustainable economic welfare in Europe. Energy 2017;141:1254–68.
[55] Yasar N. The relationship between energy consumption and economic growth: evidence from different income country groups. Int J Energy Econ Policy 2017;7(2):86–97.
[56] Apergis N, Payne JE. Renewable energy consumption and growth in Eurasia. Energy Econ 2010;32(6):1392–7.
[57] Ozcan B, Ozturk I. Renewable energy consumption-economic growth nexus in emerging countries: a bootstrap panel causality test. Renew Sustain Energy Rev 2019;104:30–7.
[58] Vaona A. Granger non-causality tests between (non)renewable energy consumption and output in Italy since 1861: the (ir)relevance of structural breaks. Energy Policy 2012;45:226–36.
[59] Omri A, Mabrou KNB, Sassi-Tmar A. Modeling the causal linkages between nuclear energy, renewable energy and economic growth in developed and developing countries. Renew Sustain Energy Rev 2015;42:1012–22.
[60] Bhattacharya M, Paramati SR, Ozturk I, Bhattacharya S. The effect of renewable energy consumption on economic growth: evidence from top 38 countries. Appl Energy 2016;162:733–41.
[61] Kahia M, Aïssa MSB, Charfeddine L. Impact of renewable and non-renewable energy consumption on economic growth: new evidence from the MENA Net Oil Exporting Countries (NOECs). Energy 2016;116:102–15.
[62] Halicioglu F, Ketenci N. Output, renewable and non-renewable energy production, and international trade: evidence from EU-15 countries. Energy 2018;159:995–1002.
[63] Tugcu CT, Topcu M. Total, renewable and non-renewable energy consumption and economic growth: revisiting the issue with an asymmetric point of view. Energy 2018;152:64–74.
[64] Gozgor G, Lau CKM, Lu Z. Energy consumption and economic growth: new evidence from the OECD countries. Energy 2018;153:27–34.
[65] Shahbaz M, Tang CF, Shabbir MS. Electricity consumption and economic growth nexus in Portugal using cointegration and causality approaches. Energy Policy 2011;39:3529–36.
[66] Gurgul H, Lach Ł. The electricity consumption versus economic growth of the Polish economy. Energy Econ 2012;34(2):500–10.
[67] Tang CF, Shahbaz M, Arouri M. Re-investigating the electricity consumption and economic growth nexus in Portugal. Energy Policy 2013;62:1515–24.
[68] Acaravci A, Ozturk I. Electricity consumption-growth nexus: evidence from panel data for transition countries. Energy Econ 2010;32(3):604–8.
[69] Ciarreta A, Zarraga A. Economic growth-electricity consumption causality in 12 European countries: a dynamic panel data approach. Energy Policy 2010;38:3790–6.
[70] Wolde-Rufael Y. Electricity consumption and economic growth in transition countries: a revisit using bootstrap panel Granger causality analysis. Energy Econ 2014;44:325–30.
[71] Afonso TL, Marques AC, Fuinhas JA, Saldanha EMM. Interactions between electricity generation sources and economic activity in two Nord Pool systems. Evidence from Estonia and Sweden. Appl Econ 2018;50(29):3115–27.
[72] Costa-Campi MT, García-Quevedo J, Trujillo-Baute E. Electricity regulation and economic growth. Energy Policy 2018;113:232–8.
[73] Pesaran MH. A simple panel unit root test in the presence of cross-section dependence. J Appl Econom 2007;22(2):265–312.
[74] Westerlund J. Testing for error correction in panel data. Oxf Bull Econ Stat 2007;69(6):709–48.
[75] Lütkepohl H. New introduction to multiple time series analysis. Springer Science Business Media; 2005.
[76] Arellano M, Bover O. Another look at the instrumental variable estimation of error-components models. J Econom 1995;68(1):29–51.
[77] EurObserv'ER. 11th EurObserv'ER Report The state of renewable energies in Europe vol. 11. 2011 Available from: http://www.eurobserv-er.org/pdf/annual-overview-2011-fr-en/, Accessed date: 7 January 2019.
[78] EurObserv'ER. The state of renewable energies in Europe. 12th EurObserv'ER Report vol. 12. 2012 Available from: http://www.eurobserv-er.org/pdf/annual-overview-2012-fr-en/, Accessed date: 7 January 2019.
[79] EurObserv'ER. The state of renewable energies in Europe. 13h EurObserv'ER Report vol. 13. 2013 Available from: http://www.eurobserv-er.org/pdf/annual-overview-2013-en/, Accessed date: 7 January 2019.
[80] EurObserv'ER. The state of renewable energies in Europe. 14th EurObserv'ER Report vol. 14. 2014 Available from: http://www.eurobserv-er.org/pdf/annual-overview-2014-en/, Accessed date: 7 January 2019.
[81] EurObserv'ER. The state of renewable energies in Europe. 16th EurObserv'ER Report vol. 16. 2016 Available from: http://www.eurobserv-er.org/pdf/annual-overview-2016-en/, Accessed date: 7 January 2019.
[82] World Bank. World development indicators. http://www.worldbank.org/data/onlinedatabases/onlinedatabases.html; 2016.
[83] Shahbaz M, Zakaria M, Shahzad SJH, Mahalik MK. The energy consumption and economic growth nexus in top ten energy-consuming countries: fresh evidence from using the quantile-on-quantile approach. Energy Econ 2018;71:282–301.