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Research article

Toward a sustainable mitigation approach of energy efficiency to greenhouse gas emissions in the European countries

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ABSTRACT

The efficient use of energy contributes to less energy consumption and the reduction of greenhouse gases released to nature, thus improving environmental sustainability. For this reason, many countries pioneered by the developed nations are trying to develop policies for energy efficiency. In this context, the relationship between energy efficiency and greenhouse gas emissions was tested by panel co-integration, panel causality, and FMOLS and DOLS analysis. Given that the study used the datasets of 29 European countries over the period 1995–2016, there result suggests that there is a long-term relationship between energy efficiency and greenhouse gas emissions and that the quantity of greenhouse gas emission decreases as energy efficiency increases. Finally, the robustness and novelty by employing the Emirmahmutoglu & Kose (2011) *Testing for Granger causality in heterogeneous mixed panels. Economic Modelling, 28(3), 870–876* approach, the findings illustrated that there is a causal relationship between energy efficiency and greenhouse gas emissions for many European countries. Overall, the current study presents a relevant policy direction for the European bloc countries.

1. Introduction

One of the main dynamics of sustainable economic growth and development for countries is that they have sufficient energy resources. As countries grow, their energy needs are growing. Ensuring the sustainability of energy resources as a basic input is vital for the sustainability of investments (Altun, 2018:95). Therefore, many countries are trying to implement projects that will reduce the dependence on forms of foreign supports for the energy they need while making various investments to grow economically. The strand of evidence has shown that when the rate of dependence on energy resources increases, the economic fragility of the country tends to increase (James, 2015; Adams et al., 2019). One of the most basic indicators of this is the global crisis, which was caused by the increase in energy costs in the 1970s. The indication from this form of resource crisis has caused many countries to shrink economically (Bozoklu and Yilanci, 2013:877). Because of the drive for less reliance on the fossil fuel reserves (oil, natural gas, coal, etc.), which are seen as non-renewable energy sources due to global dynamics, it becomes imperative for most countries to consciously search for alternative energy sources in order to meet their energy needs. In the last decades, the search for alternate energy sources has led to the discovery of nuclear energy and renewable energy sources, which are now largely used across the globe. The power of nuclear energy, one of these energy sources, was brought to limelight after the launch of the atomic bomb during the Second World War in Hiroshima in 1945. Prior to the 1945 incident, the Atomic Energy Conference of 1955 noted the importance of the peaceful use of nuclear reactors for energy production, especially the USA, UK, and Russia. Nuclear power, which has been preferred by countries for years due to its high energy generation capability, has been criticized especially for its high radiation hazards (Hubbert, 1956:19–20).

Renewable energy sources are a source of energy that is considered as an alternative to nuclear energy and are vastly being invested in by many countries. The energy crisis in the 1970s pushed countries to seek alternative energy. The establishment of the wind turbine industry in Denmark came into question in the post-crisis period due to the energy cost of the 1970s, and thus countries began to invest in renewable energy resources (Sorensen, 1991:9–10). Since both nuclear energy investments and renewable energy investments require high costs especially for the developing and the third world countries, thus the consumption of fossil fuels remains a necessity. However, the consumption of fossil fuels for energy needs has continued to create enormous environmental problems

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across the globe (Alola, 2019a). In this context, increasing energy (fossil fuel) demand has remained the most important factor that causes greenhouse gas emissions (Hamit-Haggar, 2012; Alola, Bekun & Sarkodie, 2019). The Greenhouse Gas (GHG), which causes environmental problems such as global warming and climate change, has remained the most important environmental issue of the international community (Alola, 2019 a & b). In particular, carbon dioxide (CO2) gas largely originating from fossil energy sources constitutes 76% of the total greenhouse gas in the world and is considered to be the most serious gas causing pollution (International Energy Agency IEA); 2012. Against this background, greenhouse gas emissions have remained a major threat to the environment and humanity. Indicatively, countries across the globe have continued to seek energy sources that are less harmful to the environment, such as renewable energy and other alternative sources.

Additionally, research and development (R&D) activities have however sought the more efficient form of energy use in order to obtain maximum efficiency from existing energy sources. In particular, as a result of global warming caused by greenhouse gas emissions in decades, the most important step taken by countries to reduce greenhouse gas emissions has been to address energy efficiency policies (Alola et al., 2019a, b; Bekun et al., 2019). The countries participating in the Third Parties Conference in Kyoto in 1997 created a timetable for reducing greenhouse gas emissions. The main factor in this calendar is to take steps to increase energy efficiency in all sectors of the economy (Ang, 2006:574). Since the world oil crisis of 1973, and monitoring the trends in energy efficiency in the economy has been an important component of energy strategy in many countries. Various indicators of energy efficiency have been developed to support this effort (Ang, 2006:574). As a matter of fact, the Official Statistics Institute of the European Union has also published the energy efficiency index since 1995, drawing attention to the concept of energy efficiency. The energy efficiency index is an index that measures the amount of economic output produced per unit of gross internal energy consumption.

Therefore, the current study draws some hypotheses from the objective of the investigation by employing the datasets of the concerned variables for the 29 European countries over the period 1995–2016. As such, the study hypothesized that the efficient use of energy will lead to the use of fewer energy sources in countries, thus contributing to the economic conditions of the countries and reducing greenhouse gas emissions. Moreover, the study is aimed at testing whether there is a relationship between energy efficiency and greenhouse gas emissions in this study. Importantly, the study is expected to contribute to the extant literature since it is the first study that applies an econometric approach to the investigation of the relationship between energy efficiency and greenhouse gas emissions.

The study consists of 5 Sections. In the first part, the importance of energy, energy resources, energy efficiency and environmental damage caused by the use of energy are presented. In the second section, the extant literature on energy use, greenhouse gas emission, and energy efficiency are included. In the third section, the data and methodology are described. While the results of the estimations are discussed in section 4, the last section (5) summarizes the results of the study and further provided suggestions for policy implementations were made.

2. Related literature

Until now, there seems to be a lack of specific literature review on the relationship between energy efficiency and greenhouse gas emissions. Therefore, studies on energy consumption, greenhouse gas emission, and energy efficiency are included in the literature section. In this context, literature studies are divided into two parts. In the first part, energy consumption and greenhouse gas emission studies are included, while the second part includes energy efficiency studies.

2.1. Energy consumption and GHG

Say and Yucel (2006) conducted on Turkey employs the regression analysis and found that there is a relationship between energy consumption and carbon emissions. Similarly, Halicioglu (2009), which used the causality analysis, found a positive relationship between energy consumption and carbon emissions. Another study employs the causality analysis is the Zhang and Cheng (2009) and found that there is one-way causality between energy consumption, carbon emissions, and economic growth in China. In Bella et al. (2010), a similar relationship between CO2 emissions and economic growth for 22 non-OECD (Organization for Economic Cooperation and Development) member countries was tested by employing the panel data analysis. Similarly, Jaunky (2011), tested the appropriateness of GDP and CO2 emissions for the EKC hypothesis for 36 high-income countries. The result supported the EKC hypothesis in Greece, Malta, Oman, Portugal and UK countries giving the desired result of the panel data unit root and co-integration estimates. In the panel data analysis, Jaunky (2011) found that a 1% increase in GDP increases the CO2 emissions by 0.68% in the short term and cause an increase of 0.22% in the long run. The above results were buttressed in the study of Ahmed and Long (2012). Ahmed and Long (2012) found that the short and long-term relationship between carbon dioxide emission and growth for Pakistan supports the EKC hypothesis. In this case, the finding revealed that economic growth and energy consumption in Pakistan triggers environmental pollution in the country.

In the same vein, Begum et al. (2015) investigated a panel causality and found a one-way panel causality from GDP and energy consumption to CO2 in the short term. In a similar study by Sarkodie and Adams (2018), the EKC hypothesis was found to be invalid for Malaysia by using the ARDL boundary test method. Whereas the study found that GDP and energy consumption has a positive and significant effect on CO2. Similarly, Sarkodie and Adams (2018) also tested for economic and political variables and obtained a result that further shows the positive relationship between total energy consumption, economic growth, and political-institutional quality. In the work of Alola (2019a & b), unique socio-economic and macroeconomic variables (renewable energy consumption and real gross domestic product (GDP)) were included in the analysis for the case of the United States. The results obtained by using the Autoregressive Distributed Lag (ARDL) method suggests both long-term and short-term positive relationship between migration and carbon emissions. The trade policy is not only significant in the short term but is revealed to have a negative relationship with carbon emissions. Also, in the case of China which accounts for about one-third of the world's total carbon emissions, Ma et al. (2019) found that the total carbon emissions, and that the intensity of carbon emissions in China which is higher than any part of the world, rapid economic development and increased urbanization are not good indicators for the mitigation of carbon emissions.

2.2. Energy efficiency

According to Brookes (1990), energy efficiency is found to exhibit a significant relationship with economic growth which is measured with the GDP. The study emphasized that improvements in energy efficiency may have a positive effect on economic growth but the impact on greenhouse gas emissions is insignificant. Saunders (1992), Inhaber and Saunders (1994) maintained that improvements in energy efficiency apparently lead to rapid economic growth. In Gómez-Calvet et al. (2014), the relationship between energy efficiency and carbon emission among the European Union (EU) countries was investigated and the evidence found that the new EU member countries have lower energy efficiency amidst high carbon emissions. Apergis et al. (2015) found that capital-intensive OECD countries have more efficient energy levels than

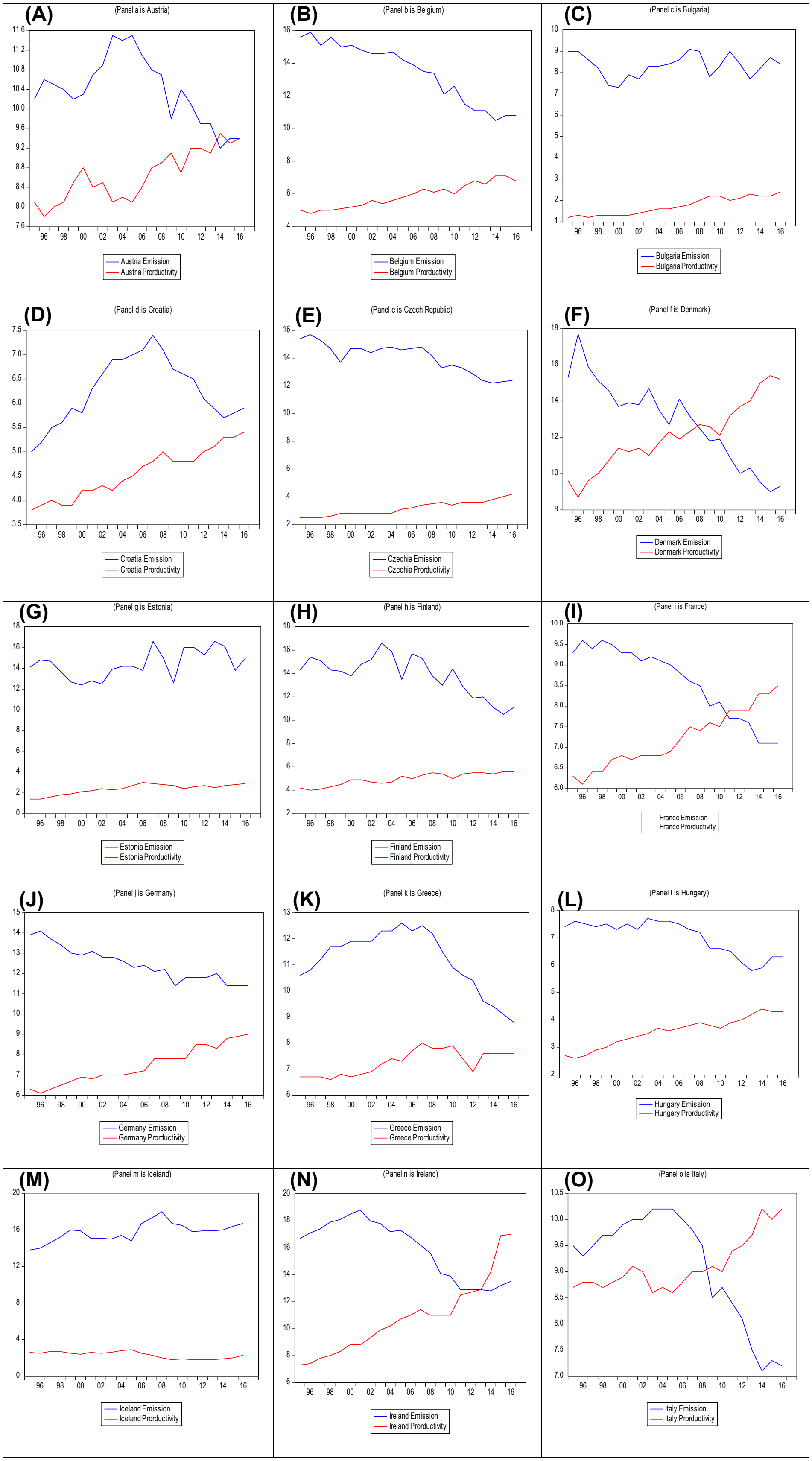

Figure 1. The time plot of the energy efficiency against GHG emissions for the examined countries. (a) Austria, (b) Belgium, (c) Bulgaria, (d) Croatia, (e) Czech Republic, (f) Denmark, (g) Estonia, (h) Finland, (i) France, (j) Germany, (k) Greece, (l) Hungary, (m) Iceland, (n) Ireland, (o) Italy, (p) Latvia, (q) Lithuania, (r) Luxembourg, (s) Netherlands, (t) Norway, (u) Poland, (v) Portugal, (w) Romania, (x) Slovakia, (y) Slovenia, (z) Spain, (aa) Sweden, (bb) Turkey, and (cc) United Kingdom.

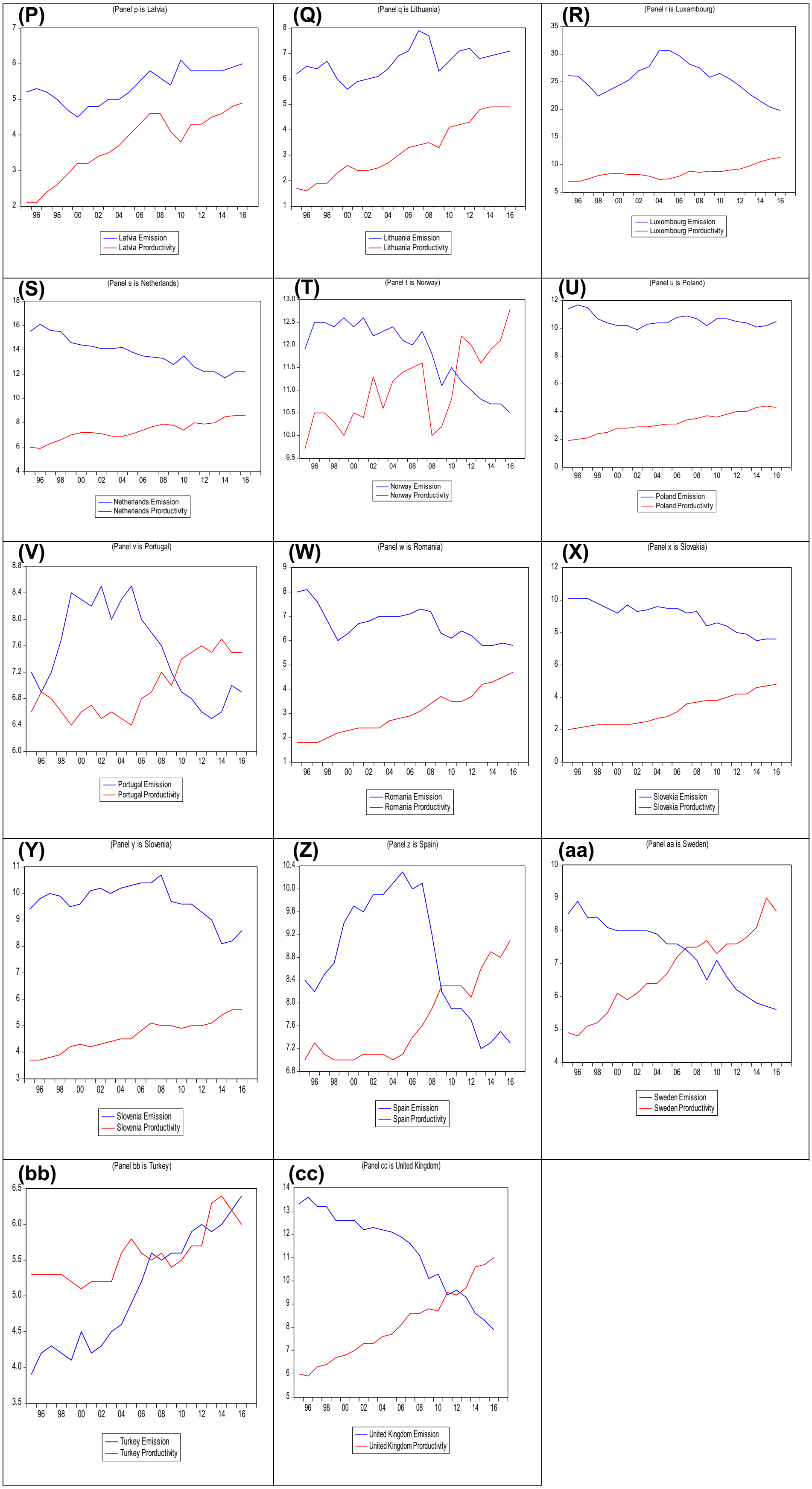

Figure 1. (*continued*).

Table 1. Descriptive statistics.

Variables	Mean	Standard error	Minimum	Maximum	Observations
EE	6.0083	2.9536	1.2000	17.0000	638
GHG	10.7768	4.3285	3.9000	30.7000	
GDP	11.8429	1.6054	8.0013	14.9579	

Table 2. Cross-sectional dependence and homogeneity test results.

Test	Statistic	Probability
LM	384.198	0.7750
CD_{LM}	-0.7650	0.2220
$\breve{\Delta}$	-2.4223	0.9923
$\breve{\Delta}_{adj.}$	-2.6651	0.9962

Table 3. Panel unit root tests.

Variables	Levin, Lin & Chu		Im, Pesaran & Shin	
	Constant	Constant and Trend	Constant	Constant and Trend
EE	2.2963	-2.5011*	6.9618	-3.5039*
ΔEE	-18.9468*	-14.0263*	-18.1235*	-13.3136*
GHG	1.8184	-2.8730*	3.9773	-1.5196
ΔGHD	-20.1985*	-16.3220*	-19.4351*	-16.0994*
lnGDP	-9.1560*	-1.0754	-2.8404*	2.4237
ΔlnGDP	-13.4438*	-12.9089*	-12.2164*	-11.0752*

*significant at 1% level of significance.

Table 4. Pedroni and Kao co-integration test results.

Pedroni panel co-integration test results

	t - statistics	Probability	Weighted t - statistics	Probability
Panel v-Statistic	2.8731***	0.0020	1.3474*	0.0889
Panel rho-Statistic	0.8398	0.7995	1.5044	0.9338
Panel PP-Statistic	-2.7856***	0.0027	-1.5472*	0.0609
Panel ADF-Statistic	-3.6893***	0.0001	-2.3267***	0.0100

(Between-Dimension)

	t-statistics	Probability
Group rho-Statistic	3.0941	0.9990
Group PP-Statistic	-0.8249	0.2047
Group ADF-Statistic	-2.3315***	0.0099

Kao panel co-integration test results

	t-statistics	Probability
ADF	–2.9474***	0.0019

*Indicates significance at 10%, ** at 5% and *** at 1% levels of significance, respectively.

labor-intensive countries. Whereas, Aye et al. (2015) measured the energy efficiency in the shocks of certain periods. by employing the TOPSIS, TOBIT and ANN algorithms. The study opined that China's international markets in the periods of the oil price shock move relative to the dynamics of Africa's energy efficiency. Additionally, Wang et al. (2017), conducted on the energy efficiency and CO2 emission reduction in China, suggests the adoption of mechanism for the reduction of CO2 emissions as a ploy toward enhancing energy efficiency. Thus, the result from the study of Wang et al. (2017) similar to that of Emir and Bekun (2019) submits that that increasing energy efficiency is one of the important ways to reduce energy consumption and global warming.

3. Data and methodology

In this study, 29 European countries (Austria, Belgium, Bulgaria, Croatia, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Turkey, and United Kingdom) are examined by employing the annual data over the period 1995 and 2016. The annual data of the energy efficiency index and the greenhouse gas emission were employed. The analysis was limited to 29 countries, as the widest data range was reached between the relevant dates and the data of 29

Table 5. DOLS and FMOLS test results.

DOLS test results ($GGE = \alpha_{it} + \beta_1 EE + \beta_2 GDP + \mu_{it}$)		
	Coefficient	t-statistics
EE	-1.4337	-14.2579*
GDP	1.9633	8.9587*
FMOLS test results ($GGE = \alpha_{it} + \beta_1 EE + \beta_2 GDP + \mu_{it}$)		
	Coefficient	t-statistics
EE	-1.2888	-16.1198*
GDP	1.5368	7.4582*

*significant at 1% level of significance.

Table 6. Emirmahmutoglu and Kose (2011) panel causality.

H_0: Energy efficiency is not the Granger cause of greenhouse gas emissions

Country	Lag[1]	Wald St.	p-value
Austria	5	9.387*	0.095
Belgium	5	5.201	0.392
Bulgaria	5	30.919***	0.000
Croatia	4	7.110	0.130
Czech Republic	1	0.270	0.604
Denmark	2	3.113	0.211
Estonia	5	29.954***	0.000
Finland	4	6.261	0.181
France	5	7.278	0.201
Germany	5	10.549*	0.061
Greece	2	0.839	0.657
Hungary	5	23.374***	0.000
Iceland	5	18.175***	0.003
Ireland	5	1.991	0.850
Italy	5	17.066***	0.004
Latvia	4	14.593***	0.006
Lithuania	1	0.700	0.403
Luxembourg	4	1.776	0.777
Netherlands	5	9.973*	0.076
Norway	2	8.169**	0.017
Poland	5	21.458***	0.001
Portugal	5	5.862	0.320
Romania	2	1.145	0.564
Slovakia	5	7.352	0.196
Slovenia	1	0.155	0.694
Spain	1	0.004	0.948
Sweden	1	0.082	0.775
Turkey	1	1.914	0.167
United Kingdom	5	6.168	0.290

*Indicates significance at 10%, ** at 5% and *** at 1% levels of significance, respectively.
[1] The lag lengths are determined according to Akaike information criteria.

countries was published continuously. Additionally, the study has considered total Greenhouse gas emissions rather than disaggregate or sector (energy, industrial, agricultural, land use, land-use change and forestry, waste management) analysis because of data unavailability. The energy efficiency index is calculated by dividing the gross domestic product (GDP) by gross domestic energy consumption for a given calendar year. The index measures the efficiency of energy consumption and indicates the degree to which energy consumption is excluded from growth in GDP (Eurostat). Greenhouse gas emissions from carbon dioxide (CO2) including methane (CH4), nitrous oxide (N2O) and F-gases (hydrofluorocarbons, perfluorocarbons, nitrogen trifluoride (NF3) and sulfur hexafluoride (SF6)) in the 'Kyoto basket' of greenhouse gases measures are utilized. Using the individual global warming potential of each gas, it is converted into a single indicator expressed in terms of CO2 equivalent. The index refers to greenhouse gas per capita in tons (Eurostat). Gross Domestic Product (GDP) data added to the model as the control variable in the analysis are in Euros. The relevant data are obtained from the official website of the European Union Eurostat and the time plot of the energy efficiency against GHG emissions for the examined countries is provided in Figure 1.

The Emirmahmutoğlu and Kose (2011) panel causality analysis which gives country-specific results, was used to determine whether there is a short-term relationship between variables.

Pedroni (1999) and Kao (1999) panel cointegration tests, which are frequently used in the literature and provide reliable results, were used for determining the existence of a long-term relationship between variables Baltagi (2008); Westerlund (2007); Asteriou and Hall (2015). In order to determine the direction of the relationship between variables, panel cointegration coefficient estimators FMOLS and DOLS methods, which are frequently used in the literature, are used Westerlund (2007); Baltagi (2008); Asteriou and Hall (2015).

In the study, cross-sectional dependence and homogeneity tests were performed for variables before unit root and co-integration analysis. The results of the test results of cross-sectional dependence and homogeneity are important in the selection of unit root tests and co-integration tests to be used in the analysis. The dependence between the cross-sections for cross-sectional dependence (countries) was tested by the LM (Lagrange Multiplier) test developed in the Breusch and Pagan (1980) and the CD_{LM} test developed in the study of Pesaran (2004).

In both tests, the time size is smaller than the cross-sectional dimension (T < N). Whether the coefficients of the co-integration coefficients were homogeneous or not, the coefficients of the explanatory variable changed from cross-section to cross-section were tested with the Slope Homogeneity test developed by Pesaran and Yamagata (2008). Levin, Lin & Chu (2002) and Im et al. (2003) first-generation unit root tests were used to determine whether the data were stable according to the results of the cross-sectional dependency and homogeneity test. Levin, Lin & Chu's (2002) unit root test is mostly preferred in homogeneous model assumptions, whereas Im, Pesaran & Shin's (2003) unit root test is mostly preferred in the heterogeneous model assumption. The co-integration analysis is used to test the long-term relationship between variables. The co-integration tests developed by Pedroni (1999) and Kao (1999) are based on the assumption that there is no cross-sectional dependence between variables and are among the most commonly used co-integration tests in empirical analyzes. The Pedroni test is based on error terms derived from the regression model. The variables in the level form after the test suggests a short term error correction coefficients obtained using the first differences of the long-term coefficients (Westerlund, 2007: 710). The Pedroni (1999) co-integration test is tested with seven different tests, three of which are estimators and three of them are "Between" estimators, and the null hypothesis of assuming that panel data is not co-integrated. Using the Pedroni (1999) study, the first stage of the co-integration tests is to calculate the residues obtained from the co-integration regression expressed as expressed in Eq. (1) (Pedroni, 1999:656).

$$y_{i,t} = \alpha_i + \delta_i t + \beta_{1i} x_{1i,t} + \beta_{2i} x_{2i,t} + \ldots + \beta_{Mi} x_{Mi,t} + \varepsilon_{i,t} \tag{1}$$

$t = 1, 2, \ldots, M;\ i = 1, 2, \ldots, N;\ m = 1, 2, \ldots, M$

y dependent variable, x independent variable, α stands for constant effect parameter, δ deterministic time trend, β slope coefficients, t observation number, i cross-sections, m variable number, M maximum number, N maximum cross-sections.

In the Pedroni co-integration analysis, the existence of co-integration between the y and x variables is tested by the stability analysis for $\varepsilon_{i,t}$ error terms. The test developed in the Kao (1999) study is based on the panel regression model expressed in Eq. (2).

$$y_{i,t} = x_{it}^{'}\beta + z_{it}^{'}\gamma + \varepsilon_{it} \tag{2}$$

The co-integration test was developed by applying the Augment Dickey-Fuller (ADF) and Dickey-Fuller (DF) stability tests to the error model. This co-integration test which is known by Kao (1999) is based on the ADF and DF static analysis and uses five different statistics. Also, it utilizes the null hypothesis that assumes that there is no co-integration relationship between variables.

The most commonly used methods for estimating the co-integration coefficients are the FOLS (Dynamic Ordinary Least Square) developed in the study of Saikkonen (1991) and Stock and Watson (1993). The FMOLS (Full Modified Ordinary Least Square) estimators developed in Phillips and Hansen (1990) but employ the Pedroni (2001) estimators of a panel data. A parametric approach, the DOLS method, is an approach that corrects autocorrelation by adding the first lagged differences to the model. The Panel DOLS estimator is expressed as follows (Breitung and Pesaran, 2008:310).

$$y_{it} = \beta^{'} x_{it} + \sum_{k=-\infty}^{\infty} \gamma_k^{'} \Delta x_{it-k} + \mu_{it} \tag{3}$$

y_{it}: dependent variable, x_{it}: argument, β: The co-integration vector, μ: the error term.

The FMOLS method is a nonparametric approach in contrast to the DOLS method. The FMOLS method takes into account the existence of a possible relationship between the fixed term, the term error and the differences of the independent variables. The Panel FMOLS estimator presented as follows:

$$y_{it} = \alpha_{it} + \beta x_{it} + \varepsilon_{it} \tag{4}$$

$$x_{it} = x_{i,t-1} + \varepsilon_{it} \tag{5}$$

In addition, the Todo and Yamamato (1995) which is an inspiration from the meta-analysis of Fisher (1932) is employed by Emirmahmutoğlu and Kose (2011). An important advantage of Emirmahmutoğlu and Kose (2011) test is that it also takes into account the cross-sectional dependence and can be used even if the co-integration relationship cannot be determined. Since the test also has a heterogeneous structure, it can give results for both the panel and for each cross-section (Kurt and Kose, 2017: 306). In this test, Eqs. (6) and (7) which have causality relation based on the two-variable VAR model can be established as follows (Emirmahmutoğlu and Kose, 2011:872).

$$x_{i,t} = \mu_i^x + \sum_{j=1}^{k_i+dmax_i} A_{11,ij} x_{i,t-j} + \sum_{j=1}^{k_i+dmax_i} A_{12,ij} y_{i,t-j} + \mu_{i,t}^x \tag{6}$$

$$y_{i,t} = \mu_i^y + \sum_{j=1}^{k_i+dmax_i} A_{21,ij} x_{i,t-j} + \sum_{j=1}^{k_i+dmax_i} A_{22,ij} y_{i,t-j} + \mu_{i,t}^y \tag{7}$$

$i = 1, 2, \ldots, N$ ve $j = 1, 2, \ldots, k\ldots$

The variables x_i and y_i denote the error terms, whereas μ_i, a constant effects matrix, $k_i$delay, $dmax_i$ the maximum integration value for each cross-section, i cross-sections, t time period.

4. Findings and discussion

The descriptive statistics of the natural data of the energy efficiency (EE), greenhouse gas emission (GHG) and logarithm GDP values used in the analysis are given in Table 1.

When the data in Table 1 are evaluated, it is seen that the energy efficiency volatility is lower than the volatility in greenhouse gas emission values. Before the unit root, co-integration and causality analyses with relevant data, cross-sectional dependence, and homogeneity tests are performed between the data. Because it guides on the appropriateness of the estimation methods used for the unit root, co-integration, and the causality tests. Depending on the cross-sectional dependence and homogeneity test, the results inform on the use of either the first generation or second generation tests. Table 2 shows the cross-sectional dependence and homogeneity test results of the relevant data.

According to the results of the cross-sectional dependence test, the null hypothesis that there is no cross-sectional dependence is not rejected (see Table 2). In the same Table 2, it also tested whether the slope coefficient is homogeneous. According to the results obtained from the relevant tests, the hypothesis that the slope coefficient is homogeneous at a 1% significance level is not rejected. According to these results, first-generation unit root and co-integration tests which do not take into account the cross-sectional dependence in the tests to be performed with the data can be used. Table 3 shows the results of the unit root tests performed on the data.

According to the results of the unit root test in Table 3, the variables were not stationary at the level values but were found to be stationary after taking the difference series. According to the results of the Pedroni and Kao co-integration tests presented in Table 4, the tests were carried by using the level values of the data, thus the co-integration relationship between variables as indicated in Table 4 is statistically significant.

According to the results of co-integration in Table 4, energy efficiency with greenhouse, gas emission and GDP are co-integrated and in other words, there is a long-term balanced relationship between variables. The results of the DOLS and FMOLS tests performed to determine the direction of the relationship between the variables is equally given in Table 5. Importantly, the FMOLS and DOLS result implies an expected indication such that energy efficiency (EE) are both observed to cause greenhouse gas emissions in the panel countries. Considering the significant and the large coefficient values of the EE in Table 5 (coefficients of DOL and FMOL are -0.879 and -0.933 respectively), the mitigation of GHG in the EU-28 and Turkey is, therefore, an imperative action that is expected to significantly incorporates the energy efficiency policy. While the study of Apergis et al. (2015) mirrored on selected OECD countries and based their objective on underpinning the relationship between energy efficiency, capital-intensive and labor-intensive economies, the relationship between energy efficiency and carbon emissions in the EU was the focal point of the work of Gómez-Calvet et al. (2014). Interestingly, it good to mention that both studies opined the role of energy efficiency in either economic development or carbon emissions. However, the current study proceeds further to measure the impact of EE in the EU-28 and Turkey by considering GHG which better captures environmental sustainability as compared to CO2 employed in the extant studies.

When DOLS and FMOLS test results were evaluated, it was found that energy efficiency had a negative and significant effect on greenhouse gas emission. Growth in GDP has been found to have a positive effect on greenhouse gas emissions. Based on the findings, a 1-unit increase in energy efficiency leads to a decrease in greenhouse gas emissions of between 1.3 and 1.4. However, a 1-unit increase in GDP appears to result in an increase of approximately 1.5–2 units in greenhouse gas emissions.

In Table 6, the panel causality results of Emirmahmutoglu and Kose (2011) are given from energy efficiency to greenhouse gas emission.

The lag values used in the study express how many periods after the independent variable caused the change in the dependent variable. Furthermore, by employing the causality approach of Emirmahmutoğlu and Kose (2011) as a robustness test, the result of the causality for each of the EU-28 plus one country poses an interesting policy outlook. Although the result as indicated earlier indicates that cointegration of EE and GHG exists in the panel countries (see Table 5), the causality approach of Emirmahmutoğlu and Kose (2011) indicates statistical significance only in Austria, Bulgaria, Estonia, Germany, Hungary, Iceland, Italy, Latvia, Netherland, Norway, and Poland. Importantly, the result implies that previous values (historical information) of energy efficiency in only eleven (11) of the EU-28 but one country are significant enough to predict environmental sustainability i. e GHG mitigation.

Importantly, the low predictive power of the GHG emission mitigation by energy efficiency among the panel of EU-28 but one country might not be far from the inability of the regional block to significantly cut GHG emissions from the combustion of fossil fuels (European Environment Agency, EEA, 2019a, b). The report of the EEA (2019a, b) implied that the increasing use of oil, gas and renewable energy sources especially in producing electricity and heat in the EU is majorly responsible for the three-year (2015, 2016, and 2017) consecutive increase in fossil fuel consumption in the regional bloc. Although the EU's commitment toward achieving a sustainable environment has yielded a decline in the energy intensity, energy consumption per capita and an almost 10-year (2004–2014) continuous decline in the EU GHG emissions (as graphically illustrated in each panel of Figure 1) is gradually ensured. Evidently, the EU's 2017 primary energy consumption has stayed at 5% and 23% above the 2020 and 2030 targets respectively (European Commission, 2019a, b). Specifically, the EU-28 has committed to limiting the primary energy consumption and final energy consumption to not more than 1483 Mtoe and 1086 Mtoe in 2020 and for not more than 1273 Mtoe and 956 Mtoe in 2030 respectively. In doing this, the EU member states expressed commitment to the Emissions Trading Scheme (ETS) and non-ETS/Effort Sharing Decision (ESD) policies. However, the 2016 GHG emissions in six member countries (Belgium, Finland, Germany, Ireland, Malta, and Poland) were reportedly higher than ESD emissions targets. By 2017, 10 EU member countries are reported to have GHG emissions that are higher than the ESD emission target (European Environment Agency, EEA, 2019a, b). More damaging is an additional report by European Environment Agency, EEA (2019a, b) that seven Member States (Austria, Belgium, Finland, Germany, Ireland, Luxembourg, and Malta) are expected to exceed the emission target by 2020. Hence, this is no surprise that the causality from energy efficiency to the GHG emissions in the current study is significant in only 11 member countries of the EU-28. This is the reason why İskenderoğlu and Akdağ (2019) maintained that renewable energy sources are more efficient in terms of efficiency than other energy sources.

5. Conclusion, policy implementation, and recommendation

The efficient use of energy and greenhouse gas emissions are among the issues that attract the attention of both the academicians and the environmental stakeholders in recent years. Countries are looking for alternative energy sources in order to reduce energy costs amidst the desire to meeting their energy needs. On the other hand, governments across the globe and intergovernmental agencies such as the United Nations Framework Convention on Climate Change (UNFCCC) are persistently working on how to use the existing energy resources and policies more efficiently. Hence, in order to reduce the environmental costs caused by the expanded resources, the stakeholders have remained committed to environmental sustainability responsibility projects on a global scale.

From the backdrop of the aforementioned concerns in the framework of global environmental outlook, this study investigated and measured the impact of the relationship between energy efficiency and greenhouse gas emissions in the EU-28 and Turkey. By utilizing the energy efficiency and greenhouse gas emission datasets of 29 European countries (EU-26 but one) between 1995 and 2016, a significant cointegration relationship between the variables was confirmed by both the Pedroni (1999) and Kao (1999) panel cointegration approaches. In a similar insight, the FMOLS and DOLS approaches opined that the relationship between the concern variables is statistically significant with the impact of EE on GHG observed to be large and negative. Thus, it indicates that energy efficiency is a potential mechanism to drive down greenhouse gas in the panel countries thereby improving environmental quality. By employing the robust approach of Emirmahmutoğlu and Kose (2011) for the panel causality analysis, Granger causality between energy efficiency and GHG is observed for 11 of the 29 investigated countries. The result translates that there is causality from energy efficiency to greenhouse gas emission for Austria, Bulgaria, Estonia, Germany, Hungary, Italy, Latvia, Netherlands, Norway, and Poland. According to the results of the analysis, it can be inferred that energy efficiency is a vital tool that possesses the capacity toward meeting the increasing energy needs and for reducing greenhouse gas emissions in the environment due to the energy use and other environmental and economic activities.

The results of the current study are similar to that of Gómez-Calvet et al. (2014) and Wang et al. (2017). Importantly, the result of the current study offers interesting policy potential. Although the European Union countries have consistently reviewed its Energy Efficiency Directive (The 2012 Energy Efficiency Directive (2012/27/EU) and 2018 Energy Efficiency (2018/2002)) to meeting 2020 and now 2030 targets (European Commission, 2019a, b), the result of the current study further suggests that a sustained commitment is expected from the member countries.

Because when countries implement policies to increase energy efficiency, both energy costs and the damage to the environment resulting from the energy used are expected to significantly decline. Also, in spite the expressed commitment to the international energy and climate agreements such as the Kyoto Protocol and the United Nations Framework Convention on Climate Change (UNFCCC) guidelines of attaining the regional bloc's targets of 2020, there is a perceived reluctance of the member countries to implement the latest amended 2018 Energy Efficiency Directive as agreed upon by the Member States by 25 June 2020. Thus, the leading member states in energy efficiency implementation should employ diplomacy approach toward encouraging the member countries that are lagging in the EE policy drive. Specifically, the current study implies that more advocacy and policy persuasion on energy efficiency directives is essential in eighteen (Belgium, Croatia, Czech Republic, Denmark, Finland, France, Greece, Ireland, Lithuania, Luxemburg, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Turkey, and the United Kingdom) of the 29 investigated countries since the panel causality from energy efficiency to greenhouse gas is not significant in those countries (see Table 6). Also, the energy-dependent countries will be expected to improve their energy efficiency especially in the household sectors, transportation, and the service sectors. This is because the energy efficiency of the EU-28 of the aforementioned sectors is reportedly not improving in the trajectory of the other sectors (European Environment Agency, EEA, 2019a, b). Additionally, in the direction of the planned 245 million smart meters ahead of the 2020 energy efficiency targets for the European member countries (European Commission, 2019a, b), courageous mechanisms such as tax and incentive policies should be geared toward the use of technologies with high energy efficiency.

Although the indication from the current study suggests useful policy guide for the EU-28 but Turkey, it is obviously a good reason to future study the concept of energy efficiency and environmental sustainability by considering the Greenhouse gas emissions by disaggregate or sector (energy, industrial, agricultural, land use, land-use change and forestry, waste management) analysis. Additionally, further studies could be extended to specific energy efficiency policy indicators like the carbon tax and technology subsidies in the context of environmental sustainability of the European countries and by extension to other case studies.

Declarations

Author contribution statement

Saffet Akdag: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data.

Hakan Yildirim: Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Additional information

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References

Adams, D., Ullah, S., Akhtar, P., Adams, K., Saidi, S., 2019. The role of country-level institutional factors in escaping the natural resource curse: insights from Ghana. Resour. Pol. 61, 433–440.
Ahmed, K., Long, W., 2012. Environmental Kuznets curve and Pakistan: an empirical analysis. Procedia Econ. Finance 1, 4–13.
Alola, A.A., 2019a. The trilemma of trade, monetary and immigration policies in the United States: accounting for environmental sustainability. Sci. Total Environ. 658, 260–267.
Alola, A.A., 2019b. Carbon emissions and the trilemma of trade policy, migration policy and health care in the US. Carbon Manag.
Alola, A.A., Yalçiner, K., Alola, U.V., Saint Akadiri, S., 2019a. The role of renewable energy, immigration and real income in environmental sustainability target. Evidence from Europe's largest states. Sci. Total Environ. 674, 307–315.
Alola, A.A., Bekun, F.V., Sarkodie, S.A., 2019b. Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in Europe. Sci. Total Environ. 685, 702–709.
Altun, T., 2018. Hanelerde Enerji Verimliliği: Davranışsal Müdahaleler ve Kamu Politikaları için anahtar İlkeler. Turk. Stud. Econ. Finance Pol. 13 (22), 91–106.
Ang, B.W., 2006. Monitoring changes in economy-wide energy efficiency: from energy–GDP ratio to composite efficiency index. Energy Pol. 34 (5), 574–582.
Apergis, N., Aye, G.C., Barros, C.P., Gupta, R., Wanke, P., 2015. Energy efficiency of selected OECD countries: a slacks based model with undesirable outputs. Energy Econ. 51, 45–53.
Asteriou, D., Hall, S.G., 2015. Applied Econometrics. Macmillan International Higher Education, UK.
Aye, G.C., Gupta, R., Wanke, P., 2015. Energy Efficiency Drivers in South Africa: 1965-2014 (No. 201571).
Baltagi, B., 2008. Econometric Analysis of Panel Data. John Wiley & Sons, UK.
Begum, R.A., Sohag, K., Abdullah, S.M.S., Jaafar, M., 2015. CO2emissions, energy consumption, economic and population growth in Malaysia, 41, 594–601.
Bekun, F.V., Alola, A.A., Sarkodie, S.A., 2019. Toward a sustainable environment: nexus between CO2 emissions, resource rent, renewable and nonrenewable energy in 16-EU countries. Sci. Total Environ. 657, 1023–1029.
Bella, G., Massidda, C., Etzo, I., 2010. A Panel Estimation of the Relationship between Income, Electric Power Consumption, and CO2 Emissions. MPRA Paper, p. 26077. https://mpra.ub.uni-muenchen.de/26077/1/MPRA_paper_26077.pdf.
Bozoklu, S., Yilanci, V., 2013. Energy consumption and economic growth for selected OECD countries: further evidence from the granger causality test in the frequency Domain. Energy Pol. 63, 877–881.
Breitung, J., Pesaran, M.H., 2008. Unit Roots and Cointegration in Panels. In the Econometrics of Panel Data. Springer, Berlin Heidelberg.
Breusch, T.S., Pagan, A.R., 1980. In: The Lagrange Multiplier Test and its Applications to Model Specification in Econometrics. Review of Economic Studies, 47. Blackwell Publishing, pp. 239–253, 1.
Brookes, L., 1990. The greenhouse effect: the fallacies in the energy efficiency solution. Energy Pol. 18 (2), 199–201.
Emir, F., Bekun, F.V., 2019. Energy intensity, carbon emissions, renewable energy, and economic growth nexus: new insights from Romania. Energy Environ. 30 (3), 427–443.
Emirmahmutoglu, F., Kose, N., 2011. Testing for Granger causality in heterogeneous mixed panels. Econ. Modell. 28 (3), 870–876.
European Commission, 2019a. Energy consumption and energy efficiency trends in the EU-28 (2000-2014). https://ec.europa.eu/jrc/en/publication/eur-scientific-and-technical-research-reports/energy-consumption-and-energy-efficiency-trends-eu-28-2000-2014.
European Commission, 2019b. Energy efficiency directive. https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficiency-directive.
European Environment Agency EEA, 2019a. Progress on energy efficiency in Europe. https://www.eea.europa.eu/data-and-maps/indicators/progress-on-energy-efficiency-in-europe-3/assessment.
European Environment Agency EEA, 2019b. Trends and Projections in EU 2019 TH-AL-19-016-EN-N. https://www.eea.europa.eu/publications/trends-and-projections-in-europe-1. (Accessed 13 December 2019).
Fisher, R.A., 1932. Statistical Methods for Research Workers, 4. Edition. Oliver and Boyd, Edinburgh.
Gómez-Calvet, R., Conesa, D., Gómez-Calvet, A.R., Tortosa-Ausina, E., 2014. Energy efficiency in the European union: what can Be learned from the joint application of directional Distance functions and slacks-based measures? Appl. Energy 132, 137–154.
Halicioglu, F., 2009. An Econometric study of CO_2 Emission, energy consumption, income and foreign trade in Turkey. Energy Pol. 37 (3), 1156–1164.
Hamit-Haggar, M., 2012. Greenhouse gas emissions, energy consumption and economic growth: a panel cointegration analysis from Canadian industrial sector perspective. Energy Econ. 34 (1), 358–364.
Hubbert, M.K., 1956. Nuclear Energy and the Fossil Fuel. In Drilling and Production Practice. American Petroleum Institute, pp. 1–25.
Im, K.S., Pesaran, M.H., Shin, Y., 2003. Testing for unit roots in heterogeneous panels. J. Econom. 115 (1), 53–74.
Inhaber, H., Saunders, H., 1994. Road to nowhere: energy conservation often backfires and leads to increased consumption. Sciences 34 (6), 20–25.
International Energy Agency, 2012. CO2 Emissions from Fuel Combustion.
İskenderoglu, Ö., Akdag, S., 2019. Comparison of nuclear energy and renewable energy consumption in terms of energy efficiency: an analysis on the EU members and candidates. Int. J. Energy Econ. Pol. 9 (6), 193–198.
James, A., 2015. The resource curse: a statistical mirage? J. Dev. Econ. 114, 55–63.
Jaunky, V.C., 2011. The CO2 emissions-income nexus: evidence from rich countries. Energy Pol. 39, 1228–1240.
Kao, C., 1999. Spurious regression and residual-based tests for cointegration in panel data. J. Econom. 90 (1), 1–44.

Kurt, G., Köse, A., 2017. Türkiye'de bankalarin finansal oranlari ile hisse senedi getirisi arasindaki panel nedensellik ilişkisi. Çukurova Üniversitesi Sosyal Bilimler Enstitüsü Dergisi 26 (3), 302–312.
Levin, A., Lin, C., Chu, C.J., 2002. Unit root tests in panel data: asymptotic and finite sample properties. J. Econom. 108 (1), 1–24.
Ma, X., Wang, C., Dong, B., Gu, G., Chen, R., Li, Y., Zou, H., Zhang, W., Li, Q., 2019. Carbon emissions from energy consumption in China: its measurement and driving factors. Sci. Total Environ. 648, 1411–1420.
Pedroni, P., 1999. Critical values for cointegration tests in heterogeneous panels with multiple regressors. Oxf. Bull. Econ. Stat. 61 (1), 653–670.
Pedroni, P., 2001. Fully Modified OLS for Heterogeneous Cointegrated Panels. In Nonstationary Panels, Panel Cointegration, and Dynamic Panels. Emerald Group Publishing Ltd, Bingley.
Pesaran, M.H., 2004. General Diagnostic tests for cross section dependence in panels. Cambridge Working Papers in Economics 435.
Pesaran, M.H., Yamagata, T., 2008. Testing slope homogeneity in large panels. J. Econom. 142 (1), 50–93.
Phillips, P.C., Hansen, B.E., 1990. Statistical inference in instrumental variables regression with processes. Rev. Econ. Stud. 57 (1), 99–125.
Saikkonen, P., 1991. Asymptotically efficient estimation of cointegration regressions. Econom. Theor. 7 (1), 1–21.
Sarkodie, S.A., Adams, S., 2018. Renewable energy, nuclear energy, and environmental pollution: accounting for political institutional quality in South Africa. Sci. Total Environ. (64), 1590–1601.
Saunders, H., 1992. The Khazzoom-Brookes postulate and neoclassical growth. Energy J. 13 (4), 131–148.
Say, N., Yücel, M., 2006. Energy consumption and CO2 emissions in Turkey: empirical analysis and future projection based on an economic growth. Energy Pol. 34, 3870–3876.
Sorensen, B., 1991. A history of renewable energy technology. Energy Pol. 19 (1), 8–12.
Stock, J.H., Watson, M.W., 1993. A simple estimator of cointegrating vectors in higher order integrated systems. Econometrica 61 (4), 783–820.
Todo, H.Y., Yamamoto, T., 1995. Statistical inference in vector autoregressions with possibly integrated processes. J. Econom. 66 (1–2), 225–250.
Wang, J., Lv, K., Bian, Y., Cheng, Y., 2017. Energy efficiency and marginal carbon dioxide emission abatement cost in urban China. Energy Pol. 105, 246–255.
Westerlund, J., 2007. Testing for error correction in panel data. Oxf. Bull. Econ. Stat. 69 (6), 709–748.
Zhang, X.P., Cheng, X.M., 2009. Energy consumption, carbon emissions, and economic growth in China. Ecol. Econ. 68, 2706–2712.