Toward a sustainable economic development in the EU member states: The role of energy efficiency-intensity and renewable energy

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Year: 2021

Version: Accepted version

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Abstract

While aiming to reach its 20% energy efficiency target for 2020 and subsequently reaching at least 32.5% by 2030, the European Union (EU) countries are consistently encouraged to implement the bloc's energy efficiency directives of 2012/27/EU and the (EU) 2018/2002. Without sacrificing existing energy standards and environmental quality, the EU has consistently favored behavioral and economic changes that is capable of increasing energy efficiency. In view of this motivation, this study examines the impact of energy efficiency on economic growth in 21 EU member countries over the 1995-2016 period. Importantly, the study examined both the regional and country specific impacts of energy intensity, energy dependency, and renewable energy utilization on economic expansion. With a respective elasticity of 0.94, 0.17, and 0.01 by the MG (Mean Group) estimator, we found that energy efficiency, renewable energy utilization, and energy dependency positively triggers economic expansion in the region. This result does not only provide a desirable economic outlook for the EU countries, the observation further offers a positive feedback on the bloc's drive for environmental sustainability. The empirical results obtained from panel causality test indicate that there is a bilateral Granger causality from economic growth to energy efficiency, energy intensity, and renewable energy. Moreover, the result provides that energy efficiency, energy intensity, energy dependency, and renewable energy utilization exhibits different degree of economic impact across the sections of examined EU countries. In general, the study captures a policy reflection of economic and environmental sustainability status and outlook of the EU countries.

Keywords: energy efficiency; economic growth; panel cointegration; panel causality; European Union

1. Introduction

In addition to other production factors such as labor, capital, and raw materials, energy sources remained increasingly important to human life, thus making energy one of the main input sources of the production process. In this context, energy production and consumption affect both the supply and demand sides of the economy and can directly influence the overall performance of the economy (Nguyen & Ngoc, 2020). The capability of countries to maintain a steady economic growth and economic sustainability requires that energy resources is safe to use, inexpensive and ensure environmental quality (Dincer & Acar, 2015; Baz et al., 2019; Adedoyin 2020b; Adedoyin, 2021a). As of today, the vast majority of energy resources needed for economic growth and development are comprised of fossil fuels such as coal, oil, and natural gas. Nevertheless, countries that are aware of the fact that fossil fuel reserves can be depleted in the future tend to search for alternative energy sources and to implement new policies in order to use existing energy sources more efficiently along with increasing technological improvements (İslatince & Haydaroğlu, 2009). Additionally, the environmental implications of material and ecosystem depletion (including energy, water, and land resources) is increasingly responsible for the drive a more efficient use of resources and energy sources especially in developed economies (Alvarez-Herranz et al., 2017; Bai, 2019; Aldieri, 2020; Adedoyin, 2021b, c, d, e).

Material or resources efficiency is considered an essential source of economic growth and competitiveness. Besides, efficiency can be used as basic statistical information in terms of many international comparisons and evaluation of countries' performances. The efficiency of energy usage involves all types of technological, behavioral and economic changes that minimizes the amount of energy usage in order to produce the same amounts of goods or services without sacrificing current quality standards (Patterson, 1996; Samargandi, 2019). The efficient use of energy can be evaluated within the scope of two aspects. The first involves producing and using more energy at the same cost, whereas the second involves providing more economic output with the same amount of energy consumption (İskenderoğlu & Akdağ, 2019). In addition to energy demand and reduction of greenhouse gas emissions, energy efficiency improvements/policies can contribute to that country's socio-economic development with their direct and indirect impacts on the GDP, employment, trade balance, and energy prices in accordance of the country's economic structure and the design of key policies.

Energy efficiency policies can promote economic growth through several potential channels. Firstly, energy efficiency improvements encourage the firms' innovation and technology development, thus enabling less energy consumption per unit output. This reduces the firms' energy demand, and therefore, production costs. Thus, the production power and profitability of the firms increase, so they can become more competitive in export markets. Secondly, these policies can generate new markets for energy-efficient technology and products. Therefore, increasing investments for the production of products with high-energy efficiency can contribute to economic growth. Thirdly, energy efficiency improvements reduce energy expenditures, particularly in energy-importing countries, and may result in more investment in other prioritized fields that would contribute more to economic growth, such as education and health, in the long-run. Subsequently, energy efficiency improvements save energy for households, increase disposable income and promote consumption that contributes to economic growth (Rajbhandari and Zhang, 2018: 129; IEA, 2014).

In recent time, increases in energy costs, climate change concerns, and energy security issues are becoming increasingly essential, thus making energy efficiency an important element in the formulation of energy policy (Alola & Alola, 2019; Johnsson et al., 2019; Yuan etal., 2019). In this context, the EU considers energy efficiency as an integral part of its low-carbon economy vision by reducing energy consumption while maintaining the same output level because of technological improvements. In fact, and as acknowledged by the EU, an increase in energy efficiency had a significant impact on the reduction of greenhouse gas emissions (Akdağ & Yıldırım, 2020). Indicatively, the directive (EU) 2018/2002 of the European Parliament on energy efficiency is aimed at further enhancing the current 2020 target of 20% energy efficiency. Thus, the 32.5% energy efficiency target that is expected to aim at reducing energy demand through accelerated energy efficiency efforts by 2030 has become the new target of the EU. Resulting from the energy efficiency policies implemented for these goals; significant progress has been made in reducing energy demand in the EU. In addition, the primary energy consumption has decreased by approximately 9% and the final energy consumption by about 6% in the EU countries during the 2005-2016 period. This indicates that the recent energy efficiency policies of the EU countries play a crucial role in the region's energy consumption mix. However, European Commission (2020a) recently identified the grey areas and potentials for improvement in the Energy Efficiency Directive 2012/27/EU.

The fact that energy is among the main sources of input in the production process has consistently inspired the investigation of the impacts of energy efficiency policies on economic growth. Although many studies in the literature tested the causal relationship between energy consumption and economic growth for the EU countries (such as Pirlogea and Cicea (2012), Bölük and Mert (2014), Śmiech and Papież (2014), Streimikiene and Kasperowicz (2016)), only a few studies has examined the relationship between energy efficiency and economic growth for the case of EU countries. In this approach, the study is further designed to examine the following structure objectives. Firstly, the contribution of energy efficiency to the economic progress of EU is clearly evaluated in a growth model framework. Secondly, the objective of the study is to further reveal the roles of energy intensity and energy dependency in the economic expansion in the panel of EU economies. Lastly, while considering the EU's drive for alternative energy development, this study is designed to further portray the desirable perspective of renewable energy utilization. Thus, to achieve this aim of investigating the impacts of energy efficiency outputs on economic growth in the EU countries over the 1995-2016 period, a more recent econometric approach that accounts for country specific factors in addition to the Emirmahmutoğlu and Köse (2011) causality test were deployed. Expectedly, the concrete evidence obtained from this study for this purpose would make a distinct contribution to the literature.

The study is comprised of four parts. In the second part, empirical studies on the subject are examined; in the third part, the econometric methodology to be used in the study is explained; in the fourth part, the empirical findings are presented, and the study is finalized with a conclusion part containing an overall evaluation with policy directive.

2. Literature Review

Studies investigating the relationship between energy and economic growth in the literature began with the oil crises experienced during the 1973-1974 and the 1978-1979 periods. Nonetheless, in these studies, the relationship between energy consumption and economic growth was investigated. The emergence of the possibility of depletion of fossil fuel reserves since the 1990s and the claims on the occurrence of related environmental problems caused energy studies to shift towards the field of energy efficiency (Şener & Karakaş, 2019: 524). It can be said that Khazzoom (1980), Brookes (1990), and Saunders (1992) conducted the pioneering studies in the field of energy efficiency. Following these studies, Semboja (1994) analyzed the impacts of the increase in energy efficiency on the Kenyan economy utilizing the computable general equilibrium model (CGE). The simulation from the study illustrate that if the increase in energy efficiency is dependent on foreign energy resources, thereby affecting savings in foreign currency, then material or resources utilization is minimized.

In Hanley et al. (2006), the drew the attention to environmental impacts as well as economic impacts of energy efficiency improvements by offering an alternative approach to energy efficiency. The study asserted that a 5% increase in energy efficiency in Scotland increased the GDP by 0.06%, 0.10%, and 0.88% in the short- and medium-, and long-term, respectively. However, the study opined that energy efficiency improvements would have increased energy consumption over time, thus causing significant environmental pollution. Similarly, Allan et al. (2007) investigated the relationship between energy efficiency and economic growth using an economy-energy-environment CGE model to examine the impact of energy efficiency on economic growth in the United Kingdom. The obtained results revealed that when energy efficiency increased 5% in the industrial sector, the GDP increased by 0.11% in the short-run and 0.17% in the long run. Wei et al. (2009), by implementing a data envelopment method to estimate the energy efficiency index in 29 provinces of China, found that all provinces had large differences in energy efficiency and the share of secondary industry in the GDP had an adverse impact on energy efficiency. Bunse et al. (2011), on the other hand, emphasized the needs of industrial companies to integrate their energy efficiency performance into production management within the framework of activity research and argued that there was a gap between industrial companies and theoretical solutions. In Zhang et al. (2011), which measured total factor energy efficiency using the data envelopment method in order to detect changes in efficiency over time in 23 developing countries, Tobit regression results indicated a U-shaped relationship between total factor energy efficiency and per capita income although measurement results differed by country.

According to the results obtained from Sinha (2015), which analyzed the impact of economic growth in India on energy efficiency using the vector error correction model with energy waste representing energy efficiency, a unilateral causality from economic growth to energy waste as well as an adverse relationship between energy waste and economic growth was detected. In Bataille and Melton (2017), which investigated the economic impacts of energy efficiency improvements in Canada, with a CGE model differentiated by both sectoral and regional aspects from other studies, the forecasting results indicated that energy efficiency improvements increased the GDP by 2%, employment by 2.5%, and household welfare by approximately 1.5% within the relevant period. By considering energy efficiency as an industrial policy to promote economic competitiveness, Rajbhandari and Zhang (2018) investigated the causal relationship between energy efficiency and economic growth using the panel vector autoregression (PVAR) method in 56 high-, middle-, and low-income countries. The analysis results reveal the presence of long-term unilateral causality from economic growth to low energy intensity for all countries and long-term bilateral causality between energy intensity and economic growth for middle- and low-income countries.

Based on these results, Rajbhandari and Zhang (2018) suggested that energy efficiency in the middle- and low-income countries contribute to the GDP in the long-run. Following Rajbhandari and Zhang (2018), Bayar and Gavriletea (2019) found that energy efficiency caused economic growth in 22 developing countries, whereas Go et al. (2019) detected such causality in Malaysia. Şener and Karakaş (2019) examined the impact of economic growth on energy efficiency in 62 countries by implementing a different method compared to their previous studies. Results obtained from the AMG (Augmented Mean Group) estimator indicated that an increase in the GDP reduced overall energy intensity for high- and upper-middle-income country groups, whereas it had no impact on energy intensity in the lower-middle-income country group. In Akdağ and Yıldırım (2020), which was conducted to determine the energy efficiency and the impact of greenhouse gas emissions and economic growth on the European countries, it was asserted that the increase in energy efficiency had an adverse impact on greenhouse gas emission and a positive impact on economic growth.

Moreover, extant studies have established the relationship between economic development and energy intensity (Deichmann et al., 2018; Mahmood & Ahmad, 2018).). For instance, Deichmann et al (2018) examined the role of energy intensity in economic expansion for the panel of 137 countries. Although the study found a negative relationship between the indicators, it further presented an existence of threshold in the nexus of energy intensity and economic growth such that a turning point is attained after the level of per capita income reaches $5,000. Similarly, Mahmood and Ahmad (2018) found a significant and negative evidence of the nexus of economic growth and energy intensity in the European countries. In addition, renewable energy consumption and economic growth are found to be related in the studies of Bhattacharya et al (2016), Alola and Alola (20118), Shahbaz et al (2020), and other studies. While Alola and Alola (2018) established a positive relationship between renewable energy consumption and economic growth in the Coastline Mediterranean countries (CMC), the recent work of Shahbaz et al (2020) examined the relationship between the two indicators in 38 renewable-energy-consuming countries. In specific, Shahbaz et al (2020) implemented the dynamic ordinary least squares (DOLS) and fully modified ordinary least squares (FMOLS), thus presenting that renewable energy utilization promotes economic expansion in the panel of examined countries. In addition to the aforementioned studies on energy intensity and economic growth nexus, the energy literature is flooded with the dimensions of energy sources and economic growth relationship (Zeraibi et al., 2020).

3. Empirical Analysis

In order to achieving the aforementioned objective of the study, the pathway of the empirical analysis is detailed in this section. Starting from the data description, the step-by-step description of the estimation procedures are detailed accordingly.

3.1. Model and Data

The empirical model of this study, in which the relationship between energy efficiency and economic growth for 21 EU countries[1] is examined, is based on the Aggregated Cobb-Douglas production function used by Shahbaz et al. (2013), Buhari et al. (2020), and Le and Bao (2020). As a modification to the growth model by Solow (1957), the employed theoretical concept is derived as

$$GDP_{it} = f(ENP_{it}, ENINT_{it}, REN_{it}, ENDR_{it}) \qquad (1)$$

In Equation (1), GDP denotes the gross domestic product; ENP denotes energy efficiency, *ENINT* is the energy intensity, *REN* is the renewable energy, and *ENDR* is the energy dependency rate such that i $(i = 1 \dots N)$ denotes the number of countries, and t $(t = 1 \dots T)$ denotes time. The logarithms of the variables are taken as seen in Equation (1), while the Cobb-Douglas production function is transformed into the natural logarithmic linear form as seen in Equation (2).

$$lnGDP_{it} = \beta_{0i} + \beta_{1i} lnENP_{it} + \beta_{2i} lnENINT_{it} + \beta_{3i} lnREN_{it} + \beta_{4i} ENDR_{it} + \varepsilon_{it} \qquad (2)$$

In Equation (2), β_{0i} denotes the constant term, $\beta_1, \beta_2, \beta_3, and\ \beta_4$ denotes the relation of the $ENP,$ ENINT, REN, and ENDR variable with the GDP variable, and ε_{it} denotes the error term. The energy efficiency variable used in the model is expected to positively affect economic growth.

[1] Germany, Austria, Belgium, Bulgaria, Czech Republic, Denmark, Finland, France, Netherlands, the UK, Ireland, Spain, Sweden, Italy, Luxembourg, Hungary, Poland, Portugal, Romania, Slovakia, Greece.

The data of the variables included in the model are obtained from Eurostat (*European Statistical Office*) over the 1995-2016 period. The natural logarithms of the variables are taken prior to performing the empirical analyses, and the definitions and descriptive statistics of the variables are presented in Table 1.

Tablo 1: Variable Description and Statistics

Variable	Symbol	Description	Number of Observation	Mean	Standard Deviation	Min.	Max.
Economic Growth	***GDP***	Constant 2010 USD	462	12.503	1.249	10.046	14.870
Energy Efficiency	***ENE***	GDP (Chained volume series (2010), million Euros	462	1.753	0.529	0.182	2.833
Energy Intensity	***ENINT***	Units of energy per unit of GDP	462	5.183	0.517	4.121	6.767
Renewable Energy	***REN***	Share of renewable energy in the total primary energy consumption.	462	11.383	1.436	6.937	13.847
Energy Dependency Rate	***ENDR***	share of net imports (imports - exports) in gross inland energy consumption.	462	52.681	28.685	-50.602	99.598

3.2. Cross-sectional Dependence Tests

Increasing economic and financial integration with other unforeseen events among countries and financial institutions in recent years has caused the interdependence among countries to become even stronger. Cross-sectional dependence is based on the assumption that all countries are affected by a shock to any of the units that constitute the panel. It also implies that other countries that constitute the panel can be affected by a macroeconomic shock that occurs in any of the countries. In addition, it then suggests that the results obtained in panel data analysis without considering cross-sectional dependence may be deviated and inconsistent. Therefore, it is necessary to test whether or not cross-sectional dependence exists prior to conducting the analysis (Hoyos & Sarafidis, 2006; Mercan, 2014; Menyah et al., 2014). The first of the cross-sectional dependence tests is the Lagrange Multiplier (Lagrange Multiplier, *LM*) test developed by Breusch and Pagan (1980) given in Equation (3).

$$LM = T\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\hat{\rho}_{ij}^2 \qquad (3)$$

In Equation (3), T denotes the period and N denotes cross-section dimension, $\hat{\rho}_{ij}$ denotes the cross-sectional correlation of the residuals obtained from individual least squares (OLS) estimates. It is assumed that this test would be used in cases where the time dimension exceeds the cross-section ($T > N$) (Pesaran, 2004). The CD_{LM} test, which can be performed in situations where both N and T are large, shown in Equation (4), is in the form of the Breusch and Pagan LM test developed by Pesaran (2004).

$$CD_{LM} = \sqrt{\frac{2T}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} (T\hat{\rho}_{ij}^2 - 1) \tag{4}$$

Since significant dimensional distortions were observed in the cases where $N > T$ in the CD_{LM} test, Pesaran (2004) developed the CD test presented in Equation (5). Accordingly, to test for the cross-sectional dependence in cases where $N > T$ (Pesaran, 2004), the estimation is give as

$$CD = \sqrt{\frac{2T}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}^2 \tag{5}$$

As an alternative cross-sectional dependence test, Pesaran et al. (2008) developed bias-adjusted LMadj test presented in Equation (6).

$$LM_{adj} = \sqrt{(\frac{2T}{N(N-1)})} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} T\hat{\rho}_{ij}^2 \frac{(T-k)\hat{\rho}_{ij}^2 \mu_{Tij}}{\sqrt{\upsilon_{Tij}^2}} \tag{6}$$

where k denotes the number of regressors in Equation (6), and the LM_{adj} statistic is asymptotically standard normally distributed (Pesaran et al., 2008: 108). In the null hypothesis of these tests, it is assumed that there is no interdependence of cross-section units.

3.3. Testing the Homogeneity of Cointegration Coefficients

Swamy (1970) conducted the first studies on homogeneity testing in panel data analysis. The Swamy test ($\hat{S}$) is shown in Equation (7):

$$\hat{S} = \sum_{i=1}^{N} (\hat{\beta}_i - \hat{\beta}_{\text{WFE}}) \frac{X_i' M_\tau X_i}{\sigma_i^2} (\hat{\beta}_i - \hat{\beta}_{\text{WFE}}) \tag{7}$$

In addition, Pesaran and Yamagata (2008) proposed delta (Δ) tests based on the Swamy model (shown in Equation (8) and (9)) to test the homogeneity of slope coefficients (β_i) in a cointegration equation such as $Y_{it} = \alpha + \beta_{it} X_{it} + \varepsilon_{it}$. In these tests, the alternative hypothesis (*H₁:* $\beta \neq \beta_j$) which claims that the slope coefficients in the above cointegration equation are homogeneous is tested against the null hypothesis (*H₀:* $\beta_i = \beta$) (Pesaran and Yamagata, 2008).

$$\tilde{\Delta} = \sqrt{N} (\frac{N^{-1}\tilde{S} - k}{\sqrt{2k}}) \tag{8}$$

$$\tilde{\Delta}_{adj} = \sqrt{N} (\frac{N^{-1}\tilde{S} - E(\tilde{z}_{iT})}{\sqrt{Var(\tilde{z}_{iT})}}) \tag{9}$$

In the above equations, N denotes the number of cross-sections; S denotes the Swamy test statistic; k denotes the number of explanatory variables, given $E(\tilde{z}_{iT}) = k$, and $Var(\tilde{z}_{iT}) = \frac{2k(T-k-1)}{T+1}$ (Pesaran and Yamagata, 2008: 57).

3.4. Panel Unit Root Test

The most important factor to consider upon performing panel unit root analysis is to determine whether the cross-sections that constitute the panel are independent of each other. In the previous stage, the stability of the series is analyzed by the Pesaran (2007) CADF (Cross-sectionally Augmented Dickey-Fuller) test, one of the more recent panel unit root tests, since the cross-sectional dependence is detected among the countries that constitute the panel for the variables used in the study.

The CADF test is the expanded version of the ADF (Augmented Dickey-Fuller) regression with the first differences of the individual series and the cross-section averages of lag levels. In the test, both the CADF statistics and individual results of each cross-section are obtained. In addition, the results of the overall panel are obtained with the CIPS (Cross-sectionally IPS) statistics, which are expanded by taking the cross-section averages. Assuming that each country is affected separately by time impacts, the CADF test yields highly consistent results even when the N and T dimensions are relatively small. Furthermore, this test can be used in cases where both $T > N$, and $N > T$ (Pesaran, 2007).

Assuming that y_{it} is an observable value in the i th cross-section unit at time t, y_{it} can be rewritten as in Equation (10).

$$y_{it} = (1 - \emptyset_i)\mu_i + \emptyset_i y_{i,t-1} + u_{it} \quad (i = 1, \dots\dots.., N; t = 1, \dots\dots., T) \tag{10}$$

Here, initial value, y_{i0}, has a density function with a finite mean and variance. The error term u_{it} has a single-factor structure.

$$u_{it} = \gamma_i f_t + \varepsilon_{it} \tag{11}$$

In Equation (11), f_t denotes the unobservable common effects of each country, and ε_{it} denotes the individual-specific error term. Based on Equations (10) and (11), Equation (12) is formed and the hypotheses of the test are created (Pesaran, 2007).

$$\Delta y_{it} = \alpha_i + \beta_i y_{i,t-1} + \gamma_i f_t + \varepsilon_{it} \tag{12}$$

$H_0: \beta_i = 0$ (*for all* i) series is non-stationary.

$H_A\colon \beta_i < 0\ (i = 1, 2, \dots\dots, N_{1,}\ \beta_i = 0, i = N_1 + 1, N_1 + 2, \dots\dots, N)$ series is stationary.

The Pesaran (2007) CADF regression is shown in Equation (13):

$$\Delta y_{it} = a_i + b_i y_{i,t-1} + c_i \bar{y}_{t-1} + d_i \Delta \bar{y}_t + e_{it} \tag{13}$$

CIPS statistics, calculated by taking the simple average of the individual CADF statistics for the overall panel, can be estimated by Equation (14):

$$CIPS\ (N, T) = N^{-1} \sum_{i=1}^{N} t_i(N, T) \tag{14}$$

In Equation (14), $t_i(N, T)$ denotes CADF statistics for the i th cross-section unit.

3.5. Panel Cointegration Test

In the study, the presence of the cointegration relationship between the variables is analyzed via the panel cointegration test developed by Westerlund (2008), which takes into account the cross-sectional dependence. Based on the Durbin-Hausman (DH) principle, where the null hypothesis is tested against the alternative hypothesis that claims the presence of the cointegration relationship, a factor model derived from factors that cannot be commonly observed among the cross-section units is used. This test, which is stronger and has less dimensional distortion than other cointegration tests that take into account the cross-sectional dependence, proposes two cointegration tests such as DH_{panel} and DH_{group}.

$$DH_p = \hat{S}_n (\tilde{\phi} - \hat{\phi})^2 \sum_{i=1}^{n} \sum_{t=2}^{T} \hat{e}_{it-1}^2 \tag{15}$$

$$DH_g = \sum_{i=1}^{n} \hat{S}_i (\tilde{\phi} - \hat{\phi})^2 \sum_{t=2}^{T} \hat{e}_{it-1}^2 \tag{16}$$

Since the autoregressive parameters are the same for all cross-sections in DH_p test, the presence of a cointegration relationship is confirmed for all n when the null hypothesis is rejected in this test. On the contrary, since autoregressive parameters differ among cross-sections, the presence of a cointegration relationship is confirmed for at least some cross-section units when the null hypothesis is rejected in DH_g test (Westerlund, 2008: 203).

3.6. Estimation of Long-Term Cointegration Coefficients

In this part of the study, the MG (Mean Group) estimator developed by Pesaran and Smith (1995) estimated the individual long-term cointegration coefficients for each cross section unit. In the MG estimation method, long-term coefficients are calculated by using the average of long-term parameters of autoregressive distributed lag models (ARDL) created for each unit.

In the model, the MG estimator that calculates the long-term coefficients of the entire panel and each cross-section unit is shown in equation (17) (Peseran & Smith, 1995:95).

$$\hat{\phi} = \sum_{i=1}^{N} \hat{\phi}_i / N \tag{17}$$

If $\emptyset_1 = 0$ in Equation (17), it indicates that there is no long-term relationship between the variables. Therefore, it should be $\emptyset_1 \neq 0$ for a long-term relationship in the model.

3.7. Panel Causality Test

In addition to the cointegration technique the reveals the long-run relationships, the panel Granger causality test developed by Emirmahmutoğlu and Köse (2011) is performed to reveal the causal relationship between energy efficiency and economic growth. The Emirmahmutoğlu and Köse (2011) causality test, which is the adaptation of the Todo-Yamamato (1995) causality test to the panel and using the meta-analysis developed in the Fisher (1932) study, is used even if the variables are not stationary at the same level. Another advantage of this test involves the fact that it takes into account cross-sectional dependence that make it suitable even if the cointegration relationship cannot be determined. Since the test also has a heterogeneous structure, it can provide results for both the overall panel and for each cross-section. In this test, Equations (18) and (19) showing a causal relationship based on the two-variable VAR model can be established as follows (Emirmahmutoğlu and Köse, 2011: 872):

$$x_{i,t} = \mu_i^x + \sum_{j=1}^{k_i+dmax_i} A_{11,ij} x_{i,t-j} + \sum_{j=1}^{k_i+dmax_i} A_{12,ij} y_{i,t-j} + \mu_{i,t}^x \tag{18}$$

$$y_{i,t} = \mu_i^y + \sum_{j=1}^{k_i+dmax_i} A_{21,ij} x_{i,t-j} + \sum_{j=1}^{k_i+dmax_i} A_{22,ij} y_{i,t-j} + \mu_{i,t}^y \tag{19}$$

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

x_i and y_i denote the variables; μ_i denotes the error term; A denotes the constant effects matrix; k_i denotes the lag length; $dmax_i$ denotes the maximum integration value for each cross-section; i denotes the cross-sections; and t denotes time.

4. Findings and Discussion

Considering the aforementioned procedures to obtain the stationarity, cross-sectional dependence with the homogeneity of the slope coefficients, cointegration, and Granger causality inferences, the revealed findings are discussed. Also in this section, the observations form the results are further compared with related studies.

4.1 Unit root and cointegration evidence

The test results that estimate the cross-sectional dependence and the homogeneity of the slope coefficients are shown in Table 2. According to the probability values of the LM, CD_{LM}, CD and LM_{adj} test statistics, the null hypothesis H_0 is rejected at a 1% significance level for the cointegration equation, and the presence of cross-sectional dependence is confirmed in all series. Moreover, according to the results obtained from $\tilde{\Delta}$ and $\tilde{\Delta}_{adj}$ tests in the lower part of Table 2, the null hypothesis H_0, which assumes that the slope coefficients are homogeneous, is rejected at a 1% significance level.

Table 2: The output from the tests for crosssectional dependence and slope heterogeneity

Cross-sectional dependence

Variables	Tests			
	LM Test	CD_{LM} Test	CD Test	LM_{adj} Test
GDP	857.912***[0.000]	31.615***[0.000]	-2.579***[0.005]	23.630***[0.000]
ENE	629.297***[0.000]	20.460***[0.000]	-2.704 [0.003]	47.014***[0.000]
ENINT	615.916***[0.000]	19.807***[0.000]	-2.587 [0.005]	42.547***[0.000]
REN	979.171***[0.000]	37.533***[0.000]	5.530 [0.000]	24.956***[0.000]
ENDR	359.794***[0.000]	7.309***[0.000]	-2.689 [0.004]	8.502***[0.000]
Cointegration equation	490.463***[0.000]	13.685***[0.000]	8.942***[0.000]	11.499***[0.000]

Homogeneity of slope test analysis

Tests	Test statistic
$\tilde{\Delta}$	3.215*** [0.001]
$\tilde{\Delta}_{adj}$	3.459*** [0.000]

Note: The values in brackets indicate the probability values. * indicates significance at 1% level.

Indicatively, the result of the cross-sectional dependence test above (Table 2) paved way for the application of the more recent unit root test by Pesaran (2007) CADF (Cross-sectionally Augmented Dickey-Fuller) as detailed in equations 10-14. Thus, the results obtained from the panel unit root tests are presented in Table 3. According to the findings, the country specific unit root test for all the variables indicate a mixed order of integration i.e I (0) and I (1). Moreover, the panel unit root illustrated but the CIPS statistics indicate that the entire panel, for all the variables are stationary at their first difference (see the lower part of Table 3).

Tablo 3: Individual CADF panel unit root tests

COUNTRIES	VARIABLES

	GDP	△GDP	ENE	△ENE	ENINT	△ENINT	REN	△REN	ENDR	△ENDR
Austria	-2.389	-5.023	-0.201	-2.000	-1.077	-4.325*	0.586	-2.654	-1.016	-2.979***
Belgium	-1.846	-4.478*	-2.641	-4.438**	-1.876	-2.262	-3.208	-3.329	-2.484	-4.251*
Bulgaria	-3.017	-2.794***	-1.813	-1.886	-2.265	-3.872**	0.733	-1.814	-3.082	-4.038*
Czech Rep.	-2.146	-3.689**	-2.335	-1.270	-1.968	-0.903	-1.382	-6.247	-1.962	-3.800**
Denmark	-1.585	-1.505***	-2.293	-3.087	-2.689	-1.254	-0.739	-3.675**	-0.698	-3.041
Finland	-2.481	-3.916**	-2.149	-4.402**	-2.576	-3.594**	-0.802	-5.649	-1.861	-3.973**
France	-0.772	-2.752**	-2.284	-2.970	-1.759	-2.146	2.957	0.872	-2.204	-3.261
Germany	-2.100	-4.177*	-1.548	-1.545	-1.877	-4.387*	0.149	-4.548*	-1.415	-3.265
Greece	-0.570	-2.294***	-2.728	-3.152	-1.062	-3.395	1.271	-1.119	-1.808	-4.903*
Hungary	-1.194	-1.000***	-3.378	-4.049*	-2.389	-4.566*	-4.559*	-3.910**	-1.790	-0.969
Ireland	-1.290	-1.550***	-2.855	-4.396*	-1.719	-2.005	2.507	-0.145	-2.987	-3.761**
Italy	-3.614**	-5.789	-2.537	-3.751**	-2.467	-4.776*	-5.786	-7.106	-1.406	-4.170*
Luxembourg	-0.604	-1.992***	-1.736	-3.950**	-1.724	-1.719	0.055	-4.192*	-2.390	-3.314
Netherlands	-3.639**	-5.942	-1.419	-3.561**	-2.355	-5.466	-1.851	-8.037	-2.137	-3.981**
Poland	-1.714	-2.176***	-2.562	-1.899	-0.956	-4.553*	2.136	-1.081	-2.101	-3.697**
Portugal	-1.664	-4.618**	-0.883	-2.561	-3.871**	-4.160*	-1.719	-3.420	-2.937	-3.384
Romania	-2.409	-1.786***	-2.663	-3.643**	-0.786	-4.587	-3.577**	-4.637*	-2.824	-2.844
Slovakia	-3.736**	-5.833	-2.528	-3.198	-1.653	-2.117	-1.632	-3.890*	-2.125	-6.295
Spain	-1.250	-2.169***	-1.485	-4.389*	-0.760	-4.327*	1.686	-0.651	-0.295	-2.282
Sweden	-2.308	-7.494	-2.201	-2.831	-1.636	-3.125	-2.074	-4.906*	-2.465	-4.508*
UK	-1.898	-3.190***	-1.721	-0.923	-1.393	-3.019	-1.614	-3.383	-1.595	-2.024
PANEL (CIPS)	**-2.011**	**-3.532***	**-2.093**	**-3.043***	**-1.850**	**-3.360***	**-0.803**	**-3.501***	**-1.980**	**-3.559***

Note: Individual critical values corresponding to 1%, 5% and 10% significance levels for each country in the Table are -4.96, -4.00, and -3.55, respectively. Critical values corresponding to 1%, 5% and 10% significance levels for the overall panel are -2.92, -2.73, and -2.63, respectively (Pesaran, 2007). ***, **, and * indicate significance levels at 1%, 5% and 10%, respectively.

In regard to the cointegration evidence, Table 4 presents the Westerlund (2008) DH panel cointegration test results. As seen from the Table, the null hypothesis of cointegration is rejected by both statistics. In the DH group test, the autoregressive parameter is allowed to differentiate between the sections. The rejection of the null hypothesis H_0 in this test claims the existence of a cointegration relationship for at least some cross-sections. In the DH panel cointegration test, the autoregressive parameter is considered the same for all cross-sections. Under this assumption, upon rejecting the H_0 hypothesis, the cointegration relationship is assumed to exist for all sections.

Tablo 4: DH Cointegration test by Westerlund (2008)

Statistics	Value	p-value	Decision
Durbin-H Group Statistics	639.884	0.000	Cointegration relationship exists.
Durbin-H Panel Statistics	39.963	0.000	Cointegration relationship exists.

4.2 The output effects of ENE, ENINT, REN, and ENDR

Given the mean Group estimate, Table 5 reports the impacts of energy efficiency, energy intensity, renewable energy consumption, and energy dependency rate on economic growth for both the panel and each of the examined EU countries. The results from the MG estimator reveals that ENE, ENINT, REN, and ENDR positively affects economic growth in EU countries with a varying degree. Although the impact of energy intensity is not significant, the positive impact of ENE, REN, and ENDR are all at 1% statistically significant level. For instance, a 1% increase in energy efficiency triggers economic expansion by 0.94%. The energy efficiency-output result which louds the extant studies (Hanley et al., 2006; Bataille & Melton, 2017) that posit a desirable pathway in the panel countries and suggesting that economic growth can be optimized with a minimal energy utilization. According to the individual results in Table 5, only in Belgium, Denmark, Finland, Greece, Hungary, Netherlands, and Sweden that economic growth is triggered positively by energy efficiency. While the impact of energy efficiency on economic growth in other countries is not significant, energy efficiency in turn, present a significant and negative setback on economic growth in Austria and Romania.

On the impact of energy intensity in the panel (also illustrated in Table 5), the impact of energy intensity on economic growth is positive but it is not statistically significant. In pursue of sustainable economic growth, an inverse relationship is expected between energy intensity and economic expansion. Hence, the impact of energy intensity on economic growth is significant and negative in Austria, Poland, and Romania as posited in the study of Mahmood and Ahmad (2018) while the impact of energy intensity on economic growth is significant and positive in Belgium and Netherlands. The mix evidence of positive and negative lauds the scenario in the study of Deichmann et al (2018) that opined a U-shaped relationship between energy intensity and economic development especially with a threshold per capita income of $5,000. On the other hand, Aboagye (2017) reported an inverted U-shaped relationship between energy intensity and economic development for Ghana. Furthermore, the result in Table 5 also present a positive and significant relationship between energy dependency ratio and economic growth in the panel of the examined countries. This result suggest that the panel country depend more on energy import as a catalyst for the region’s economic development. According to the country specific result, more dependency on energy import as a share of inland energy consumption is injurious to the economies of Bulgaria and Denmark while it significantly trigger growth in Austria, Finland, France, Greece, Hungary, Ireland, Italy, Netherlands, Poland, Romania, and Spain.

Furthermore, Table 5 further illustrates the relationship between renewable energy and economic development. In line with expectation and the findings from many studies, there is a significant and positive relationship between renewable energy utilization and economic development in the panel countries (given an elasticity of 0.170). The evidence in the current study is similar to the extant studies (Tugcu, Ozturk & Aslan, 2012; Bhattacharya et al 2016; Alola & Alola, 2018; Adedoyin, Bekun & Alola, 2020a; Kirikkaleli, Adedoyin & Bekun, 2020). Concerning the country specific result, renewable energy consumption is significantly essential for economic growth in Austria, Belgium, Denmark, Finland, Hungary, Italy, Luxembourg, Netherlands, Poland, and Romania. In specific, consumption of renewable energy promotes economic expansion in Romania (Emir & Bekun, 2019), Austria (Faninger, 2003), and the Netherlands (Bulavskaya & Reynès, 2018).

Tablo 5: The effect of the variables on GDP (Mean Group coefficient estimates)

COUNTRIES	VARIABLES			
	ENE	ENINT	REN	ENDR
Austria	-2.281*[0.093]	-2.944***[0.029]	0.354***[0.000]	0.008***[0.002]
Belgium	1.150***[0.001]	0.701***[0.014]	0.079***[0.019]	-0.000 [0.758]
Bulgaria	-0.034 [0.965]	-1.154 [0.180]	-0.103 [0.147]	-0.006**[0.069]
Czech Rep.	-0.079 [0.948]	-1.157 [0.365]	-0.000 [0.994]	-0.002 [0.704]
Denmark	0.950**[0.040]	0.720 [0.128]	0.122***[0.000]	-0.000***[0.000]
Finland	1.072**[0.078]	0.443 [0.453]	0.568***[0.000]	0.007**[0.043]
France	0.678 [0.479]	-0.506 [0.630]	0.052 [0.631]	0.019***[0.000]
Germany	0.794 [0.416]	0.244 [0.781]	0.014 [0.682]	0.005 [0.167]
Greece	3.872**[0.062]	2.159 [0.238]	0.136 [0.660]	0.014**[0.073]
Hungary	1.124**[0.067]	0.518[0.398]	0.081***[0.001]	0.007***[0.004]
Ireland	0.449 [0.705]	-0.652 [0.594]	0.030 [0.818]	0.007***[0.004]
Italy	1.665 [0.167]	1.626 [0.178]	0.101***[0.000]	0.132***[0.000]
Luxembourg	5.228 [0.102]	4.740 [0.133]	0.321***[0.000]	0.010 [0.703]
Netherlands	1.632***[0.000]	1.327***[0.000]	0.210***[0.000]	0.002***[0.002]
Poland	-0.526 [0.297]	-1.059***[0.031]	0.218***[0.000]	0.006***[0.000]
Portugal	1.342 [0.225]	1.249 [0.249]	1.019***[0.000]	-0.000 [0.929]
Romania	-1.260**[0.047]	-2.072**[0.001]	-0.038 [0.418]	0.013***[0.000]
Slovakia	-0.284 [0.664]	-0.999 [0.131]	0.061***[0.000]	0.003 [0.207]
Spain	1.850 [0.238]	1.798 [0.296]	0.359***[0.000]	0.025***[0.000]
Sweden	1.351***[0.000]	0.695 [0.117]	0.130 [0.225]	-0.001 [0.449]
UK	1.053 [0.591]	0.033 [0.987]	-1.133 [0.235]	0.000 [0.605]
PANEL	**0.940*** [0.007]**	**0.272 [0.453]**	**0.170*** [0.002]**	**0.006*** [0.000]**

Note: ***, **, and * indicate significance levels at 1%, 5%, and 10%, respectively.

Moreover, Table 6a presents the Emirmahmutoğlu and Köse (2011) causality test results. According to the test results, the null hypothesis suggesting "energy efficiency does not cause economic growth" in the panel is rejected at a 1% significance level, while a similar hypothesis claiming that "economic growth does not cause energy efficiency" in the panel is also rejected at a 5% significance level. Thus, this indicates the existence of a bilateral causal relationship between energy efficiency and economic growth in EU countries. Upon examining causality test results by country; a unilateral causal relationship from energy efficiency to economic growth is established for Austria, Czech Republic, Finland, Germany, Greece, the Netherlands, and Sweden; whereas a bilateral causal relationship for Bulgaria, Poland, Slovakia, and England is established. In addition, the causality between economic development (GDP) and the other explanatory variables (renewable energy consumption and energy intensity) are presented in Tables 6b and 6c.

Table 6a: The Emirmahmutoğlu and Köse (2011) Causality Test Results

Countries	**ENE ⇒ GDP**			**GDP ⇒ ENE**		
	Lag	**Wald**	**p-value**	**Lag**	**Wald**	**p-value**
Austria	1	4.438**	0.035	1	0.574	0.449
Belgium	1	2.217	0.136	1	0.055	0.814
Bulgaria	3	29.168***	0.000	3	8.971**	0.030
Czech Rep.	1	4.361**	0.037	1	0.731	0.393
Denmark	2	3.773	0.152	2	2.849	0.241
Finland	1	10.248***	0.001	1	0.957	0.328
France	2	3.696	0.158	2	1.695	0.428
Germany	1	4.089**	0.043	1	1.635	0.201
Greece	3	6.499*	0.090	3	3.767	0.288
Hungary	2	1.182	0.554	2	2.182	0.336
Ireland	1	0.013	0.909	1	0.283	0.595
Italy	1	0.318	0.573	1	0.716	0.397
Luxembourg	1	0.253	0.615	1	1.439	0.230
The Netherlands	3	66.543***	0.000	3	5.482	0.140
Poland	3	8.863**	0.031	3	7.061*	0.070
Portugal	2	0.650	0.723	2	2.101	0.350
Romania	3	5.216	0.157	3	2.253	0.522
Slovakia	3	8.652**	0.034	3	6.318*	0.097
Spain	2	1.734	0.420	2	1.349	0.509
Sweden	1	8.706***	0.003	1	1.463	0.226
The UK	3	9.926***	0.019	3	9.218**	0.027
Panel Statistics						
Fisher Test Value (λ)		**180.647*****	**0.000**		**60.299****	**0.033**

Note: ***, **, * indicate significance levels at 1%, 5% and 10%, respectively. ENE and GDP denote energy efficiency and economic growth respectively.

Table 6b: The Emirmahmutoğlu and Köse (2011) Causality Test Results

Countries	**REN ⇒ GDP**			**GDP ⇒ REN**		
	Lag	**Wald**	**p-value**	**Lag**	**Wald**	**p-value**
Austria	1.000	4.761**	0.029	1.000	2.043	0.153
Belgium	2.000	2.401	0.301	2.000	29.312***	0.000
Bulgaria	4.000	1.589	0.811	4.000	6.088	0.193
Czech Rep.	3.000	3.229	0.358	3.000	21.392***	0.000
Denmark	1.000	2.046	0.153	1.000	0.561	0.454
Finland	4.000	2.796	0.593	4.000	3.018	0.555
France	4.000	8.867*	0.065	4.000	4.204	0.379
Germany	3.000	0.817	0.845	3.000	37.646***	0.000
Greece	1.000	5.456**	0.019	1.000	1.000	0.317
Hungary	4.000	1.975	0.740	4.000	7.775	0.100
Ireland	1.000	3.541*	0.060	1.000	0.269	0.604
Italy	1.000	3.198*	0.074	1.000	2.118	0.146
Luxembourg	1.000	3.872**	0.049	1.000	0.789	0.374
The Netherlands	1.000	2.851*	0.091	1.000	1.765	0.184
Poland	1.000	3.496*	0.062	1.000	0.177	0.674
Portugal	2.000	2.916	0.233	2.000	3.842	0.146
Romania	2.000	11.831***	0.003	2.000	0.962	0.618
Slovakia	1.000	1.254	0.263	1.000	3.902**	0.048
Spain	4.000	7.750	0.101	4.000	1.395	0.845
Sweden	2.000	7.793**	0.020	2.000	13.301***	0.001
The UK	3.000	3.220	0.359	3.000	8.230**	0.041
			Panel Statistics			
Fisher Test Value (λ)		**90.132*****	**0.000**		**142.940***	**0.000**

Note: ***, **, * indicate significance levels at 1%, 5% and 10%, respectively.

Table 6c: The Emirmahmutoğlu and Köse (2011) Causality Test Results

Countries	ENINT ⇒ GDP			GDP ⇒ ENINT		
	Lag	Wald	p-value	Lag	Wald	p-value
Austria	4.000	3.367	0.498	4.000	16.763***	0.002
Belgium	2.000	0.230	0.891	2.000	4.572	0.102
Bulgaria	4.000	1.809	0.771	4.000	3.686	0.450
Czech Rep.	2.000	0.731	0.694	2.000	1.627	0.443
Denmark	2.000	0.241	0.887	2.000	1.117	0.572
Finland	4.000	108.294***	0.000	4.000	7.800**	0.099
France	4.000	9.844*	0.043	4.000	11.146**	0.025
Germany	2.000	5.625*	0.060	2.000	2.363	0.307
Greece	2.000	0.433	0.805	2.000	1.314	0.518
Hungary	4.000	5.460	0.243	4.000	4.129	0.389
Ireland	2.000	6.579*	0.037	2.000	1.359	0.507
Italy	3.000	4.587	0.205	3.000	2.248	0.523
Luxembourg	2.000	0.333	0.847	2.000	3.626	0.163
The Netherlands	4.000	4.470	0.346	4.000	16.206***	0.003
Poland	2.000	0.710	0.701	2.000	1.142	0.565
Portugal	1.000	0.888	0.346	1.000	1.432	0.231
Romania	2.000	0.545	0.761	2.000	1.763	0.414
Slovakia	1.000	3.696*	0.055	1.000	5.984**	0.014
Spain	2.000	1.696	0.428	2.000	2.776	0.250
Sweden	4.000	16.443***	0.002	4.000	6.506	0.164
The UK	2.000	0.459	0.795	2.000	4.077	0.130
Panel Statistics						
Fisher Test Value (λ)		**154.118*****	**0.000**		**81.609*** **	**0.000**

Note: ***, **, * indicate significance levels at 1%, 5% and 10%, respectively.

5. Conclusion and Policy Direction

Resulting from the developments in the socio-economic structure of countries since the beginning of the 20th century, the importance of energy in human life has continued to increase. Indicatively, energy has become one of the main input sources of the production process as well as other production factors such as labor, capital, and raw materials. In this context, energy production and consumption influence both the supply and demand sides of the economy and can directly affect the overall performance of the economy. Today, the vast majority of energy resources needed for economic growth and development consist mainly of fossil fuel sources such as coal, oil, and natural gas. Nonetheless, countries that are conscious of the depleting fossil fuel reserves tend to be in pursuit of alternative energy resources and to generate new policies for more efficient use of existing energy resources via increasing technology. Thus, the pertinent question to be answered in this study is to what extend is the technological, behavioral and economic changes that result in a reduction of the amount of energy used to produce the same products without sacrificing existing quality standards? This is because energy efficiency improvements, besides energy demand and reduction of greenhouse gas emissions, can contribute to countries' socio-economic development with its direct and indirect effects on GDP, employment, trade balance, and energy prices according to the countries' economic structures and the design of key policies.

In this study, the impacts of energy efficiency on economic growth in EU countries is investigated using the Westerlund (2008) Durbin-Hausman panel cointegration, the Peseran and Smith (1995) MG, and the Emirmahmutoğlu and Köse (2011) causality tests. In addition to this objective, the current study examined the impact of energy intensity, energy dependency, and renewable energy consumption on economic expansion in the panel of EU countries. The results revealed that energy efficiency improvement positively affect economic growth in EU countries. In specific, the panel result posits that a 1 % increase in energy efficiency level causes a rise of approximately 0.94 % in the economic growth rate of that period. In specific, the positive and significant impact of energy efficiency on economic growth is observed in Belgium, Denmark, Finland, Greece, Hungary, Netherlands, and Sweden. Additionally, there is a bilateral causal relationship between energy efficiency and economic growth in the panel. Moreover, the study found that energy dependency and renewable energy are both significant factor for economic development in the panel countries. Although the impact of energy intensity is positive, it is not a significant determinant of economic expansion according to the panel examination.

The results of the analysis provide strong evidence that energy efficiency is a crucial factor in the economic growth of EU countries. According to these results, the Energy Efficiency Directive 2012/27/EU (European Commission, 2020a) of the EU countries should be modified to accommodate the achievements and drawbacks of the 2020 policy targets especially with specific consideration to the regional and country specific terms. Additionally, development programs that encourage the use of new and energy-efficient technologies, prevent overuse of energy, and encourages more investment in renewable energy sources should be strengthen across the region. More steps should be taken to minimize the use of fossil fuels, and this could include a review of tax policy that encourage (promote) the utilization of clean and alternative (renewable or low-carbon) energy sources. Moreover, policy on energy efficiency could be far rewarding when there is financial liberation that targets sector compliance such as the Smart Finance for Smart Buildings (SFSB) initiative and the European Structural and Investment Funds (ESIF) (European Commission, 2020b).

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