Environmental Science and Pollution Research (2021) 28:54551–54564
https://doi.org/10.1007/s11356-021-14473-6

RESEARCH ARTICLE

Analyzing the determinants of clean energy consumption in a sustainability strategy: evidence from EU-28 countries

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Received: 26 October 2020 / Accepted: 14 May 2021 / Published online: 20 May 2021

Abstract

The current global spirit for sustainable development has led to increased attention to reducing the use of conventional energy sources and managing the issue of climate change. Renewable (or clean) energy consumption is a key element of any country's environmental quality and sustainable economic growth. This study provides a comprehensive analysis of the impacts on clean energy consumption of common factors in pursuing a sustainability strategy, including environmental degradation (measured as carbon dioxide (CO2) emissions), clean energy technology, gross domestic product (GDP) growth, institutional quality, and globalization for a panel of European Union (EU) 28 countries in the period from 1995 to 2017. We employ two estimation techniques, continuous updating-fully modifying (CUP-FM) and continuous updating-bias correcting (CUP-BC). In addition, the study incorporates Driscoll-Kraay regression for a panel model to investigate the validity and reliability of long-term elasticities' results. The findings of long-run analyses indicate that CO2 emissions, clean energy technology, GDP growth, and globalization positively impact clean energy consumption and institutional quality negatively impacts it. Finally, the results of causality testing indicate a unidirectional causal relationship between clean energy technology and clean energy consumption and a bidirectional association between institutional quality and clean energy consumption. The study's outcomes have policy implications, especially regarding designing strategic choices to promote investment in clean energy technology to increase the use of clean energy sources and to overcome the issues of institutional quality in supporting clean energy consumption in the EU-28 countries.

Keywords Clean energy consumption · Environment degradation · Sustainable development · Clean energy technology · Institutional quality · Globalization

Introduction

One of the grand challenges policymakers around the world face is to address climate change while meeting the demand for energy consumption. The worldwide energy demand and pattern of total energy consumption have radically changed because of increases in industrial production and the world's population. The global demand for energy is projected to increase by 30% by the year 2040 (IEA 2017). Because of this increase in the demand for energy, measures to increase sustainable and cost-efficient clean energy sources must be made to control the issues of environmental degradation and attain sustainable economic growth across the globe. The challenge of achieving this objective requires action plans and supportive policies to develop efficient and effective renewable energy resources (Han et al. 2017; Wiser et al. 2016) that can contribute to a sustainable energy, economic, environmental, and societal structure (Kuriqi et al. 2017). In a comprehensive empirical study of the effects of various factors on renewable energy demand, Aguirre and Ibikunle (2014) illustrated that carbon dioxide (CO_2) emissions, energy consumption, and gross domestic product (GDP) per capita can influence the use of renewable energy in the effort to implement the Kyoto protocol. A spatial spillover effect on production of renewable energy was recorded in the countries of the EU

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(Shahnazi and Shabani 2020). In addition, the EU countries have endorsed targets to attain a 20% share in consumption of renewable energy by 2020 and to increase that share up to 32% by 2030.[1] The policy related to renewable energy sources in the EU has demonstrated the importance of renewable energy consumption since 2000.

A sustainable and renewable energy system is a significant improvement over a conventional energy system because it uses resources that can be replenished (Apergis and Danuletiu 2014). The use of renewable energy sources is a potential solution to the climate change crisis and issues of energy security around the world (Elliot 2008). Paramati et al. (2017a, b) empirical study indicated that G20 countries substantially reduce CO_2 emissions through the consumption of various sources of renewable energy. Thus, in developed countries, CO_2 emission levels can be the primary driving force in demanding consumption of clean energy (Omri and Nguyen 2014). More recently, Gozgor et al. (2020) found that CO_2 emissions per capita have a positively impact on the consumption of clean energy in thirty OECD countries.

A sustainability strategy is considered long-term when it includes investment in green technology to increase future economic growth (Hart and Dowell 2011). Increasing restrictions on the use of fossil fuels help to overcome climate change and motivate sustainable development through the transition from the conventional energy sector to the clean energy sector (Gallo et al. 2016). The Bloomberg New Energy Finance BNEF (2020) reported that, in 2019, the worldwide investment in clean energy sources was $282.2 billion, a 1% increase from 2018.

The growing concern about sustainable economic development has generated research interest in examining the importance of renewable energy consumption. For instance, Stiglitz (2002) stated that sustainable development is attained through various aspects but renewable energy is the fundamental synergy factor. Kaygusuz (2007) also indicated that renewable energy promotes a continuous process of modernization in the energy sector and supports the goals of sustainable economic development in various countries. Studies have documented that per capita GDP growth is one of the main determinants of the positive affect of clean energy consumption (Dogan and Ozturk 2017; Kahia et al. 2016; Sadorsky 2009a, 2009b). In a study of the casual link between renewable energy use and economic growth, Saad and Taleb (2018) reported unidirectional causality in the short run and bidirectional causality in the long run between economic growth and renewable energy use in twelve EU countries.

Research has also inspected the relationships among institutional quality, green energy consumption, and environmental quality. For instance, García-Álvarez et al. (2018) examined the EU's renewable energy policies based on three aims—sustainability, competitiveness, and security—for the period from 2000 to 2014 and found that elements of governmental policy like quota, contract duration, and tariff size have positive influences on the production of clean technologies. This stream of research has suggested that green energy consumption and carbon emissions may depend on certain institutional and economic conditions, including the rule of laws, corruption, bureaucratic quality, state disclaimers of contracts, and risk of expropriation. For example, Callway (2013) study of political and economic issues identified higher frontier costs, credit repayment terms, variations in subsidies, and the taxation system as key obstacles in the investment and development of renewable energy and its consumption. Recently, Uzar (2020) investigated a panel of 38 countries for the period from 1990 to 2015 and reported a positive effect of institutional quality and CO_2 emissions on renewable energy consumption, but a negative impact of GDP growth on renewable energy. Market incentives like research and development grants, tax incentives, lower financing rates, and lower insurance premiums ease the adoption of clean energy technology (Aragón-Correa and Sharma 2003).

Shahbaz et al. (2018a, b, c) found that globalization promotes financial development, trade openness, and economic development across the globe. They argued that foreign trade, industrialization, increasing investment, and urbanization to attain a high level of economic development cause pollution and overall environmental degradation. Çoban and Topcu (2013) reported that growth in financial development has a significant positive influence on energy use among the older member countries of the EU. Finally, Gozgor et al. (2020) empirical investigation of thirty OECD countries found that the economic factors of globalization contribute to enhancing the use of renewable energy. The EU countries lead the world in the use and research and development of renewable energy (Halicioglu and Ketenci 2018). Therefore, this study analyzes EU-28 countries' contemporary challenge of increasing their clean energy consumption in terms of CO_2 emissions, clean energy technology, GDP growth, institutional quality, and globalization.

Since few empirical studies have tested the impact of environment degradation, rapid economic growth, and globalization on clean energy consumption, our study contributes to the literature by investigating the effects of clean energy technology and institutional quality on clean energy consumption in the EU-28 countries. This study differs from others, first, in that it includes EU-28 countries' public and private sector investment in renewable technologies integrated into the system, new technologies and services for consumers, the resilience and security of the energy system, new materials and technologies for buildings, energy efficiency for industry, a competitive global battery sector, decarbonization

[1] Details related to the discussion can be found at https://www.irena.org/europe.

technologies, renewable fuels, nuclear safety, and others. Thus, this study provides a broader and better description of the role of clean energy technology in the use of clean energy. Second, this study is the first to explore the effects of clean energy technology on clean energy consumption in the EU countries. Third, this research paper employs two long-run analysis methodologies, the continuous updating-fully modifying (CUP-FM) technique, and the continuous updating-bias correcting (CUP-BC) technique. We validate our study findings by applying Driscoll and Kraay's (DK) standard error technique. Therefore, this study provides a broad and reliable picture of the factors involved in clean energy consumption.

The rest of this study proceeds as follows: the "Literature review" section describes the nexus among all study variables. The "Materials and methodology" section discusses the data sources and describes the variables and data analysis techniques. The "Results and discussion" section reveals the results of the data analysis and the various analysis techniques. Finally, the conclusion concludes the study and suggests its policy implications.

Literature review

Given the important role of clean energy consumption in sustainable economic growth, clean energy meets many countries' need for energy and is important in mitigating the issue of CO_2 emissions. Tang and Tan (2015) reported a casual association between energy consumption and CO_2 emissions in Vietnam using annual data for the period from 1976 to 2009. Several empirical studies have investigated the role of the relationship between clean energy technology and clean energy consumption on environmental degradation. The findings of the limited literature that has explained the association between these variables have been ambiguous and contrasting. Therefore, Balcilar et al. (2018) argued that new studies are required to validate and explicate the existing literature and address these current contrasting findings. Various studies have indicated that technological innovation is necessary if a country is to face ecological challenges and mitigate environmental degradation (Alvarez-Herranz et al. 2017; Andreoni and Levinson 2001; Lorente and Álvarez-Herranz 2016). The nexus between the use of energy and economic growth can be tested through four categories of hypotheses: conservation, feedback, growth, and neutrality (Apergis and Payne 2012). Many studies have supported the feedback hypothesis by reporting bidirectional causality between renewable energy use and economic growth in both the short run and the long run (Apergis and Payne 2011; Kahia et al. 2016; Sebri and Ben-Salha 2014).

Khoshnevis Yazdi and Shakouri (2017b) showed unidirectional causality between renewable energy consumption and economic growth, and Dogan and Ozturk (2017) argued for unidirectional causality between economic growth and consumption of renewable energy in the short run and in the long run, finding support for the feedback hypothesis through findings of bidirectional causality. Institutional voids like underdeveloped infrastructure and inadequate rules, regulations, and law enforcement generate barriers and uncertainty in the business environment (Mair et al. 2012). Studies have shown the negative impact of technological innovation when institutions like these are absent or weak (Michailova et al. 2013; Zhu et al. 2012). Adoption of clean energy technology is eased by market incentives like research and development grants, tax incentives, low bank financing rates, and low insurance premiums (Aragón-Correa and Sharma 2003). Many economic and market incentives are also connected to policy instruments; for instance, credit policies for emission trading influence investment in low-carbon and green technologies (Wordsworth and Grubb 2003).

The literature has provided three main reasons for increased energy consumption that is due to globalization channels. First is the impact of scales and the argument that the positive correlation between globalization and energy consumption is due to increased economic activities (Cole 2006). Second is the impact of technologies, which suggests that globalization, rather than lowering the level of economic activity, works as a motivation to import new technologies that reduce energy consumption (Dollar and Kraay 2004). Third is the impact of consumption, as globalization reduces the energy consumption that is due to increased economic activities (Stern 2007).

Globalization is measured by proxies like trade openness, imports, exports, and trade liberalization, proxies that have also been used to assess the connection between energy consumption and globalization (Shahbaz et al. 2016). Normally, globalization expands with increased energy consumption because of the high level of economic growth. This view is observed in the literature, although other studies report a reverse influence of globalization on consumption of energy. For instance, Shahbaz et al. (2018a, 2018b, 2018c) used a panel data set of 25 economies to find a positive link between energy consumption and globalization in 12 countries, but a negative link in the UK and the USA. The literature review of studies that have addressed the nexus between clean energy consumption, CO_2 emissions, clean energy technology, GDP growth, institutional quality, and globalization is summarized in Table 1.

Materials and methodology

Methodological framework

The primary objective of this study is to test the long-run associations among clean energy consumption, CO_2

Table 1 Summarized literature review

Authors	Country	Time	Methodology	Results
Apergis, Payne, Menyah, and Wolde-Rufael (2010)	19 developed and developing economies	1984–2007	VECM	The association between RE and CO_2 emissions is statistically positive and significant
Gozgor et al. (2020)	30 OECD countries	1970–2015	FMOLS and PCSEs	Per capita CO_2 emissions positively impact RE consumption
Azlina et al. (2014)	Malaysia	1975–2011	VECM	RE consumption and CO_2 emissions have a unidirectional causal connection
Sharif et al. (2019)	74 most carbon dioxide emissions economies	1990–2015	FMOLS and DOLS	RE consumption decreases CO_2 emissions and bidirectional causal connection among them
Salim and Rafiq (2012)	Major 6 emerging economies	1980–2006	FMOLS and DOLS	CO2 emissions and GDP growth are main determinants of RE consumption. These three variables have a bidirectional causal relationship among them
Shafiei and Salim (2014)	29 OECD countries	1980–2011	AMG and GMM	CO_2 emissions decrease with RE consumption. CO_2 emissions and RE consumption have unidirectional causality
Paramati et al. 2017a, 2017b	G20 countries	1991–2012	FMOLS	RE consumption improves environmental quality
Bekun et al. (2019)	16 EU countries	1996–2014	PMG	RE consumption plays a significant role in decreasing CO_2 emissions
Tang and Tan (2013)	Malaysia	1970–2009	ARDL	Consumption of electricity, economic growth, and technological innovation are closely related
Fei et al. (2014)	Norway and New Zealand	1971–2010	ARDL	Technological innovation plays important role in mitigating environmental degradation and increasing clean energy sources
Alvarez-Herranz et al. (2017)	17 OECD countries	1990–2012	TSLS	Technological innovation is necessary to face ecological challenges and mitigate environmental degradation
Bilgili et al. (2016)	17 OECD countries	1977–2010	FMOLS and DOLS	The development of clean energy and RE significantly minimizes CO_2 emissions
Shahbaz et al. (2018a, 2018b, 2018c)	France	1955–2016	Bootstrap ARDL	Energy-related technological innovations have a negative impact on CO_2 emissions. Financial stability is required for research and development in clean energy innovations and improvement in environmental quality
Lin and Zhu (2019)	China	2000–2015	Fixed and random effects model	Technological innovation of RE reduces CO_2 emissions through increases in renewable energy consumption
Ganda (2019)	OECD countries	2000–2014	GMM	Investments in technology research and development and RE consumption are main determinants of environmental quality
Jiang et al. 2020	China	2009–2016	GMM and VAR	Green technology innovation significantly supports economic sustainability by reducing total energy consumption
Sadorsky (2009a)	18 emerging economies	1994–2003	FMOLS, DOLS and OLS	Economic growth is one of the main determinants of RE consumption
Sadorsky (2009b)	G7 countries	1980–2005	FMOLS and DOLS	Per capita GDP is positively related to RE demand
Kahia et al. (2016)	MENA countries	1980–2012	FMOLS	Sustainable development requires efficient strategies for RE consumption and trade
Saad and Taleb (2018)	12 EU countries	1990–2014	PVEC	There are unidirectional and bidirectional casual associations between RE consumption and economic growth in the short run and the long run, respectively
Eren et al. (2019)	India	1971–2015	DOLS and VECM	GDP growth and financial development have positive and statistically significant effects on RE consumption
Adedoyin et al. 2020	16 EU countries	1997–2015	PMG-ARDL	

Table 1 (continued)

Authors	Country	Time	Methodology	Results
				Research & development expenditures increase RE consumption and the feedback causality relationship between GDP growth and RE consumption
Allen et al. (2019)	27 EU countries	2004–2014	Fixed effects model	Various determinants of institutional quality have casual impacts on the use of RE
Saidi et al. (2020)	MENA countries	1986–2015	PVEC	Institutional measures impact the relationship between GDP growth and RE consumption, and there is significant causality between RE usage and various institutional measures
Wu and Broadstock (2015)	22 emerging economies	1990–2010	GMM	Institutional quality and financial structure have significant positive impacts on RE use
Danish and Ulucak (2020)	18 APEC countries	1992–2015	FMOLS and DOLS	Institutional quality enhances environmental quality by increasing RE consumption
Omri and Nguyen (2014)	64 countries	1990–2011	GMM	Trade openness has a positive impact on RE use
Shahbaz et al. (2016)	India	1971–2012	ARDL	Energy demand decreases with globalization, and financial development has an adverse influence on energy consumption
Khoshnevis Yazdi and Shakouri (2017a)	Iran	1992–2014	ARDL	Globalization positively influences growth; financial development, globalization and RE consumption show bidirectional causality
Shahbaz et al. (2018a, 2018b, 2018c)	25 countries	1970–2014	CMG and AMG	Twelve countries have a positive link between energy consumption and globalization, while the UK and the USA have a negative link
Gozgor et al. (2020)	30 OECD countries	1970–2015	FMOLS and PCSEs	The economic factors of globalization have positive impacts on RE consumption
Paramati et al. (2017a, 2017b)	OECD, EU and G20	1993–2012	ARDL	Capital formation at the domestic and foreign levels positively promotes clean energy consumption
Kutan et al. (2018)	BRICS economies	1990–2012	FMOLS	Inflows of foreign direct investment and development of the stock market promote RE consumption

Note: RE, renewable energy; OECD, Organization for Economic Cooperation and Development; ARDL, autoregressive distributive lag model; APEC, Asia-Pacific Economic Cooperation; EU, European Union; BRICS, Brazil, Russia, India, China and South Africa; FMOLS, fully modified ordinary least square estimator; CMG, common correlated effects mean group; AMG, augmented mean group; OLS, ordinary least square regression; DOLS, dynamic ordinary least square estimator; GMM, generalized method of moments; PVEC, panel vector error correction; VAR, Vector Auto Regression; TSLS, Two-Stage Least Squares; PMG, Pool Mean Group; PCSEs, Panel correlated standard errors; VECM, vector error correction model; MENA, Middle East and North Africa

emissions, clean energy technology, GDP growth, institutional quality, and globalization. The paper conducts empirical analyses of panel cointegration, tests elasticities for long-run associations, and tests for non-causality of heterogeneity to identify the direction of causal relationships among the study variables. Equation 1 is based on a benchmark model:

$$CEC = f(CO_2 + CET + GDP + QOI + GOB) \quad (1)$$

where CEC, CO_2, CET, GDP, QOI, and GOB refer to clean energy consumption, CO_2 emissions, clean energy technology, GDP, institutional quality, and globalization, respectively.

We have used the log-linear by employing natural logs for all study variables, rather than using the simple linear form of the model. Studies like Shahbaz et al. (2012) have argued that the empirical results estimated through log-linear are more reliable and consistent than simple linear. The empirical models' log-linear provides direct estimations of elasticities because it works as the coefficients of the study's explanatory variables of the study. The log-linear form of clean energy consumption function is presented in Eq. 2:

$$\ln CEC_{it} = \alpha_0 + \alpha_1 \ln CO_{2it} + \alpha_2 \ln CET_{it} + \alpha_3 \ln GDP_{it} + \alpha_4 \ln QOI_{it} + \alpha_5 \ln GOB_{it} + \mu_{it} \quad (2)$$

where *ln* is the natural log form of the variables in Eq. (2); α_0 is the slope intercept; α_1, α_2, α_3, α_4, and α_5 are the coefficient estimates of CO_2 emissions, clean energy technology, GDP growth, institutional quality, and globalization, respectively.

Error term is represented by μ, which is normally distributed. Subscript i (i=1,......., N) is the country, and subscript t (t=1,.......,T) is the time period.

Cross-sectional dependence (CD) and panel unit root tests

Empirical studies have recommended the characteristics and properties of variables in a time series data set; the main property is stationarity vs. non-stationarity. First- and second-generation unit root tests are used to examine this property, but the selection of a particular test is based on the assumption of cross-sectional independence. In general, the variables of panel data of many countries are linked because of regionally and global associations. If researchers fail to measure the assumption of cross-sectional independence, the chances of misleading estimated results are high (Phillips and Sul 2003). Therefore, we investigate cross-sectional dependence using Pesaran (2004) test of cross-sectional dependence. The test is performed with the following Eq. 3:

$$CD = \sqrt{\frac{2T}{N(N-1)}}\left(\sum_{i=1}^{N-1}\sum_{k=i+1}^{N}\rho_{ik}\right) \tag{3}$$

where T and N are the time period and the sample size, respectively. Correlations between the error terms of different cross-sections of a country i and k are indicated by ρ_{ik}.

After collecting evidence of cross-sectional dependence among study variables through these tests, this study used second-generation panel unit root tests to examine the residual stationarity in the presence of cross-sectional dependence because first-generation tests can give indecisive estimations when there is cross-sectional dependence (Dogan and Seker 2016). The panel unit root test in this study is performed using cross-sectionally augmented IPS (CIPS) and cross-sectionally augmented ADF (CADF). The unit roots tests of CIPS and CADF are applied using Eqs. 4 and 5, as Pesaran (2007) suggested:

$$\Delta Y_{it} = \gamma_{it} + \chi_i Y_{i,t-1} + \lambda_i T + \sum_{k=1}^{n}\pi_{ik}\Delta Y_{i,t-k} + \mu_{it} \tag{4}$$

where Δ is a difference operator; I_{it} are variables used in the empirical analysis; and T, γ, and μ_{it} are the time trend, the individual intercept, and the error term, respectively.

Next, CADF test is investigated using the standard augmented Dickey-Fuller (ADF), which add the averages of lagged levels' cross-sections ($\overline{X}_{t-1}$) and uses the first difference values of an individual series. Thus, the CADF test uses Eq. 5:

$$\Delta X_{it} = \alpha_i + \beta_i X_{i,t-1} + \delta_i \overline{X}_{t-1} + \lambda \Delta \overline{X}_t + \mu_{it} \tag{5}$$

where $\overline{X}_t$ is the average values of all available N observations in the sample at time period t. This equation includes a proxy to measure unobserved effects through common factors.

Panel cointegration test

If the levels of the study's variables have no stationarity, then a cointegration test of the variables is used to ensure the economic and statistical accuracy of the coefficient estimations through long-run analysis. To determine whether cointegration exists between clean energy consumption, CO_2 emissions, clean energy technology, GDP, institutional quality, and globalization, this study uses a bootstrap test for cointegration as provided by Westerlund and Edgerton (2007). Equation 6 is used for the bootstrap test:

$$\begin{aligned} y_{it}^{*} &= \widehat{\alpha}_i + x_{it}^{*'}\widehat{\beta}_i + z_{it}^{*} \\ &\textit{with} \\ x_{it}^{*} &= \sum_{j=1}^{t}\Delta x_{ij}^{*}, \end{aligned} \tag{6}$$

where $\widehat{\alpha}_i$ and $\widehat{\beta}_i$ are determined through the fully modified terms of α_i and β_i. The bootstrap test's null hypothesis is that the variables of a panel data set are cointegrated. The small sample size also covers by this test and is suitable to allow all cross-sectional units' dependency in cases of both between and within. Furthermore, problems like dependence of cross-sections and heterogeneity during the estimation procedure of cointegration between variables are also controlled through the bootstrap test.

Long-run elasticities

The long-run elasticities estimation between independent and dependent variables is done using two estimation techniques as proposed by Bai and Kao (2006) and Bai et al. (2009). Equation 7 is employed to determine two estimators that can overcome the issues of bias that result from dependence of cross-sections, serial correlation, and endogeneity:

$$\left(\widehat{\beta}_{CUP}, \widehat{F}_{CUP}\right) = \text{argmin}\frac{1}{nT^2}\sum_{i=1}^{n}(y_i - x_i\beta)' M_F (y_i - x_i\beta) \tag{7}$$

where repeated fully modified least squares (FM-OLS) are applied to measure the β coefficient, as FM-OLS uses previous stage residuals until full convergence occurs. The terms F and $M_F = I_T - T^{-2}FF'$, I_T show a common factor, which is presumed by the dimensions of matrix T and error terms, respectively. Hence, F allocates the initial estimations and continues this process until all convergence is complete. The CUP-FM and the CUP-BC both continuously update until the convergence is complete (Bai et al. 2009). These two estimators provide consistent and unbiased results even in the case of exogenous regressors. Moreover, both estimators help to control issues *I(1)/I(0)* of mixed factors and establish robust outcomes. The FM-OLS procedure is followed by both estimators, so they provide consistent findings even in the absence of endogeneity (Bai et al. 2009).

Long-run elasticities results are also estimated by applying the DK standard error technique to investigate the effect of the study's variables on clean energy consumption for a panel of EU-28 countries. Before the DK standard error technique can be employed, the product average among errors and independent variables must be calculated, and these calculated values used in estimating weighted heteroskedasticity and autocorrelation consistent (HAC) to determine standard errors. Doing so will help to deal with cross-sectional dependence (Jalil 2014).

The DK standard error technique is considered a preferred method, even cases of serial and spatial dependency or heteroscedasticity in the data set (Ozokcu 2017; Sarkodie and Strezov 2019). The technique allows all dimensions of large time and is flexible because it is a non-parametric approach. In addition, the DK technique works as a covariance estimator that handles missing values and it can be applied to either balanced as well or unbalanced panel data. The technique's estimators are robust to general procedures of temporal and cross-sectional dependence. This study uses the DK standard error technique as a robustness test by using Eq. 8, a linear model equation expression of pooled ordinary least squares (OLS):

$$y'_{i,t} = x'_{i,t}\propto + \mu_{i,t}, i = 1, \ldots, N, t = 1, \ldots, T \quad (8)$$

where $y'_{i,t}$ is the study's dependent variable (clean energy consumption) and $x'_{i,t}$ is the independent variables (CO_2 emissions, clean energy technology, GDP, institutional quality, and globalization).

Heterogeneous panel causality test

Econometric methods for measuring long-run elasticities estimate only the associations between dependent and independent variables, but policymakers also require short-run analysis to estimate the directions of causal relationships among study variables. Therefore, to determine the direction of casual associations between the dependent variable (clean energy consumption) and independent variables (CO_2 emissions, clean energy technology, GDP, institutional quality, and globalization), this study uses an advanced procedure for a simple test of Granger causality that Dumitrescu and Hurlin (2012) suggested.

The heterogeneous issues and unbalanced panel properties of $T < N$ and $T > N$ can handle through flexible characteristics of Dumitrescu and Hurlin test. Moreover, this test incorporates the standard regression form of Granger causality in case of cross-sections, along with differences and average values of all coefficients by all units in the various cross-sections. Equation 9, a bivariate model equation, was used to apply the causality test:

$$y_{i,t} = \alpha_i + \sum_{k=1}^{k} \lambda_i^{(k)} y_{i,t-k} + \sum_{k=1}^{k} \beta_i^{(k)} x_{i,t-k} + \varepsilon_{i,t} \quad (9)$$

where α_i is the slope intercept, λ_i and β_i are coefficients of the slope, and k is the lags length in numbers.

Data and variables measure

A balanced panel data set was collected from the EU-28 countries: Austria, Belgium, Bulgaria, Croatia, Cyprus, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovenia, Slovakia, Spain, Sweden, and the UK. The choice of time period of 1995 to 2017 was based on availability of annual data for the period. Measurements of the study variables and their data sources are given as follows.

Clean energy consumption (CEC) Clean energy, or non-carbon energy, is produced through various renewable energy sources that do not produce CO_2: hydropower, wind, solar, and geothermal. This study measures CEC as total renewable energy consumption in billion kilowatt hours (Kwh). The CEC data is collected from the U.S. Energy Information Administration (EIA 2019).

Carbon dioxide emissions (CO_2) The CO_2 emissions in metric tons of a country are divided by the country's total population to measure it in per capita values. This study uses CO_2 emissions as a proxy for environmental degradation. The CO_2 emissions data was gathered from the World Development Indicators (WDI 2019) database.

Clean energy technology (CET) The CET is measured by combining the public and private investment in renewable energy research and development expenditures (in constant 2010 US dollars). The CET data was collected from the European Commission's database.[2]

Gross domestic product (GDP) The GDP variable is measured in per capita values, dividing GDP figures (in constant 2010 US dollars) by the country's total population. The WDI (2019) database was used to collect the GDP data.

Institutional quality (QOI) The QOI is measured using countries' economic freedom indices. The economic freedom index consists of the size of government, legal structure and property rights, ease of accessing sound money, trade policies

[2] The Information related to Systems of Technologies by Europa-Strategic Energy can be accessed at https://setis.ec.europa.eu

Table 2 Descriptive statistics

Countries	CEC		C02		CET		GDP		QOI		GOB	
	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.	Mean	Std. dev.
Austria	11.256	1.089	7.742	0.923	554.880	316.57	44463.09	3925.80	7.642	0 .215	87.421	1.838
Belgium	19.843	3.895	9.914	1.329	234.795	82.119	42095.69	3302.025	7.387	0 .122	88.784	1.641
Bulgaria	25.286	2.709	6.196	0.525	38.789	12.026	5769.521	1561.81	6.588	0.967	73.969	5.610
Croatia	7.456	2.724	4.451	0.553	21.555	10.691	12495.5	1997.05	7.184	0.529	71.417	9.631
Cyprus	2.597	1.163	6.709	0.868	18.152	9.397	28433.28	2558.982	6.972	0.486	72.904	8.283
Czech Republic	14.156	4.193	10.915	1.281	85.070	17.653	17901.44	2980.859	6.975	0.490	80.103	4.793
Denmark	3.717	2.656	8.637	2.527	356.656	209.290	57125.5	3524.334	7.797	0.129	87.392	1.737
Estonia	0.391	0.502	12.820	1.372	22.104	13.044	13760.69	3692.154	7.467	0 .542	77.177	5.886
Finland	21.275	2.155	10.646	1.451	357.079	212.705	43085.11	4958.03	7.740	0.140	85.136	1.917
France	45.902	1.911	5.464	0.877	2510.31	1161.69	39514.36	2490.728	7.257	0.165	84.740	2.396
Germany	12.947	0.942	9.552	0.866	5360.02	3296.68	40514.92	3725.151	7.613	0.079	85.739	2.709
Greece	3.101	1.819	7.747	1.077	14.255	7.105	24563.04	3080.924	6.879	0.300	77.602	3.684
Hungary	15.570	2.072	5.233	0.640	43.720	30.731	12354.22	1999.319	7.059	0.350	81.816	4.607
Ireland	2.096	1.819	9.276	1.511	78.267	34.426	48827.18	11205.51	7.530	0.488	83.421	1.401
Italy	5.643	1.585	6.983	1.314	736.912	365.068	35499.83	1596.619	7.170	0.227	79.945	2.299
Latvia	5.184	2.137	3.406	0.301	15.475	9.960	10437.23	3367.997	7.228	0.686	69.193	7.772
Lithuania	23.518	17.227	4.263	0.358	18.823	15.702	10752.03	3638.605	7.181	0.681	72.197	7.297
Luxembourg	0.427	0.187	20.012	2.885	71.338	41.174	98098.55	11292.58	7.654	0.114	83.921	3.225
Malta	0.488	0.758	5.958	0.500	24.072	12.496	20138.34	3296.937	7.331	0.432	73.178	5.810
Netherlands	1.786	0.498	10.712	0.788	635.977	248.398	47826.89	4177.663	7.646	0.086	88.087	2.093
Poland	0.474	0.445	7.982	0.682	184.743	72.012	10850.71	2828.424	6.753	0.617	74.773	5.998
Portugal	6.136	2.821	5.257	0.754	15.849	11.550	21486.84	1295.441	7.353	0.142	80.215	2.855
Romania	10.682	5.313	4.313	0.623	22.310	15.005	7243.462	1967.846	6.551	1.257	71.238	7.297
Slovakia	24.786	3.256	6.686	0.958	25.556	7.225	14116.07	3647.986	7.035	0.651	76.274	7.859
Slovenia	25.215	2.688	7.230	1.052	23.229	22.785	21264.68	3230.959	6.633	0.586	74.075	7.781
Spain	16.922	2.594	6.471	1.101	308.125	168.139	29383.9	2571.911	7.457	0.168	81.575	3.068
Sweden	46.131	3.150	5.387	0.738	443.582	312.828	48744.93	5892.396	7.434	0.118	88.295	1.705
UK	10.814	1.855	8.058	1.416	1082.72	535.608	37967.66	3445.915	8.141	0.184	87.581	1.873

and international trade, and the regulation of business, credit, and labor markets. QOI data was obtained from the Fraser Institute Index.[3]

Globalization (GOB) To measure the GOB, we used the globalization index, which is captured from KOF Swiss economic institute (Dreher 2006). The globalization KOF Index is a combination of three categories: economic, social, and political globalization. The data related to economic globalization consists of restrictions and actual flows; social globalization comprises the personal contacts, cultural immediacy, and the flow of information data; and political globalization includes factors like the country's embassy relationships, international treaties, membership in international organizations, and participation level in missions of the UN Security Council. The KOF index is scaled between 0 and 100, where 0 indicates the country is not globalized, and 100 indicates it is completely globalized.

Results and discussions

Descriptive statistics results

The summary statistics of all variables included in this study such as clean energy consumption (total renewable energy consumption in billion kilowatt hours), CO2 emissions (CO2 emissions in metric tons per capita), clean energy technology (public and private investment in renewable energy research and development expenditures, constant 2010 US dollars), GDP growth (GDP per capita, constant 2010 US

[3] The economic freedom index data set can be accessed at https://www.fraserinstitute.org/economic-freedom/dataset

Table 3 Analysis of cross-sectional dependence

Variables	lnCEC	lnCO2	lnCET	lnGDP	lnQOI	lnGOB
CD test	41.20***	47.12***	43.76***	79.22***	40.57***	87.38***
p values	0.000	0.000	0.000	0.000	0.000	0.000

Note: *** sign shows the statistical significance at 1% level. CD test which was introduced by Pesaran (2004) is used to generate these results, null hypothesis of the test presents the independence of cross-sections and standard of two tails is employed for statistical distribution. Here, cross-sectional dependence (CD) test, lnCEC is the natural log of clean energy consumption, lnCO2 is the natural log of carbon dioxide emissions, lnCET representing the natural log of clean energy technologies, lnGDP indicates the natural log of economic growth, lnQOI is the natural log of quality of institutions, and lnGOB represents the natural log of globalization

dollars), institutional quality (economic freedom index), and globalization (KOF index is scaled between 0 and 100) of each of the EU-28 countries is given in Table 1. The highest mean values for clean energy consumption (46.131), CO_2 emissions (20.012), clean energy technology (5360.02), GDP growth (98098.55), institutional quality (8.141), and globalization (88.784) are in Sweden, Luxembourg, Germany, Luxembourg (again), the UK, and Belgium, respectively. The lowest mean values for clean energy consumption (0.391), CO_2 emissions (3.406), clean energy technology (14.255), GDP growth (5769.521), institutional quality (6.551), and globalization (69.193) are in Estonia, Latvia, Greece, Bulgaria, Romania, and Latvia (again), respectively.

In addition, Luxembourg shows the highest variation from the mean in CO_2 emissions and GDP growth, with values of 2.885 and 11292.58, respectively. Lithuania, Germany, Romania, and Croatia have the highest variation from the mean in clean energy consumption (17.227), clean energy technology (3296.68), institutional quality (1.257), and globalization (9.631), respectively. The EU countries with the lowest variation from the mean in clean energy consumption (0.187), CO_2 emissions (0.301), clean energy technology (7.105), GDP growth (1295.441), institutional quality (0.079), and globalization (1.401) are Luxembourg, Latvia, Greece, Portugal, Germany, and Ireland, respectively (Table 2).

Results of cross-sectional dependence and panel unit root tests

The analysis of panel data started with the cross-sectional dependence test Pesaran (2004) suggested. Table 3 presents the results of this test. After confirming the presence of cross-sectional dependence in the panel data, we examined stationarity in the panel data set using second-generation unit root tests. We employed the second-generation CIPS and CADF tests Pesaran (2007) proposed to control for the cross-sectional dependence. Table 4 shows results of the CIPS and CADF unit root tests. The first difference results of both tests indicate the presence of stationarity, so the panel data set has no unit roots at first difference.

LM bootstrap cointegration results

This study's empirical analysis tests the cointegration among all of its variables using bootstrapping, as given by Westerlund and Edgerton (2007). The results of the technique are shown in Table 5. The null hypothesis cannot be rejected, so cointegration exists among the variables, supporting the long-run relationship among the variables clean energy

Table 4 Unit root tests of second generation

Variables	CIPS		CADF	
	Levels	First difference	Levels	First difference
lnCEC	−1.977	−4.405***	−2.063	−3.019***
lnCO2	−1.808	−4.548***	−1.611	−3.075***
lnCET	−3.343***	−4.853***	−2.737**	−3.848***
lnGDP	−2.354	−2.940***	−2.966***	−3.497***
lnQOI	−2.524	−4.507***	−2.521	−3.646***
lnGOB	−2.401	−4.102 ***	−2.557	−2.995***

Note: The statistical significance of values is denoted by ** and *** to present 5 and 1% levels of significance, respectively. In unit root tests by Pesaran [73] include both constants and trends. Rejection of null hypothesis is based on stationarity of at least 1 country among all countries that considered in the study. The sign of *** is used to indicate the rejection of null hypothesis. The results are reported on the basis of lag = 1 statistical analysis. The critical values of CIPS and CADF tests are as −2.58 at 10%, −2.66 at 5%, and −2.81 at 1%, respectively

Table 5 Results of testing LM bootstrap cointegration

LM statistic	Bootstrap *p* value
39.529	0.975

Note: The statistics of 5000 replications is employed to measure the bootstrap test. This test is done by a null hypothesis which means all units in a panel have cointegration against each other, whereas this test has alternative hypothesis which means there is no cointegration exists in panel

Table 6 Panel long-run analysis

Variables	CUP-FM	CUP-BC
$lnCO_2$	0.10966*** (6.3293)	0.10876*** (6.2486)
LnCET	0.07369*** (3.3291)	0.05669** (2.5512)
LnGDP	0.44831*** (20.0580)	0.48539*** (20.1133)
LnQOI	−0.15870*** (−4.0440)	−0.16550*** (−4.2438)
LnGOB	0.22093*** (3.2388)	0.14442** (2.4123)

Note: The statistical significance of coefficient values is presented by ** aad *** at 5 and 1% level of significance, respectively. The methods of continuous updating-fully modifying (CUP-FM) and continuous updating-bias correcting (CUP-BC) determine the common factors by using technique of ICρ2 information. Moreover, the PMG approach based on SIC criterion is utilized to select the optimum lag length. CEC = f (CO_2, CET, GDP, QOI, GOB)

consumption, CO_2 emissions, clean energy technology, economic growth, institutional quality, and globalization.

Results of long-run analysis

Several econometric methodologies can be used to measure the variables' long-run elasticities. Our long-run analysis uses two of these: first, the CUP-FM and the CUP-BC methods (Bai et al. (2009) and then the DK standard errors technique. The results of the CUP-FM and CUP-BC techniques, provided in Table 6, show that CO_2 emissions have a significant and positive impact on the consumption of clean energy, which supports the notion that countries are motivated to consume clean energy when their environmental pollution, measured as CO_2 emissions, increases. These results echo the argument of Kusumadewi et al. (2017) in Thailand and Salim and Rafiq (2012) in Brazil, China, India, and Indonesia that renewable energy consumption mitigates the problem of increased environmental pollution.

Table 7 Regression results of Driscoll-Kraay standard errors technique

Variables	Coefficients	t-statistics
Constant	−20.7332***	−36.72
$lnCO_2$	0.3292***	25.33
LnCET	0.0331***	13.91
LnGDP	0.2762***	38.40
LnQOI	−0.8232***	−8.93
LnGOB	1.5521***	10.08
F-statistic	13001.32	
Prob. F-statistic	0.0000	
R-square	0.5639	

Note: *** represents the significance level at 1%. Dependent variable = clean energy consumption

These results show a positive and significant long-run relationship between clean energy consumption and clean energy technology. This finding is consistent with Dinda (2004) and Brock and Taylor (2005), who suggested that countries must use technologies that are based on environmentally friendly energy sources to control further environmental degradation. Further, GDP growth and energy consumption are generally considered to be among the main determinants of environmental pollution. Currently, policymakers focus on sustainable economic growth through the use of clean energy sources. This study reports that GDP growth has a positive and significant impact on clean energy consumption in EU countries, supporting Sadorsky (2009a) argument that economic growth plays a significant role in renewable energy consumption in eighteen emerging countries.

Wu and Broadstock (2015) argued that institutional quality has a positive and significant influence on renewable energy use, but this study reports a negative association between these two variables, perhaps because of the EU's strict law enforcement, administration system, financial regulations, and taxation laws. The results of the CUP-FM and CUP-BC techniques show a positive and significant impact of globalization on clean energy consumption, which is consistent with Soytas et al. (2007) findings.

In the second part of long-run analysis, we apply the DK standard errors technique. The results of this regression test are given in Table 7. All reported coefficients in the DK standard errors technique show findings similar to those we found in using the CUP-FM and CUP-BC techniques. Figure 1 illustrates the key findings of our long-run analyses.

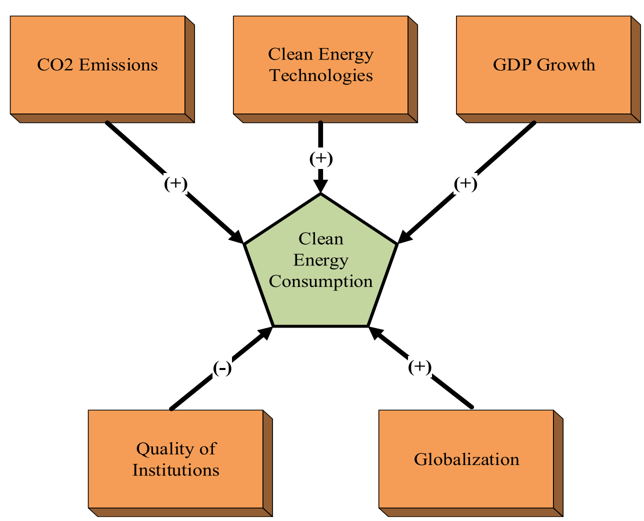

Fig. 1 Key findings of long-run analysis

Table 8 Results of Dumitrescu and Hurlin heterogeneous panel causality test

Variables	LnCEC	lnCO2	lnCET	lnGDP	lnQOI	lnGOB
lnCEC	-	5.8447*** (0.000)	1.1195 (0.262)	−0.0642 (0.948)	1.9382* (0.052)	−0.6538 (0.513)
lnCO2	0.9080 (0.363)	-	0.1966 (0.844)	0.1408 (0.888)	0.2181 (0.827)	1.2943 (0.195)
lnCET	1.9493* (0.051)	3.1595*** (0.001)	-	0.2724 (0.785)	−0.3786 (0.704)	3.0320*** (0.002)
lnGDP	2.8252*** (0.004)	5.4265*** (0.000)	2.5111** (0.012)	-	4.4149*** (0.000)	−0.3374 (0.735)
lnQOI	3.5340*** (0.000)	2.1292* (0.033)	1.6323 (0.102)	2.5759** (0.011)	-	4.3174*** (0.000)
lnGOB	3.0364*** (0.000)	0.8053 (0.4206)	1.6076 (0.107)	1.3672 (0.171)	3.3305*** (0.000)	-

Note: Here, *p* values are presented in parentheses. Statistical significance is indicated by *, **, and *** signs at 10, 5, and 1% level of significance, respectively. The optimum lag length selection is based on SIC criterion

Results of Dumitrescu and Hurlin causality test

This study examined the causality effects between all of its variables using a panel causality effect approach introduced by Dumitrescu and Hurlin (2012). The results of pair-wise panel causality, presented in Table 8, show that clean energy consumption and CO_2 emissions have unidirectional causality, a finding that is consistent with studies by Ajmi et al. (2015) in G7 countries and Azlina et al. (2014) in Malaysia. The findings also show unidirectional causality between clean energy consumption and clean energy technology, which indicates that a continuous process in the development of clean energy technology is required to increase the use of clean energy. This finding supports findings in the studies of Lin and Zhu (2019) in China and Ganda (2019) in OECD countries, which argued that technological innovation in renewable energy is necessary to increase renewable energy consumption and control environmental pollution.

Clean energy consumption and GDP growth show unidirectional causality, which is in line with the findings of studies by Khoshnevis Yazdi and Shakouri (2017b) and Dogan and Ozturk (2017). Institutional quality and clean energy consumption show bidirectional causality, which matches the results of studies by Saidi et al. (2020) in MENA countries and Wu and Broadstock (2015) in 22 emerging economies. Globalization and clean energy consumption show unidirectional causality, which supports the findings of Apergis et al. (2010) in 19 developing and developed economies. Figure 2 shows the main causality effects.

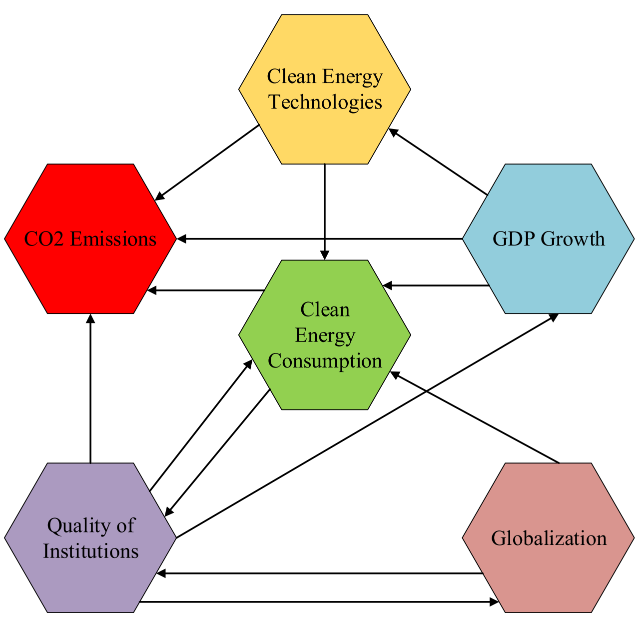

Fig. 2 Main results of causality effects

Conclusion

Given the commitments and efforts of EU-28 countries to deal with environmental degradation issues by implementing sustainable strategies and increasing the consumption of clean energy, this study contributes to examinations of the effects of CO_2 emissions, GDP growth, institutional quality, and globalization on clean energy consumption for the period from 1995 to 2017. To meet the main purpose of this study, we examined a panel data set using cross-sectional, panel unit root, and cointegration tests. We also employed CUP-FM and CUP-BC estimators, as suggested by Bai and Kao (2006) and Bai et al. (2009). Moreover, the study measures the validity and reliability of long-run coefficients using the DK standard error regression technique and determines the short-run causal relationships between variables by applying Dumitrescu and Hurlin (2012) heterogeneous panel causality test.

The findings of the long-run analyses show that CO_2 emissions, clean energy technology, GDP growth, and globalization play a positive role in increasing clean energy consumption but a negative effect of institutional quality on clean energy consumption. The Granger causality test of the short-run causal connections between variables shows unidirectional causality between CO_2 emissions, clean energy technology, GDP growth, and globalization with clean energy consumption. Institutional quality has a bidirectional relationship with clean energy consumption. In terms of environmentally friendly clean energy consumption, our study's findings have useful implications, especially for EU-28 countries.

The study's empirical findings have several policy implications. First, policymakers should understand the positive impact of CO_2 emissions on environmental degradation and increase clean energy consumption. Second, the positive effects of clean energy technology show that EU countries are going in the right direction. However, they should maintain their investments in clean energy technologies if they are to achieve the commitment by the Council of the European Union (2014) that at least 27% of energy come from renewable sources by the end of 2030. In addition, by doing this, the EU can fulfil its' commitment to achieving climate neutrality at the end of 2050 and to reaching target of dropping emissions of greenhouse gases by 55% at the end of 2030 in comparison to 1990 levels.[4]

Third, future economic growth is based on continuous implementation of sustainable strategies through investing in green technologies. Therefore, the EU-28 countries' governments should design policies that establish confidence among investors at both the domestic and the international levels to start green energy projects and industrial production systems. Most importantly, government should provide tax benefits for green energy industries to encourage potential investors. Fourth, the governments should examine their countries' legal structure, property rights laws, domestic and international trade policies, and regulation of business and credit markets to ensure institutional quality. Finally, the empirical findings of this study endorse the need for cooperation among the EU countries to reduce CO_2 emissions, exchange technological innovations, share sustainable development ideas, and ensure adequate financial resources.

Our findings are limited to EU countries. In addition, the study does not perform separate comparison analyses for low- and high-income EU countries. Future research could examine the overall global social response to reducing CO_2 emissions and increasing clean energy consumption by comparing developing and developed economies across the world. Such an investigation would provide additional insights by identifying the determinants of reducing CO_2 emissions and encouraging the use of clean energy sources. It may also support policymakers in their efforts to develop environmentally friendly policies that can lead to sustainable economic growth.

[4] The details related to provisional agreement of European Climate Law can be accessed via link https://ec.europa.eu/commission/presscorner/detail/en/ip_21_1828.

Acknowledgments Authors would like to thankful of financial support provided by National Natural Science Foundation of China and the Social Science Funding Project of Jiangsu Province.

Authors' contributions MU: conceptualization study design; data collection; methodology framework; paper writing; empirical analysis; review and editing. ZM: checking validation; supervision; project administration; evaluations of results; review. MWZ: conceptualization; visualization; data analysis; investigation; critical review. AW: conceptualization; methodology; investigation; visualization; reviewing. ML: methodology; data validation; supervision; project administration; evaluations of results.

Funding This research work was funded by the National Natural Science Foundation of China [grant number 7167031130] and the Social Science Funding Project of Jiangsu Province [grant number 18GLB024].

Declarations

Competing interests The authors declare no competing interests

References

Adedoyin FF, Bekun FV, Alola AA (2020) Growth impact of transition from non-renewable to renewable energy in the EU: the role of research and development expenditure. Renew Energy 159:1139–1145

Aguirre M, Ibikunle G (2014) Determinants of renewable energy growth: a global sample analysis. Energy Policy 69:374–384

Ajmi AN, Hammoudeh S, Nguyen DK, Sato JR (2015) On the relationships between CO2 emissions, energy consumption and income: the importance of time variation. Energy Econ 49:629–638

Allen ML, Allen MM, Cumming D, Johan S (2019) Comparative capitalisms and energy transitions: renewable energy in the European Union. British Journal of Management.

Alvarez-Herranz A, Balsalobre-Lorente D, Shahbaz M, Cantos JM (2017) Energy innovation and renewable energy consumption in the correction of air pollution levels. Energy Policy 105:386–397

Andreoni J, Levinson A (2001) The simple analytics of the environmental Kuznets curve. J Public Econ 80(2):269–286

Apergis N, Danuletiu DC (2014) Renewable energy and economic growth: Evidence from the sign of panel long-run causality. Int J Energy Econ Policy 4(4):578

Apergis N, Payne JE (2011) On the causal dynamics between renewable and non-renewable energy consumption and economic growth in developed and developing countries. Energy Systems 2(3-4):299–312

Apergis N, Payne JE (2012) Renewable and non-renewable energy consumption-growth nexus: Evidence from a panel error correction model. Energy Econ 34(3):733–738

Apergis N, Payne JE, Menyah K, Wolde-Rufael Y (2010) On the causal dynamics between emissions, nuclear energy, renewable energy, and economic growth. Ecol Econ 69(11):2255–2260

Aragón-Correa JA, Sharma S (2003) A contingent resource-based view of proactive corporate environmental strategy. Acad Manag Rev 28(1):71–88

Azlina A, Law SH, Mustapha NHN (2014) Dynamic linkages among transport energy consumption, income and CO2 emission in Malaysia. Energy Policy 73:598–606

Bai J, Kao C (2006) On the estimation and inference of a panel cointegration model with cross-sectional dependence. Contributions to economic analysis 274:3–30

Bai J, Kao C, Ng S (2009) Panel cointegration with global stochastic trends. J Econ 149(1):82–99

Balcilar M, Ozdemir ZA, Ozdemir H, Shahbaz M (2018) The renewable energy consumption and growth in the G-7 countries: Evidence from historical decomposition method. Renew Energy 126:594–604

Bekun FV, Alola AA, Sarkodie SA (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

Bilgili F, Koçak E, Bulut Ü (2016) The dynamic impact of renewable energy consumption on CO2 emissions: a revisited Environmental Kuznets Curve approach. Renew Sust Energ Rev 54:838–845

BNEF (2020) Late Surge in Offshore Wind Financings Helps 2019 Renewables Investment to Overtake 2018. The Bloomberg New Energy Finance, London and New York

Brock WA, Taylor MS (2005) Economic growth and the environment: a review of theory and empirics. *Handbook of economic growth* 1: 1749–1821 Elsevier

Callway R (2013) Governance for sustainable development: a foundation for the future: Earthscan

Çoban S, Topcu M (2013) The nexus between financial development and energy consumption in the EU: A dynamic panel data analysis. Energy Econ 39:81–88

Cole MA (2006) Does trade liberalization increase national energy use? Econ Lett 92(1):108–112

Danish Ulucak R. (2020) The pathway toward pollution mitigation: Does institutional quality make a difference?. Business Strategy and the Environment, n/*a*(n/a). doi: 10.1002/bse.2597

Dinda S (2004) Environmental Kuznets curve hypothesis: a survey. Ecol Econ 49(4):431–455

Dogan E, Ozturk I (2017) The influence of renewable and non-renewable energy consumption and real income on CO 2 emissions in the USA: evidence from structural break tests. Environ Sci Pollut Res 24(11):10846–10854

Dogan E, Seker F (2016) An investigation on the determinants of carbon emissions for OECD countries: empirical evidence from panel models robust to heterogeneity and cross-sectional dependence. Environ Sci Pollut Res 23(14):14646–14655

Dollar D, Kraay A (2004) Trade, growth, and poverty. Econ J 114(493): F22–F49

Dreher A (2006) Does globalization affect growth? Evidence from a new index of globalization. Appl Econ 38(10):1091–1110

Dumitrescu E-I, Hurlin C (2012) Testing for Granger non-causality in heterogeneous panels. Econ Model 29(4):1450–1460

EIA. (2019) U.S. Energy Information Administration

Elliot D (2008) Nuclear or Not? Does Nuclear Power Have a Place in a Sustainable Energy Future? ECONOMIC ISSUES-STOKE ON TRENT *13*(1):96

Eren BM, Taspinar N, Gokmenoglu KK (2019) The impact of financial development and economic growth on renewable energy consumption: Empirical analysis of India. Sci Total Environ 663:189–197

EUC (2014) Council of the European Union. 2030 Framework for climate and energy: Brussels: Council of the European Union

Fei Q, Rasiah R, Shen LJ (2014) The clean energy-growth nexus with CO2 emissions and technological innovation in Norway and New Zealand. Energy & environment 25(8):1323–1344

Gallo A, Simões-Moreira J, Costa H, Santos M, dos Santos EM (2016) Energy storage in the energy transition context: A technology review. Renew Sust Energ Rev *65*:800–822

Ganda F (2019) The impact of innovation and technology investments on carbon emissions in selected organisation for economic Co-operation and development countries. J Clean Prod 217:469–483

García-Álvarez MT, Cabeza-García L, Soares I (2018) Assessment of energy policies to promote photovoltaic generation in the European Union. Energy 151:864–874

Gozgor G, Mahalik MK, Demir E, Padhan H (2020) The impact of economic globalization on renewable energy in the OECD countries. Energy Policy 139:111365

Halicioglu F, Ketenci N (2018) Output, renewable and non-renewable energy production, and international trade: Evidence from EU-15 countries. Energy 159:995–1002

Han S, Won W, Kim J (2017) Scenario-based approach for design and comparatively analysis of conventional and renewable energy systems. Energy 129:86–100

Hart SL, Dowell G (2011) Invited editorial: A natural-resource-based view of the firm: Fifteen years after. J Manag 37(5):1464–1479

IEA (2017) World Energy Outlook, Organisation for Economic Co-operation and Development: OECD2017

Jalil A (2014) Energy–growth conundrum in energy exporting and importing countries: Evidence from heterogeneous panel methods robust to cross-sectional dependence. Energy Econ 44:314–324

Jiang Z, Lyu P, Ye L, Wenqian Zhou Y. (2020) Green Innovation Transformation, Economic Sustainability and Energy Consumption during China's New Normal Stage. Journal of Cleaner Production, 123044

Kahia M, Aïssa MSB, Charfeddine L (2016) Impact of renewable and non-renewable energy consumption on economic growth: New evidence from the MENA Net Oil Exporting Countries (NOECs). Energy 116:102–115

Kaygusuz K (2007) Energy for sustainable development: key issues and challenges. Energy Sources, Part B: Economics, Planning, and Policy *2*(1):73–83

Khoshnevis Yazdi S, Shakouri B (2017a) The globalization, financial development, renewable energy, and economic growth. Energy Sources, Part B: Economics, Planning, and Policy *12*(8):707–714

Khoshnevis Yazdi S, Shakouri B (2017b) Renewable energy, nonrenewable energy consumption, and economic growth. Energy Sources, Part B: Economics, Planning, and Policy *12*(12):1038–1045

Kuriqi A, Pinheiro AN, Sordo-Ward A, Garrote L (2017) Trade-off between environmental flow policy and run-of-river hydropower generation in Mediterranean climate. Eur Water *60*:123–130

Kusumadewi TV, Winyuchakrit P, Limmeechokchai B (2017) Long-term CO2 emission reduction from renewable energy in power sector: the case of Thailand in 2050. Energy Procedia 138:961–966

Kutan AM, Paramati SR, Ummalla M, Zakari A (2018) Financing renewable energy projects in major emerging market economies: Evidence in the perspective of sustainable economic development. Emerg Mark Financ Trade 54(8):1761–1777

Lin B, Zhu J (2019) The role of renewable energy technological innovation on climate change: empirical evidence from China. Sci Total Environ *659*:1505–1512

Lorente DB, Álvarez-Herranz A (2016) Economic growth and energy regulation in the environmental Kuznets curve. Environ Sci Pollut Res *23*(16):16478–16494

Mair J, Marti I, Ventresca MJ (2012) Building inclusive markets in rural Bangladesh: How intermediaries work institutional voids. Acad Manag J *55*(4):819–850

Michailova S, McCarthy DJ, Puffer SM, Chadee D, Roxas B (2013) Institutional environment, innovation capacity and firm performance in Russia. Critical perspectives on international business

Omri A, Nguyen DK (2014) On the determinants of renewable energy consumption: International evidence. Energy 72:554–560

Ozokcu SOO (2017) Regression with Driscoll-Kraay standard errors. pdf. Renew Sust Energ Rev 72:639–647

Paramati SR, Apergis N, Ummalla M (2017a) Financing clean energy projects through domestic and foreign capital: The role of political cooperation among the EU, the G20 and OECD countries. Energy Econ 61:62–71

Paramati SR, Mo D, Gupta R (2017b) The effects of stock market growth and renewable energy use on CO2 emissions: evidence from G20 countries. Energy Econ 66:360–371

Pesaran MH (2004). General diagnostic tests for cross section dependence in panels.

Pesaran MH (2007) A simple panel unit root test in the presence of cross-section dependence. J Appl Econ 22(2):265–312

Phillips PC, Sul D (2003) Dynamic panel estimation and homogeneity testing under cross section dependence. Econ J 6(1):217–259

Saad W, Taleb A (2018) The causal relationship between renewable energy consumption and economic growth: evidence from Europe. Clean Techn Environ Policy 20(1):127–136

Sadorsky P (2009a) Renewable energy consumption and income in emerging economies. Energy Policy 37(10):4021–4028

Sadorsky P (2009b) Renewable energy consumption, CO2 emissions and oil prices in the G7 countries. Energy Econ 31(3):456–462

Saidi H, El Montasser G, Ajmi AN (2020) The role of institutions in the renewable energy-growth nexus in the MENA region: a panel cointegration approach. Environ Model Assess 25(2):259–276

Salim RA, Rafiq S (2012) Why do some emerging economies proactively accelerate the adoption of renewable energy? Energy Econ 34(4): 1051–1057

Sarkodie SA, Strezov V (2019) Effect of foreign direct investments, economic development and energy consumption on greenhouse gas emissions in developing countries. Sci Total Environ 646:862–871

Sebri M, Ben-Salha O (2014) On the causal dynamics between economic growth, renewable energy consumption, CO2 emissions and trade openness: Fresh evidence from BRICS countries. Renew Sust Energ Rev 39:14–23

Shafiei S, Salim RA (2014) Non-renewable and renewable energy consumption and CO2 emissions in OECD countries: a comparative analysis. Energy Policy 66:547–556

Shahbaz M, Lean HH, Shabbir MS (2012) Environmental Kuznets curve hypothesis in Pakistan: cointegration and Granger causality. Renew Sust Energ Rev 16(5):2947–2953

Shahbaz M, Mallick H, Mahalik MK, Sadorsky P (2016) The role of globalization on the recent evolution of energy demand in India: Implications for sustainable development. Energy Econ 55:52–68

Shahbaz M, Mallick H, Mahalik MK, Hammoudeh S (2018a) Is globalization detrimental to financial development? Further evidence from a very large emerging economy with significant orientation towards policies. Appl Econ 50(6):574–595

Shahbaz M, Nasir MA, Roubaud D (2018b) Environmental degradation in France: the effects of FDI, financial development, and energy innovations. Energy Econ 74:843–857

Shahbaz M, Shahzad SJH, Mahalik MK, Sadorsky P (2018c) How strong is the causal relationship between globalization and energy consumption in developed economies? A country-specific time-series and panel analysis. Appl Econ 50(13):1479–1494

Shahnazi R, Shabani ZD (2020) Do renewable energy production spillovers matter in the EU? Renew Energy 150:786–796

Sharif A, Raza SA, Ozturk I, Afshan S (2019) The dynamic relationship of renewable and nonrenewable energy consumption with carbon emission: A global study with the application of heterogeneous panel estimations. Renew Energy 133:685–691

Soytas U, Sari R, Ewing BT (2007) Energy consumption, income, and carbon emissions in the United States. Ecol Econ 62(3-4):482–489

Stern DI (2007) The effect of NAFTA on energy and environmental efficiency in Mexico. Policy Stud J 35(2):291–322

Stiglitz JE (2002) Globalization and its Discontents (Vol. 500): New York Norton

Tang CF, Tan EC (2013) Exploring the nexus of electricity consumption, economic growth, energy prices and technology innovation in Malaysia. Appl Energy 104:297–305

Tang CF, Tan BW (2015) The impact of energy consumption, income and foreign direct investment on carbon dioxide emissions in Vietnam. Energy 79:447–454

Uzar U (2020) Political economy of renewable energy: Does institutional quality make a difference in renewable energy consumption? Renew Energy 155:591–603

WDI (2019) World Bank Indicators

Westerlund J, Edgerton DL (2007) A panel bootstrap cointegration test. Econ Lett 97(3):185–190

Wiser R, Millstein D, Mai T, Macknick J, Carpenter A, Cohen S, Cole W, Frew B, Heath G (2016) The environmental and public health benefits of achieving high penetrations of solar energy in the United States. Energy 113:472–486

Wordsworth A, Grubb M (2003) Quantifying the UK's incentives for low carbon investment. Clim Pol 3(1):77–88

Wu L, Broadstock DC (2015) Does economic, financial and institutional development matter for renewable energy consumption? Evidence from emerging economies. International Journal of Economic Policy in Emerging Economies 8(1):20–39

Zhu Y, Wittmann X, Peng MW (2012) Institution-based barriers to innovation in SMEs in China. Asia Pac J Manag 29(4):1131–1142