TYPE Original Research
PUBLISHED 24 October 2022
DOI 10.3389/fenvs.2022.975481

Biomass energy consumption and carbon neutrality in OECD countries: Testing pollution haven hypothesis and environmental Kuznets curve

Yujing Wang, Weimin Guan*, Ling Liu and Xinyuan Ma

School of Economics, Tianjin University of Commerce, Tianjin, China

Check for updates

OPEN ACCESS

EDITED BY
Asif Razzaq,
Ilma University, Pakistan

REVIEWED BY
Hafiz Waqas Kamran,
Iqra University, Pakistan
Ahsan Anwar,
National College of Business Administration and Economics, Pakistan

*CORRESPONDENCE
Weimin Guan,
weibe89@163.com

SPECIALTY SECTION
This article was submitted to Environmental Economics and Management,
a section of the journal
Frontiers in Environmental Science

RECEIVED 22 June 2022
ACCEPTED 24 August 2022
PUBLISHED 24 October 2022

CITATION
Wang Y, Guan W, Liu L and Ma X (2022), Biomass energy consumption and carbon neutrality in OECD countries: Testing pollution haven hypothesis and environmental Kuznets curve.
Front. Environ. Sci. 10:975481.
doi: 10.3389/fenvs.2022.975481

Rising pollution enhances the need for eco-friendly measures such as technological development and the enhancement of nonrenewable energy resources to achieve sustainable economic progress. Biomass energy consumption is an innovative form of renewable energy source which influences the environment positively. The current study explores the impact of biomass energy consumption and foreign direct investment on the environmental degradation of 32 OECD countries under the framework of the environmental Kuznets curve (EKC) hypothesis from 1990 to 2018. The cross-sectional ARDL estimation method has been deployed to address slope heterogeneity and cross-section dependency. The long-run result shows that biomass energy consumption reduces environmental pollution, while foreign direct investment exerts pressure on environmental quality, endorsing the pollution heaven hypothesis. Moreover, the findings validate the EKC hypothesis in the long run. The error correction term is significantly negative, confirming the convergence towards long-run equilibrium with a 46% adjustment rate. The robustness of the estimated model is also verified using alternative estimators. The study's outcome is encouraging the policymakers to devise policies for using biomass energy sources as an alternative clean energy source to ensure a sustainable environment.

KEYWORDS

biomass energy consumption, foreign direct investment, carbon neutrality, OECD, EKC, PHH

1 Introduction

Economic expansion in the past few decades has resulted in energy depletion and environmental deterioration. The Paris Agreement signed in 2016 by more than 196 countries around the globe is witnessed to protect the environment from harmful emissions. Protection of the environment from harmful emissions was the core objective of the agreement. Hence, environmental degradation is gaining attention due to rising ecological concerns (Hughes et al., 2017). The database of Global Atmospheric Research reports that since 1970, the OECD and other emerging countries have been responsible for discharging 85% of the harmful global emissions. Recently, OECD (2021) revealed that these economies are releasing almost 35% of carbon dioxide emissions due to the implementation of strict environmental regulations in the region and the emergence of COVID-19 slowing down the industrialization process in the respective countries. The limited human activities decrease greenhouse gas emissions, specifically in 2020. Australia, the United States, and Luxembourg are the highest emitters between 2017 and 2020; however, Colombia, Mexico, and Sweden are the minor emitters in the region (Jianguo et al., 2022). The probable threat to the earth's survival has been endangered mainly by the carbon dioxide contribution causing environmental degradation and pollution (Bilgili et al., 2016). Among the various vital determinants, foreign direct investment, economic growth, and biomass energy consumption are promising factors for exploring the dimensions of environmental hazards.

Biomass energy is an alternative to oil that is almost used to fulfill all the energy requirements such as electric power production, overheating houses, and progressed energy sources for an industrial manufacturing plant. Biomass is applied to various aspects, namely, edibles, building materials, and fuel energy, to signify any accessible plant substances such as cropping. The benefits of biomass energy based on power resources are to lessen the oil dependence of foreign-reliant nations. It is nearly a primary contributor to reducing inflation and enhancing employment opportunities in rural areas. Furthermore, bioenergy can be transformed into electric energy, fuel, and active thermal radiation. Biomass is also advantageous for decreasing carbon dioxide production and encouraging energy safety by restoring power through renewable energy (Bildirici and Ersin, 2015; Bilgili and Ozturk, 2015; Sun et al., 2022a). As reported by the Global Bioenergy Statistics, the World Bioenergy Association (2018) revealed that in 2016, biomass energy incorporated 56.5% of the entire renewable energy sources worldwide. The report also details that biomass energy comprises 13% of usage in the world's ultimate energy utilization; also, this tempo is expected to rise by 22% in the upcoming years.

International Energy Agency (2018) published a report in World Energy Outlook stating that the desire for contemporary biomass energy in 2017 was 726 million tons of oil and is expected to increase to 1 billion 427 million tons of oil, identical in early 2040. Both reports disclose that this world has progressed by opting for sustainable energy source like modern biomass energy and moving toward a technology-intensive venture. The essential task is adapting energy facilities that lean on ecological production automation (Chien et al., 2021). The exhaustion of fossil fuels is the leading cause of the economy's growth in the late 20th century. But, the shortage of fossil fuels and the alarming situation to the safety of energy, fluctuation of energy worth, climate crisis, and the production of greenhouse gases is the mainspring of non-restorable energy sources. Additionally, in 1970, the oil confrontation forced world decision-makers to hit upon some substitute power source. Therefore, in the early 21st century, most nations started to realize the advantage of accelerating the overflow of renewable energy resources in their society. For instance, the current biomass energy source offers people a maintainable energy source, building some new openings in trade and work on the industrial air pollution besides breakdown in climatic conditions (Ozturk and Bilgili, 2015; Ali et al., 2017; Keeley and Ikeda, 2017; Aydin, 2018). Renewable energy resources are in demand due to the swift emissions of harmful gases in the air (Dong et al., 2018). Energy requirements and environmental protection can be achieved by biomass energy (Dogan and Inglesi-Lotz, 2017). Yet, economic growth correspondence to carbon dioxide emissions has been vague under specific findings (Adewuyi and Awodumi, 2017). One concept has established that greenhouse gas emissions have been elevated through biomass energy (Bilgili et al., 2016); conversely, Solarin et al. (2018) endorsed that biomass energy contributes to the emissions the same as fossil fuels do.

Similarly, Shahbaz et al. (2017) and Dogan and Inglesi-Lotz (2017) proposed that biomass energy consumption can reduce pollution; meanwhile, it has been asserted that biomass energy accelerates environmental degradation (Shahbaz et al., 2019). Conversely, the profitable realization adaptation cannot be achieved till appropriate technology works accurately and capitalization is equally handed out in globalization. Because of that, natural, human, and economic resources are appropriately allocated around the globe; also, the prices of inexhaustible sources affect the financial situations, says the one that was sharing the resources among the countries is very significant as it goes along with FDI and contributes to a suitable sponsorship (Keeley and Ikeda, 2017). Practically, FDI is classified into direct and indirect investments.

Foreign direct investment (FDI) can be an investment made by a firm belonging to a developed country in any other company of an emerging economy to expand its business outside the country. This way, advanced technology in labor, machinery, and business development can be introduced into the manufacturing industries of developing countries. The neoclassical model explains that FDI needs to raise the speculation rate because of that increment in per capita income, excluding technological advancements and employment escalation. But, the advance hypothesis manifests FDI and technological progress as two parameters capable of long-lasting effects with technological advancements and growth in the presenter country. The technological advancements and development in an open market will smooth the deal's progress and hold up the state's shift. Even so, in the industrial flight theory, overseas businesspersons invest in their countries to reduce manufacturing cost, which leads to the present country's sources and environmental situations declining with time. The theory states the reality that secure and sustainable energy resources demand economic advancements in nations, and debatable disagreements about the environments should be figured out to encourage the rise of FDI among nations (Khan et al., 2020). FDI helps bridge the gap between innovative technology and economic prosperity by enhancing the skills and exports of the country. FDI is a beneficial investment for developing countries due to the exchange rate difference; thus, the material cost produces profits for the investor (Hakro and Ghumro, 2007). Globalization accelerates economic growth, and more energy is required to sustain the country's development. Fossil fuels mainly fulfill the global energy requirements. Economic growth contributes to utilizing the energy produced by fossil fuels, resulting in increased carbon dioxide emissions. Thus, the harmful effect of progress is the upsurge of global environmental hazards.

Given the background of the critical aspects and the previous literature that has been discussed, institutional, technological, and environmental sustainability for the OECD countries is still needed. Recently, the research work by Barış-Tüzemen and Tüzemen (2022) has explored the bioenergy, FDI, and EKC framework for BRICS countries. This effort has been made to elaborate on the broad policy implications in order to achieve ecological sustainability for the selected countries. The relationship between biomass energy consumption and foreign direct investment in the scenario of EKC by taking the economic growth as a control variable is the primary objective of the current research. The present study is a novel effort in the context of 32 OECD regions to promote sustainability in the region. Biomass energy consumption, an innovative form of renewable energy, foreign direct investment of the countries, and economic growth have been taken to test the validity of the EKC framework, which is the prime need of the present analysis.

There are several contributions of the present study in the environment, energy, and income literature. As per the author's knowledge, none of the investigations before discussed biomass energy consumption and foreign direct investment with the environmental degradation in the scenario of OECD countries. Sun and Razzaq (2022) argue that ecological sustainability and the preservation of energy resources are the primary concerns for the OECD countries; therefore, considering the economic progress and a healthy environment, implications are discussed to fill the gap in the literature. Consequently, the influence of bioenergy on carbon dioxide discharge is the focus of the study, keeping sustainable growth in the region. Moreover, other ignored explanatory variables are also included in the study, such as foreign direct investment and linear and quadratic economic growth, to validate the Kuznets theory. The present study will contribute to making sophisticated policies in the OECD countries following the sound technological methods for sustainable development.

The remaining study consists of four sections. Section 2 discusses the critical review of literature related to biomass energy consumption, foreign direct investment, and economic growth. Section 3 explains the methodological framework applied in the study, followed by the discussions in Section 4. The study concludes in the last section.

2 Literature review

The association between energy consumption, foreign direct investment, and economic growth with environmental degradation has been widely discussed under single-country or cross-country analysis. The influential concept of the environmental Kuznets curve hypothesis originated in 1955. The formal analysis of economic growth and environmental pollution by Grossman and Kruger (1991) reveals that harmful emissions increase to a specified point, and once earnings cross the edge, they start decreasing. Later on, Panayotou (1993) tested the validity of the hypothesis and empirically analyzed the framework of EKC.

Energy consumption started to associate with the structure of EKC in early 2000. After that, numerous studies have explored the EKC hypothesis by incorporating energy consumption as a covariate in the model. The available literature on energy consumption is classified into two divisions: aggregated and disaggregated energy consumption. The studies such as those of Danish (2021), Zaman et al. (2016), Al-Mulali et al. (2015a), Sarkodie and Strezov (2019), and Zhang et al. (2017) discussed the impact of aggregated energy on the various indicators of environmental health. Moreover, the energy is further segregated into renewable and nonrenewable energy. Various scholars (Cherni and Jouini, 2017; Destek and Aslan, 2017; Dogan and Ozturk, 2017; Danish, 2021) have confirmed that nonrenewable energy resources are the key determinant in minimizing greenhouse gas emissions. Understanding the increasing demand for nonrenewable energy products, recent studies focus on exploring bioenergy consumption and its impact on carbon neutrality. Studies such as Bilgili et al. (2016), Katircioglu (2015), Shahbaz et al. (2017), Dogan and Inglesi-Lotz (2017), Ajmi and Inglesi-Lotz (2020), and Danish & Wang (2019) claimed that biomass energy helps control harmful atmospheric emissions. On the contrary, several studies (Solarin et al., 2018; Shahbaz et al., 2019) consider that biomass energy is nothing but similar to fossil fuel consumption and contributes to destroying the environment. Compared with the other renewables, Baležentis et al. (2019) assert that biomass energy resources shine among others, as their impact is high on controlling pollution. Hence, the available literature and findings are less to indicate the possible relation of biomass energy with the ecosystem; however, previous studies are still unclear in establishing the nature of biomass energy relation with carbon neutrality.

Existing literature focused on foreign direct investment notifies that industrial-based countries should regulate their

TABLE 1 Variables of the study.

Sign	Indication	Description	Measurement unit	Source
CN	Dependent	Carbon neutrality	Carbon emission metric tons per capita	British Petroleum
BEC	Independent	Biomass energy consumption	Biomass extraction in metric tons	Material Flows. Net
FDI	Independent	Foreign direct investment	Foreign direct investment inflows (constant 2011 US dollars)	World Bank
GDP	Control	Economic growth	Real GDP (constant 2011 US dollars	World Bank
SQGDP	Control	Square of economic growth	Reflect EKC hypothesis	World Bank

manufacturing sectors in compliance with the protection of the environment (Abdouli and Hammami, 2017). Globalization may push the FDI inflows and accelerate the growth of the developing nations; however, it directly affects the environment, enhancing the need to test the pollution haven hypothesis (PHH). Lee (2013) highlighted that developing countries are the investment venue for various aspects, taking part in increasing economic progress and enriching technology innovations. Numerous studies, for instance, Lau et al. (2014), Anwar and Nguyen (2010), Nguyen and Nguyen (2007), Omri et al. (2014), and Liu and Lin (2019)explored the relation of FDI with the quality of the environment. Shahbaz et al. (2015) studied the FDI of MENA regions supporting PHH. PHH comprises two effects, the scale effect and the composition effect. For the scale effect, the PHH is established after capturing the technological aspects, while the composition effect is based on pollution; thus, emerging economies find it hard to attain the validity of PHH. Governments should invest more in implementing the environmental rules than in production (Copeland and Taylor, 2013; Sun et al., 2022b). Gallagher (2009) emphasized that advanced technology methods dependent on the labor force are more eco-friendly than conventional production modes. There are mixed outcomes found related to the impact of FDI concerning the validity of PHH, such as the study by Shahbaz et al. (2015) which confirms the hypothesis, while Al-Mulali and Tong (2013) and Paramati et al. (2016) come with contrary evidence. Liu et al. (2017) encourage FDI to reduce emissions with technology-efficient methods. For a single-country analysis of Turkey, Koçak and Şarkgüneşi (2018) endorse the validity of the environmental Kuznets curve along with the pollution haven hypothesis. On the contrary, Bakhsh et al. (2017) and Solarin et al. (2018) negate the positive effect of FDI on the environment.

Keeping the importance of EKC, it has been shown that while attaining economic prosperity to a certain level of income, the environment suffers loss. This situation arises in developing countries where growth is a top priority. The concept has been intensified through the pioneering work of Grossmen and Krueger (1991). The recent study by Shahbaz and Sinha (2019) comprehensively explored the innovative versions of the EKC model. Consistent with the same framework, N-shaped EKC is also the desirable approach for various studies. The positive relationship holds between income and the ecosystem until the curve's first turning point is achieved. Afterward, the negative impact will have started to impose during the second turning point of the curve. It shows that the economic system should be revisited by introducing modern technologies promoting clean resources in manufacturing, as income generated through the FDI inflows harms the environment (Alvarez-Herranz et al., 2017). Shahbaz and Sinha (2019) list out the detailed phases of the N-shaped EKC process. Regarding the exploration of EKC in the panel framework, Kongbuamai et al. (2020) studied the ASEAN countries and validated the EKC hypothesis in the region. Regarding the BRICS countries, Aydin and Turan (2020) claim that trade is important in explaining environmental pollution rather than economic growth. Baloch et al. (2019) contributed to the literature by concluding that FDI had an adverse impact on the environment for BRI countries.

The enlightening literature still has no clear consensus about the impact of biomass energy consumption on environmental degradation, especially in OECD countries. In terms of achieving sustainable development goals, previous studies do not address them adequately. The research gap lies in explaining the policy implications for the OECD regions taking biomass energy consumption and foreign direct investment under the framework of EK. Furthermore, the studies cover G7 nations, emerging countries, the West African region, MENA, and EU countries. Thus, the current study is the first in the domain of clean energy products, income, and economic growth for the OECD region.

3 Methodology

3.1 Theoretical background and data description

The seminal work of Grossman and Krueger (1991) motivated the current study to validate the environmental Kuznets curve (EKC) hypothesis, implying that economic growth will hurt the quality of the environment after achieving a certain threshold of income (Shahbaz and Sinha, 2019). In this context, GDP should increase carbon dioxide emissions as energy consumption raises serious environmental concerns. If the countries are associated with nonrenewable

TABLE 2 CSD and slope homogeneity test.

Variable	CSD test	
	F-value	*p*-value
CN	13.210*	0.000
BEC	9.540*	0.000
FDI	15.732*	0.000
GDP	10.640*	0.000
SQGDP	14.521*	0.000
Slope homogeneity test		
Test	Value	*p*-value
$\hat{\Delta}$	9.250*	0.000
$\hat{\Delta}_{adjusted}$	7.631*	0.000

Note: *$p < 1\%$.

energy consumption, the discharge of greenhouse gases cannot be controlled, suggesting that development may affect the country's resources. Moreover, foreign direct investment may influence carbon neutrality positively and lead the results to test the pollution haven hypothesis (PHH), confirming the N-shaped association between economic progress and FDI on the environmental degradation of BRICS nations. Related to biomass energy consumption, ambiguous outcomes are observed in the literature (Adewuyi and Awodumi, 2017). Based on the said theoretical background and to establish the required relationship among the variables, the baseline regression model consistent with Danish and Wang's (2019) model has been used and defined below

$$CN_{jt} = \gamma_0 + \gamma_1 BEC_{jt} + \gamma_2 FDI_{jt} + \gamma_3 GDP_{jt} + \gamma_4 GDP^2{}_{jt} + \varepsilon_{jt} \quad (1)$$

where CN is termed as carbon neutrality measured as carbon emission metric tons per capita, BEC presents the biomass energy consumption, FDI is foreign direct investment, and GDP is the control variable used as a proxy of economic progress with the square term followed by the error term. The subscript " j" presents the cross-section of OECD regions, and "t" refers to the time in years ranging from 1990 to 2018. The coefficient γ_1 (biomass energy consumption) is supposed to be negative as it can reduce carbon dioxide emissions (Shahbaz et al., 2017). On the contrary, Solarin et al. (2018) suggested that biomass energy replicates fossil fuels, harming the environment. The expected sign of γ_3 is positive, while an inverted U-shape curve needs to be observed with $\gamma_4 < 0$ in Eq. 1. γ_2 appears to be positive because the increase in foreign direct investment also accelerates the country's emissions.

The annual data of OECD countries have been taken to meet the desired goals. The frequency of data lies between 1990 and 2018. As reported by Global Atmospheric Research, 85% of the global carbon emission is emitted through the discharge produced by the OECD countries. As the industrialization process was slow in late 2008, it has been documented that the region's greenhouse gas emissions decreased. Emissions are again increasing due to the pandemic of COVID-19 as numerous economies suffered in the lockdown era. Thus, the region is beneficial for discussing the mentioned objectives to improve the quality of the environment. The details related to the variables under study and their sources are illustrated in Table 1.

3.2 Econometric methodology

The formal analysis will take place after investigating the cross-sectional dependence test, slope homogeneity test, and unit root testing procedure. Co-integration was then confirmed by Westerlund (2007), followed by the CS-ARDL method.

3.2.1 Cross-sectional dependence test and slope homogeneity test

Before embarking on the formal empirical modeling, the current study initializes by testing cross-section dependence and slope homogeneity tests. The cross-sectional dependency and heterogeneity among the cross-sections cannot be ignored while dealing with longitudinal data (Khan et al., 2020; Ulucak and Khan, 2020). The slope coefficient heterogeneity has been accessed by Baltagi and Hashim Pesaran's (2007) test under the null hypothesis of homogenous slope coefficients with the following test statistics:

$$\tilde{\Delta}_{slope\,coeffecient\,heterogeneity} = \left(n^{\frac{1}{2}}\right)\left(2m^{-\frac{1}{2}}\right)\left(\frac{1}{n}\tilde{k} - m\right) \quad (2)$$

$$\tilde{\Delta}_{adjused\,slope\,coeffecient\,heterogeneity} = \left(n^{\frac{1}{2}}\right)\left(\frac{2m(t-m-1)}{t+1}\right)^{-\frac{1}{2}}\left(\frac{1}{n}\tilde{k} - 2m\right) \quad (3)$$

The advanced cross-section dependence test proposed by H M Pesaran (2007) is used to capture the series' sudden economic or financial jerks and structural breaks. The null hypothesis of cross-sections is independent versus alternative cross-sections that are dependent will be the background of the test.

3.2.2 Unit root testing procedure

A suitable unit root test is the desirable need for time series data to identify the order of stationarity. Usual statistical and econometric approaches are ideal for stationary data at various levels. The current study drives the heterogeneity of slope coefficients and dependent cross-sections to apply second-generation unit root tests as first-generation tests are not robust to the said issues of panel data (Im et al., 2003). The cross-section unit root test of CIPS and CADF recently proposed by Pesaran (2007) controlled the problem of heterogeneity by taking additional lags and obtaining the first difference through amplified and mean cross-sections. The FDI, biomass energy level, and carbon neutrality of OECD countries differ across the region; thus, CIPS and CADF tests are significantly more robust to capture the cross-section dependence. Consider the following form for the test:

$$\Delta X_{j,t} = \delta_j + \delta_j \Delta X_{j,t-1} + \delta_j \bar{X}_{t-1} + \sum_{i=0}^{k} \delta_{j1} \Delta \bar{X}_{t-1} + \sum_{i=1}^{k} \delta_{j1} \Delta X_{t-1} + \mu_{jt} \quad (4)$$

The lagged terms are $\bar{X}_{t-1}$ and the first differenced terms are $\Delta\bar{X}_{t-1}$, respectively. The null hypothesis of non-stationarity has been tested by the following test statistic with the cross-section augmented Dickey–Fuller term:

$$\widehat{Csimps} = \frac{1}{n} \sum_{j=1}^{N} C - ADF_j \quad (5)$$

3.2.3 Panel co-integration test

The long-term association between biomass energy consumption, foreign direct investment, and economic growth with environmental degradation has been accessed by using the second-generation co-integration test of Westerlund (2007) as the cross-section heterogeneity and dependence among the panels are considered through the test. Westerlund (2007) offers four test statistics types, grouped mean (Eqs 6, 7) and panel statistics (Eqs 8, 9). No long-run association versus the existence of association among the data series has been tested by using the following test statistics:

$$G_T = \frac{1}{n} \sum_{j=i}^{n} \left[\beta_j / SE(\beta_j) \right] \quad (6)$$

$$G_\beta = \frac{1}{n} \sum_{j=i}^{n} \left[t\beta_j / \beta_j (1) \right] \quad (7)$$

$$P_T = \left[\beta_j / SE(\beta_j) \right] \quad (8)$$

$$P_\beta = t\beta_j \quad (9)$$

3.2.4 Cross-section autoregressive distributed lag model

The long-run elasticities of the estimated model have been retrieved through the CS-ARDL model. The test was formally introduced by Chudik and Pesaran (2021), presenting the solutions to various time-series panel modeling procedures. Li et al. (2020) assert that CS-ARDL is unbiased and sufficient than conventional pooled mean group methods. The estimates are robust and efficient regarding heterogeneity, cross-section dependence, nonstationarity or stationary at various orders, and endogeneity concerns (Khan et al., 2020). The functional form of the model is specified as below:

$$CN_{jt} = \gamma_0 + \sum_{k=1}^{m} \theta_{jt} CN_{j,t-k} + \sum_{k=0}^{m} \beta_{jt} Z_{t-k} + \sum_{k=0}^{m} \vartheta_j' L\bar{W}_{j,t-k} + \mu_{jt}. \quad (10)$$

TABLE 3 CIPS and CADF unit root Tests.

Variable	CIPS		CADF	
	I (0)	I (I)	I (0)	I (I)
CN	−2.425	−4.208*	−1.876	−4.509*
BEC	−2.043	−3.641*	−2.140	−3.216*
FDI	−0.960	−3.420*	−1.217	−2.957**
GDP	−1.463	−3.695*	−1.100	−3.531*
SQGDP	−0.857	−3.065**	−1.532	−3.070*

Note: $^*p < 1\%$ and $^{**}p < 5\%$.

The aforementioned model comprises covariates, that is, biomass energy consumption and foreign direct investment, along with the control variables of linear and quadratic terms of economic. $\bar{W}_{j,t-k}$ presents the differenced mean of the dependent variable and average of explanatory data series. Eberhardt (2012) suggests the augmented pooled mean group test to check the robustness of the estimated model; hence, the test has been used in the current study. As explained earlier about the concerns of the panel data, the said test overcame the issues efficiently.

4 Results and discussion

Because of the cross-section data, the first step of the analysis approached testing the cross-section dependence and heterogeneity among the slope coefficients. For this purpose, the CSD test has been used. Table 2 presents the CSD and slope homogeneity test outcomes for all the variables. It has been shown that all variables are significant at a 1% level of significance, specifying the dependency of cross-sections. The null hypothesis of slope hemogeniety is also rejected and concluded that slopes of all selected variables are heterogeneous.

The stationarity properties of the variables are accessed through the CIPS and CADF tests, as these tests retrieve robust results in slope heterogeneity and cross-section dependent variables. The motive of the study is to apply the CS-ARDL method of estimation; thus, identification of order of integration for all variables is of primary interest (Sun et al., 2022c). Results in Table 3 indicate that the variables are stationary after taking the first difference. Thus, the variables carbon neutrality (CN), biomass energy consumption (BEC), foreign direct investment (FDI), and linear and quadratic terms of economic growth (GDP and SQGDP) are stationary at first difference.

The panel co-integration test of Westurlund (2007) has been deployed, and the outcomes are presented in Table 4. The group mean and panel test statistics confirm the long-run equilibrium relationship among the variables. In other words, the covariates biomass energy consumption (BEC), foreign direct investment (FDI), and linear and quadratic terms of economic growth (GDP

TABLE 4 Co-integration outcomes.

Statistics	Gt	Ga	Pt	Pa
Value	−3.650***	−7.630	−7.610*	−10.235
p-value	0.078	0.845	0.000	0.420

Note: *$p < 1\%$, **$p < 5\%$ and ***$p < 10\%$.

TABLE 5 Cross-sectional ARDL results.

Variable	Long-run			Short-run		
	Coeff.	t-stats	Sig.	Coeff.	t-stats	Prob.
ECT-1	—	—	—	−0.465	−3.682	***
BEC	−0.138	−2.320	**	−0.085	−2.536	**
FDI	0.325	2.527	**	0.149	2.109	**
GDP	0.540	3.160	***	0.213	3.214	***
SQGDP	−0.267	−2.215	**	−0.074	−1.850	*

Note: *$p < 1\%$, **$p < 5\%$, and ***$p < 10\%$.

and SQGDP) hold a long-run association with the carbon neutrality (CN). Now, the analysis moves to the long- and short-run estimates.

Table 5 portrays the long-run and short-run estimates obtained through the CS-ARDL methodology. The estimation procedure is robust to the small sample size and less sensitive to the order of integration. The left pane of Table 5 is the long-run estimates. The association between biomass energy consumption and carbon neutrality is found to be negative and highly significant at a 5% level of significance, revealing that biomass energy leaves positive marks on the atmosphere and helps decrease carbon emissions in the OECD region. The innovative methods to convert biomass wastes seem to reduce greenhouse emissions in the region. The government ought to enhance the implementation of green technology and revisit its policies on trade in the region. Biomass also lowers the cost of producing energy as extrinsic factors control fossil fuel prices. Still, the energy produced by biomass remains stable and cheaper than the energy produced by fossil fuels. Similarly, imports of energy products can also be reduced. The outcomes of the bioenergy are consistent with the studies of Shahbaz et al. (2017), Danish (2021), and Reinhardt and Von Falkenstein (2011), while dissimilar to that of Sinha et al. (2017). The long-run estimates of FDI appear to be positively related to carbon neutrality, showing an adverse impact on the environment. This outcome is unrelated to the results of Danish and Wang (2019), who found an insignificant effect of FDI for MENA countries. It has been documented that FDI raises investment, causing an increased income per capita in the country, neglecting the research and technology sector.

Thus, if advancements in technological parameters are related to the FDI inflows, the long-term economic benefit can be attained.

TABLE 6 Robustness estimators.

Variable	CCEMG			AMG		
	Coeff.	t-stats	Sig.	Coeff.	t-stats	Prob.
BEC	−0.097	−2.512	**	−0.110	−2.216	**
FDI	0.344	3.018	***	0.337	2.850	**
GDP	0.495	3.435	***	0.510	2.980	***
SQGDP	−0.248	−2.198	**	−0.189	−2.050	**

Note: *$p < 1\%$, **$p < 5\%$, and ***$p < 10\%$.

The OECD region should enhance the utilization of advanced technology in the manufacturing sector, resulting in a positive impact on trade. FDI can also bring technological innovations to the country, encouraging the use of nonrenewable energy like bioenergy. Investment opportunities may increase in the region if FDI contributes to the advancement in the utilization of energy products. As far as the economic growth of the OECD region is concerned, its impact is positive and highly significant on carbon neutrality, indicating harmful consequences in the air. It can be shown that prosperity in terms of economic growth is accelerating carbon dioxide emissions in the atmosphere. The square term of GDP is negative and significant, revealing that carbon neutrality is increasing as the earning sources are rising in the country and again decreased in the second turning point. This outcome confirms the U-shaped relationship between economic growth and environmental degradation, and validates the EKC hypothesis for the OECD region. These results align with Afshan and Yaqoob's (2022) and Danish's (2021) outcomes. The short-run estimates of the estimated model indicate the same nature of the relationship; however, the coefficients are lower in magnitude. The error correction term is negative and significant, showing that about 0.465% will be the speed of adjustment of the variables to hold the equilibrium relationship. Biomass energy consumption is negatively influenced by carbon dioxide emissions, while FDI and economic growth affect it positively. The EKC hypothesis is evident from the negative and significant coefficient of the quadratic term of the GDP.

Robustness tests have been performed using CCEMG and AMG testing procedures (Table 6). The coefficient of FDI and GDP is positive and significant in both methods. The FDI caused an increase in environmental pollution by 0.34% in the region, while economic growth raised it by 0.49%. Biomass energy consumption poses a positive effect on carbon neutrality. Overall, both tests support the estimates obtained by CS-ARDL methods.

5 Conclusion and policy implications

Increasing economic output leads to higher energy consumption and resource depletion. The fulfillment of energy demands through nonrenewable energy resources causes environmental pollution. Nonrenewable energy resources threaten the sustainability of society. Such countries should adopt clean energy resources to meet their energy requirements, as renewables are cheap and eco-friendly. Biomass energy is considered a clean energy source because it is based on organic characteristics, resulting in minimum harmful emissions that will be discharged. The sustainable development goals also promote clean energy sources to protect the environment in the OECD countries. Thus, the study explores the impact of new clean energy source biomass energy on the environmental quality. Foreign direct investment and economic growth are also included in the model. The cross-section autoregressive distributive lag (CS-ARDL) model has been used to capture the slope heterogeneity and cross-section dependence in parameters and panel units. Estimation results obtained from 1990 to 2018 reveal that biomass energy positively impacts the carbon dioxide emissions in the OECD region. The result shows that biomass energy enhances sustainable development, unlike nonrenewable sources. Foreign direct investment is negatively affecting the ecological traces of the OECD. The environmental Kuznets curve hypothesis is evident through the negative relationship between a quadratic term of economic growth and carbon neutrality.

Considering the obtained results, several policy implications are suggested for the OECD countries. Clean energy consumption should increase in the region and the use of nonrenewable energy resources in the manufacturing sector must be discouraged. Bioenergy is a renewable form of energy, and is a comprehensive source to generate in the OECD region. These measures involved a trained process of transforming old sectors into new and clean ones, or else the biomass energy sector would be confined as a replacement for reducing foreign oil dependency only. The empirical findings encourage policymakers to attain sustainable development criteria in the OECD countries. The EKC has been endorsed by the study outcomes, showing an inverted U-shaped relationship between economic growth and carbon dioxide emissions. As developing economies and nonsignatory to the Kyoto protocol, the OECD region is still responsible for addressing the environmental risk attached to energy upheaval and promoting administrative plans to increase efficiency and reduce pollution. Environmental quality is essentially relative to the FDI inflows in this performance. FDI inflows can attract green foreign capital by implementing novel policies. The investments from outside countries provide a new venue for technological innovations. Green foreign capital by positive FDI inflow can be attracted by implementing a novel action plan and could have a constructive impact in the medium term. OECD countries have captured dirty FDI inflows through oil and other energy sources in the last decennium. Due to these actions, there is a decreasing tendency in FDI inflows on carbon dioxide emissions. Some countries of the OECD should concentrate their efforts on environmental regulation now, which will bring relaxing rules regarding ecological deterioration to attain more investments.

Essential environmental deterioration has been hindered mainly by the absence of political will, insufficient institutional and sometimes financial constraints, or investor lobbying. For the sake of green technological transformation and adaptation of renewable sources in the region, the government of developed nations like the United States should take an interest in implementing sound policies for the developing members for FDI. Policy inquisitors have been stimulated by the amide linkage of energy and the environment to inquire about the adversity of economic improvement conditional on environmental features and power reduction. Continuous usage of hydrocarbons (fossil fuels) based energy like oil, gas, and coal due to increased energy stipulation has increased environmental perturbation. But the deteriorating environment can be tackled by adopting alternative energy like solar, wind, hydro, bioenergy, and thermal energy. Higher living standards have cost rigorous energy usage, resulting in environmental perils due to increased harmful emissions. To meet the rapid energy stipulation without causing environmental damage is now a need of the day because economic progress and environmental protection have a back-and-forth impact.

Still, there is room for further implications as the study possesses few limitations. Undoubtedly, bioenergy is the new source of clean resources. FDI may be an excellent channel through which bioenergy can be implemented in developing economies, as their focus on achieving economic progress is immensely important. There should be some other factors that can help to enhance the FDI and various other factors that increase the channels of clean energy. More robust environmental pollution indicators can also help to elaborate the comprehensive picture of the climate. Concerning the statistical methodology, the single country analysis for developing nations seems more beneficial for policymakers.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material; further inquiries can be directed to the corresponding author.

Author contributions

YW: conceptualizing, writing, and drafting—original draft. WG: conceptualizing and writing—original draft. LL: conceptualizing and writing—original draft. XM: Data and empirical estimations.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors, and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

Abdouli, M., and Hammami, S. (2017). The impact of FDI inflows and environmental quality on economic growth: An empirical study for the MENA countries. *J. Knowl. Econ.* 8 (1), 254–278. doi:10.1007/s13132-015-0323-y

Adewuyi, A. O., and Awodumi, O. B. (2017). Biomass energy consumption, economic growth and carbon emissions: Fresh evidence from west Africa using a simultaneous equation model. *Energy* 119, 453–471. doi:10.1016/j.energy.2016.12.059

Afshan, S., and Yaqoob, T. (2022). The potency of eco-innovation, natural resource and financial development on ecological footprint: A quantile-ARDL-based evidence from China. *Environ. Sci. Pollut. Res.* 29, 50675–50685. doi:10.1007/s11356-022-19471-w

Ajmi, A. N., and Inglesi-Lotz, R. (2020). Biomass energy consumption and economic growth nexus in OECD countries: A panel analysis. *Renew. Energy* 162, 1649–1654. doi:10.1016/j.renene.2020.10.002

Al-Mulali, U., Saboori, B., and Ozturk, I. (2015a). Investigating the environmental Kuznets curve hypothesis in Vietnam. *Energy policy* 76, 123–131. doi:10.1016/j.enpol.2014.11.019

Al-Mulali, U., and Tang, C. F. (2013). Investigating the validity of pollution haven hypothesis in the gulf cooperation council (GCC) countries. *Energy Policy* 60, 813–819. doi:10.1016/j.enpol.2013.05.055

Al-Mulali, U., Weng-Wai, C., Sheau-Ting, L., and Mohammed, A. H. (2015b). Investigating the environmental Kuznets curve (EKC) hypothesis by utilizing the ecological footprint as an indicator of environmental degradation. *Ecol. Indic.* 48, 315–323. doi:10.1016/j.ecolind.2014.08.029

Ali, H. S., Law, S. H., Yusop, Z., and Chin, L. (2017). Dynamic implication of biomass energy consumption on economic growth in sub-saharan africa: Evidence from panel data analysis. *GeoJournal* 82, 493–502. doi:10.1007/s10708-016-9698-y

Alvarez-Herranz, A., Balsalobre-Lorente, D., Shahbaz, M., and Cantos, J. M. (2017). Energy innovation and renewable energy consumption in the correction of air pollution levels. *Energy policy* 105, 386–397. doi:10.1016/j.enpol.2017.03.009

Anwar, S., and Nguyen, L. P. (2010). Foreign direct investment and economic growth in Vietnam. *Asia Pac. Bus. Rev.* 16 (1-2), 183–202. doi:10.1080/10438590802511031

Aydin, F. F. (2018). D-8 ülkelerinde biyokütle enerjisi tüketimi ile ekonomik büyüme arasındaki i?lişki. *Anemon Mus. Alparslan Univ. Sos. Bilim. Derg.* 6 (3), 371–377. doi:10.18506/anemon.373532

Aydin, M., and Turan, Y, E. (2020). The influence of financial openness, trade openness, and energy intensity on ecological footprint: Revisiting the environmental Kuznets curve hypothesis for BRICS countries. *Environ. Sci. Pollut. Res.* 27, 43233–43245. doi:10.1007/s11356-020-10238-9

Bakhsh, K., Rose, S., Ali, M. F., Ahmad, N., and Shahbaz, M. (2017). Economic growth, CO2 emissions, renewable waste and FDI relation in Pakistan: New evidences from 3SLS. *J. Environ. Manag.* 196, 627–632. doi:10.1016/j.jenvman.2017.03.029

Baležentis, T., Streimikiene, D., Zhang, T., and Liobikiene, G. (2019). The role of bioenergy in greenhouse gas emission reduction in EU countries: An Environmental Kuznets Curve modelling. *Resour. Conservation Recycl.* 142, 225–231. doi:10.1016/j.resconrec.2018.12.019

Baloch, M. A., ZhangIqbal, K., and Iqbal, Z. (2019). The effect of financial development on ecological footprint in BRI countries: Evidence from panel data estimation. *Environ. Sci. Pollut. Res.* 26, 6199–6208. doi:10.1007/s11356-018-3992-9

Barış-Tüzemen, Ö., and Tüzemen, S. (2022). The impact of foreign direct investment and biomass energy consumption on pollution in BRICS countries: A panel data analysis. *Glob. J. Emerg. Mark. Econ.* 14 (1), 76–92. doi:10.1177/09749101211067092

Bildirici, M., and Ersin, O. (2015). An investigation of the relationship between the biomass energy consumption. economic growth and oil prices. *Procedia - Soc. Behav. Sci.* 210, 203–212. doi:10.1016/j.sbspro.2015.11.360

Bilgili, F., and Ozturk, I. (2015). Biomass energy and economic growth nexus in G7 countries: Evidence from dynamic panel data. *Renew. Sustain. Energy Rev.* 49, 132–138. doi:10.1016/j.rser.2015.04.098

Bilgili, F., Öztürk, İ., Koçak, E., Bulut, Ü., Pamuk, Y., Muğaloğlu, E., et al. (2016). The influence of biomass energy consumption on CO2 emissions: A wavelet coherence approach. *Environ. Sci. Pollut. Res.* 23 (19), 19043–19061. doi:10.1007/s11356-016-7094-2

Cherni, A., and Jouini, S. E. (2017). An ARDL approach to the CO2 emissions, renewable energy and economic growth nexus: Tunisian evidence. *Int. J. Hydrogen Energy* 42 (48), 29056–29066. doi:10.1016/j.ijhydene.2017.08.072

Chien, F., Anwar, A., Hsu, C. C., Sharif, A., Razzaq, A., and Sinha, A. (2021). The role of information and communication technology in encountering environmental degradation: Proposing an SDG framework for the BRICS countries. *Technol. Soc.* 65, 101587. doi:10.1016/j.techsoc.2021.101587

Copeland, B. R., and Taylor, M. S. (2013). *Trade and the environment*. New Jersey, United States: Princeton university press.

Danish (2021). Nexus between biomass energy consumption and environment in OECD countries: A panel data analysis. *BIOMASS Convers. BIOREFINERY*. doi:10.1007/s13399-020-01256-1

Danish, and Wang, Zhaohua (2019). Does biomass energy consumption help to control environmental pollution? Evidence from BRICS countries. *Sci. Total Environ.* 670, 1075–1083. doi:10.1016/j.scitotenv.2019.03.268

Destek, M. A., and Aslan, A. (2017). Renewable and nonrenewable energy consumption and economic growth in emerging economies: Evidence from bootstrap panel causality. *Renew. Energy* 111, 757–763. doi:10.1016/j.renene.2017.05.008

Dogan, E., and Inglesi-Lotz, R. (2017). Analyzing the effects of real income and biomass energy consumption on carbon dioxide (CO2) emissions: Empirical evidence from the panel of biomass-consuming countries. *Energy* 138, 721–727. doi:10.1016/j.energy.2017.07.136

Dogan, E., and Ozturk, I. (2017). The influence of renewable and nonrenewable energy consumption and real income on CO2 emissions in the USA: Evidence from structural break tests. *Environ. Sci. Pollut. Res.* 24 (11), 10846–10854. doi:10.1007/s11356-017-8786-y

Dong, K., Sun, R., and Dong, X. (2018). CO2 emissions, natural gas and renewables, economic growth: Assessing the evidence from China. *Sci. Total Environ.* 640, 293–302. doi:10.1016/j.scitotenv.2018.05.322

Gallagher, K. P. (2009). Economic globalization and the environment. *Annu. Rev. Environ. Resour.* 34 (1), 279–304. doi:10.1146/annurev.environ.33.021407.092325

Grossman, G. M., and Krueger, A. B. (1991). Environmental impacts of a North American free trade agreement. *Work. Pap. Ser. No* 3914, 1–57.

Hakro, A. N., and Ghumro, A. A. (2007). *Foreign direct investment, determinants and policy analysis: Case study of Pakistan*. University of Glasgow: Department of Economics.

Hughes, T. P., Kerry, J. T., Álvarez-Noriega, M., Álvarez-Romero, J. G., Anderson, K. D., Baird, A. H., et al. (2017). Global warming and recurrent mass bleaching of corals. *Nature* 543 (7645), 373–377. doi:10.1038/nature21707

International Energy Agency (2018). World energy outlook

Jianguo, D., Ali, K., Alnori, F., and Ullah, S. (2022). The nexus of financial development, technological innovation, institutional quality, and environmental quality: Evidence from OECD economies. *Environ. Sci. Pollut. Res.* 29, 58179–58200. doi:10.1007/s11356-022-19763-1

Katircioglu, S. T. (2015). The impact of biomass consumption on CO2 emissions: An empirical investigation from Turkey. *Int. J. Clim. Change Strategies Manag.* 7, 348–358. doi:10.1108/ijccsm-06-2014-0077

Keeley, A., and Ikeda, Y. (2017). Determinants of foreign direct investment in wind energy in developing countries. *J. Clean. Prod.* 161, 1451–1458. doi:10.1016/j.jclepro.2017.05.106

Khan, Z., Ali, S., Umar, M., Kirikkaleli, D., and Jiao, Z. (2020). Consumption-based carbon emissions and international trade in G7 countries: The role of environmental innovation and renewable energy. *Sci. Total Environ.* 730, 138945. doi:10.1016/j.scitotenv.2020.138945

Koçak, E., and Şarkgüneşi, A. (2018). The impact of foreign direct investment on CO2 emissions in Turkey: New evidence from cointegration and bootstrap causality analysis. *Environ. Sci. Pollut. Res.* 25 (1), 790–804. doi:10.1007/s11356-017-0468-2

Kongbuamai, N., Bui, Q., Yousaf, H, M, A., and Liu, Y. (2020). The impact of tourism and natural resources on the ecological footprint: A case study of ASEAN countries. *Environ. Sci. Pollut. Res.* 27, 19251–19264. doi:10.1007/s11356-020-08582-x

Lau, L. S., Choong, C. K., and Eng, Y. K. (2014). Investigation of the environmental Kuznets curve for carbon emissions in Malaysia: Do foreign direct investment and trade matter? *Energy policy* 68, 490–497. doi:10.1016/j.enpol.2014.01.002

Lee, J. W. (2013). The contribution of foreign direct investment to clean energy use, carbon emissions and economic growth. *Energy policy* 55, 483–489. doi:10.1016/j.enpol.2012.12.039

Liu, K., and Lin, B. (2019). Research on influencing factors of environmental pollution in China: A spatial econometric analysis. *J. Clean. Prod.* 206, 356–364. doi:10.1016/j.jclepro.2018.09.194

Liu, Y., Hao, Y., and Gao, Y. (2017). The environmental consequences of domestic and foreign investment: Evidence from China. *Energy Policy* 108, 271–280. doi:10.1016/j.enpol.2017.05.055

Nguyen, A. N., and Nguyen, T. (2007). Foreign direct investment in Vietnam: An overview and analysis the determinants of spatial distribution across provinces. Available at SSRN 999550.

OECD (2021). Air and GHG emissions. Available at https://doi.org/10.1787/93d10cf7-en.

Omri, A., Nguyen, D. K., and Rault, C. (2014). Causal interactions between CO2 emissions, FDI, and economic growth: Evidence from dynamic simultaneous-equation models. *Econ. Model.* 42, 382–389. doi:10.1016/j.econmod.2014.07.026

Owusu, P. A., and Asumadu-Sarkodie, S. (2016). A review of renewable energy sources, sustainability issues and climate change mitigation. *Cogent Eng.* 3 (1), 1167990. doi:10.1080/23311916.2016.1167990

Ozturk, I., and Bilgili, F. (2015). Economic growth and biomass consumption nexus: Dynamic panel analysis for Sub-Sahara African countries. *Appl. Energy* 137, 110–116. doi:10.1016/j.apenergy.2014.10.017

Panayotou, T. (1993). Empirical tests and policy analysis of environmental degradation at different stages of economic development. *ILO Work. Pap.*

Paramati, S. R., Ummalla, M., and Apergis, N. (2016). The effect of foreign direct investment and stock market growth on clean energy use across a panel of emerging market economies. *Energy Econ.* 56, 29–41. doi:10.1016/j.eneco.2016.02.008

Pesaran, M. H. (2007). A simple panel unit root test in the presence of cross-section dependence. *J. Appl. Econ. Chichester. Engl.* 22 (2), 265–312. doi:10.1002/jae.951

Pesaran, M. H. (2021). General diagnostic tests for cross-sectional dependence in panels. *Empir. Econ.* 60 (1), 13–50. doi:10.1007/s00181-020-01875-7

Reinhardt, G. A., and Von Falkenstein, E. (2011). Environmental assessment of biofuels for transport and the aspects of land use competition. *biomass bioenergy* 35 (6), 2315–2322. doi:10.1016/j.biombioe.2010.10.036

Sarkodie, S. A., and Strezov, V. (2019). A review on environmental Kuznets curve hypothesis using bibliometric and meta-analysis. *Sci. total Environ.* 649, 128–145. doi:10.1016/j.scitotenv.2018.08.276

Shahbaz, M., Balsalobre, D., and Shahzad, S. J. H. (2019). The influencing factors of CO2 emissions and the role of biomass energy consumption: Statistical experience from G-7 countries. *Environ. Model. Assess. (Dordr).* 24 (2), 143–161. doi:10.1007/s10666-018-9620-8

Shahbaz, M., Nasreen, S., Abbas, F., and Anis, O. (2015). Does foreign direct investment impede environmental quality in high-middle-and low-income countries? *Energy Econ.* 51, 275–287. doi:10.1016/j.eneco.2015.06.014

Shahbaz, M., and Sinha, A. (2019). Environmental Kuznets curve for CO2 emissions: A literature survey. *J. Econ. Stud.* 46 (1), 106–168. doi:10.1108/jes-09-2017-0249

Shahbaz, M., Solarin, S. A., Hammoudeh, S., and Shahzad, S. J. H. (2017). Bounds testing approach to analyzing the environment Kuznets curve hypothesis with structural beaks: The role of biomass energy consumption in the United States. *Energy Econ.* 68, 548–565. doi:10.1016/j.eneco.2017.10.004

Sinha, A., Shahbaz, M., and Balsalobre, D. (2017). Exploring the relationship between energy usage segregation and environmental degradation in N-11 countries. *J. Clean. Prod.* 168, 1217–1229. doi:10.1016/j.jclepro.2017.09.071

Solarin, S. A., Al-Mulali, U., Gan, G. G. G., and Shahbaz, M. (2018). The impact of biomass energy consumption on pollution: Evidence from 80 developed and developing countries. *Environ. Sci. Pollut. Res.* 25 (23), 22641–22657. doi:10.1007/s11356-018-2392-5

Sun, Y., Anwar, A., Razzaq, A., Liang, X., and Siddique, M. (2022a). Asymmetric role of renewable energy, green innovation, and globalization in deriving environmental sustainability: Evidence from top-10 polluted countries. *Renew. Energy* 185, 280–290. doi:10.1016/j.renene.2021.12.038

Sun, Y., Guan, W., Razzaq, A., Shahzad, M., and An, N. (2022b). Transition towards ecological sustainability through fiscal decentralization, renewable energy and green investment in OECD countries. *Renew. Energy* 190, 385–395. doi:10.1016/j.renene.2022.03.099

Sun, Y., and Razzaq, A. (2022). Composite fiscal decentralisation and green innovation: Imperative strategy for institutional reforms and sustainable development in OECD countries. *Sustain. Dev.*, 1–14. doi:10.1002/sd.2292

Sun, Y., Razzaq, A., Sun, H., and Irfan, M. (2022c). The asymmetric influence of renewable energy and green innovation on carbon neutrality in China: Analysis from non-linear ARDL model. *Renew. Energy* 193, 334–343. doi:10.1016/j.renene.2022.04.159

Tiba, S., and Omri, A. (2017). Literature survey on the relationships between energy, environment and economic growth. *Renew. Sustain. Energy Rev.* 69, 1129–1146. doi:10.1016/j.rser.2016.09.113

Ulucak, R., and Khan, S. U. D. (2020). Does information and communication technology affect CO2 mitigation under the pathway of sustainable development during the mode of globalization? *Sustain. Dev.* 28 (4), 857–867. doi:10.1002/sd.2041

World Bioenergy Association (2018). Global bioenergy statistics.

Zaman, K., bin Abdullah, A., Khan, A., bin Mohd Nasir, M. R., Hamzah, T. A. A. T., and Hussain, S. (2016). Dynamic linkages among energy consumption, environment, health and wealth in BRICS countries: Green growth key to sustainable development. *Renew. Sustain. Energy Rev.* 56, 1263–1271. doi:10.1016/j.rser.2015.12.010

Zhang, B., Wang, B., and Wang, Z. (2017). Role of renewable energy and nonrenewable energy consumption on EKC: Evidence from Pakistan. *J. Clean. Prod.* 156, 855–864. doi:10.1016/j.jclepro.2017.03.203