Environmental Science and Pollution Research
https://doi.org/10.1007/s11356-023-25428-4

RESEARCH ARTICLE

The role of renewable energy consumption on environmental degradation in EU countries: do institutional quality, technological innovation, and GDP matter?

Nooshin Karimi Alavijeh[1] · Mohammad Taher Ahmadi Shadmehri[1] · Nazia Nazeer[2] · Samane Zangoei[1] · Fatemeh Dehdar[3]

Received: 25 August 2022 / Accepted: 16 January 2023

Abstract
In the face of climate change and environmental degradation, reducing emission of greenhouse gases has become a key factor for environmental sustainability. Therefore, the present research is intended to explore the roles of renewable energy consumption, institutional quality, technological innovation, and GDP on carbon dioxide emissions in the 14 EU countries. In doing so, this study employed novel method of moments quantile regression (MMQR) using annual data from 2000 to 2019. Also, a number of other estimators were applied for robustness check including the fully modified ordinary least square (FMOLS), the dynamic ordinary least squares (DOLS), and the fixed effect ordinary least square (FE-OLS). The empirical findings indicate that renewable energy consumption significantly reduces CO_2 emissions across all quantiles (0.1–0.9). Furthermore, institutional quality and technological innovation improve environmental quality in 0.1–0.7 quantiles, although GDP enhances carbon emissions significantly in all quantiles. In addition, the FMOLS, DOLS, and FE-OLS results confirmed the MMQR results. The outcomes of this study suggest insights for the policymakers to mitigate carbon emissions through promoting innovative technologies for environmental protection and investing more in the development of renewable energy.

Keywords Renewable energy · CO_2 emissions · Governance · R&D · MMQR

Introduction

Countries consume more energy to achieve economic growth and they are using almost 85% of fossil fuels to increase production, which is responsible for 57% of carbon emissions around the global (Mehmood 2021). Environmental degradation has become a concern of researchers rather recently. CO_2 emissions, the major component of greenhouse gas that drives global climate change, have been rising in the last few decades. Environmental issues are challenges not only in Europe but also all over the world. So, it is necessary to examine all dimensions related to this problem. The response of the European Union Commission is the European Green Deal that should reduce 55% of greenhouse gas emissions to zero by 2030 compared with 1990 levels. Almost 2.54 billion metric tons of carbon emissions have been produced by The European Union in 2020 (Nazarko et al. 2022). CO_2 produced by human activities is a primary cause of global warming. Climate change affects all regions around the world. The effects of CO_2 emissions are summarized in Fig. 1 (Ali et al. 2020a, b).

Responsible Editor: Eyup Dogan

✉ Mohammad Taher Ahmadi Shadmehri
shadmhri@um.ac.ir

Nooshin Karimi Alavijeh
n.karimialavijeh@mail.um.ac.ir

Nazia Nazeer
nazia.nazeer@nu.edu.pk

Samane Zangoei
samane.zangoei@mail.um.ac.ir

Fatemeh Dehdar
fatemeh@fe.uc.pt

1 Department of Economics, Faculty of Economics and Administrative Sciences, Ferdowsi University of Mashhad, Mashhad, Iran

2 FAST School of Management, National University of Computer and Emerging Sciences, Karachi, Pakistan

3 Faculty of Economics, University of Coimbra, 3004-512 Coimbra, Portugal

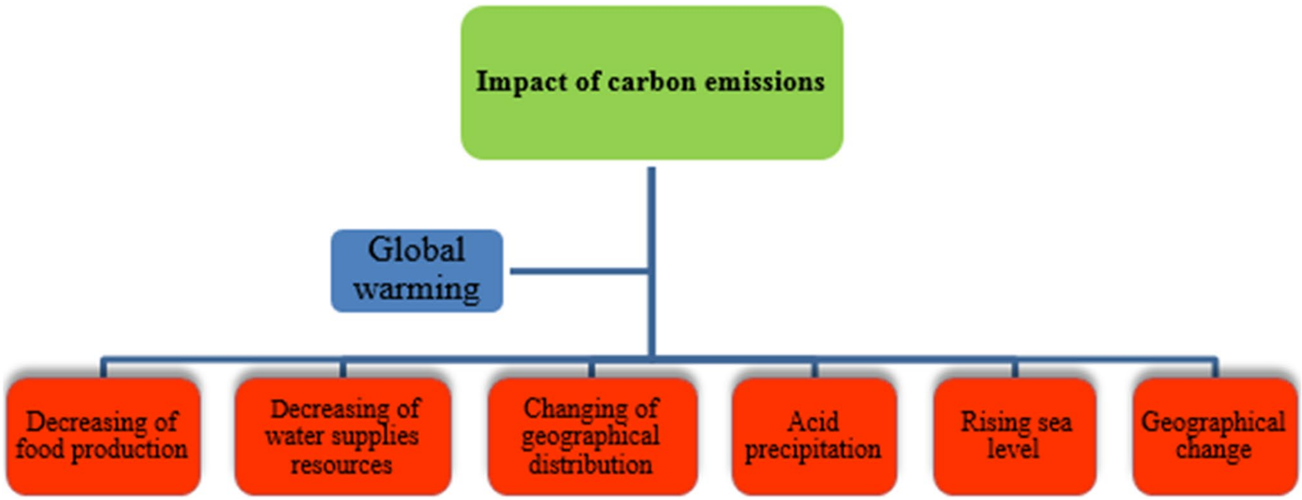

Fig. 1 Impacts carbon emissions on the environment. The authors created this figure

One possible solution for reducing the harmful impact of CO_2 emission is using renewable energy. Previous studies showed that this solution is better than others because it is not an obstacle to economic growth (Balsalobre-Lorente et al. 2018; Lee et al. 2021), and it has also less pressure on the environment (Sarkodie and Strezov 2019; Ben Jebli et al. 2019). Renewable energy has a significant role in energy independence. Concerning the relation between environmental degradation and the use of renewable energy, several researchers have demonstrated a negative linkage (Arain et al. 2020; Kirikkaleli and Adebayo 2021b). The adverse effects of renewable energy on the environment are due to old technologies and poor transmission systems (Mahjabeen et al. 2020). So, the adverse effects of renewable energy can be minimized by adopting efficient technology (Shahzad et al. 2017).

On the other side, another factor affecting the environmental quality is the existence of institutions with proper functioning. The significant benefits of institutional quality for environmental quality have been examined by several studies and most of them show that institutional quality reduces CO_2 emissions (Ali et al. 2019a, 2020a, b; Wang et al. 2017). A paper conducted by Hasnisah et al. (2019) shows that appropriate institutional policies are extremely important to achieving long-term climate goals. Institutional quality can support the private sector and property rights. It can also enhance the quality of contract execution, strong rule of law, and impartiality. On the contrary, weak institutions harm the private sector and exacerbate corruption and make a poor regulatory environment (Dehdar et al. 2020; Salman et al. 2019).

Technology innovation has a considerable role in reducing carbon dioxide emissions and increasing economic development (Abdallh and Abugamos 2017). Technological advancement increases economic growth and productivity and can help to decrease environmental degradation (He et al. 2021; Mensah et al. 2018). So, another solution for developing economic growth and environmental quality is technology innovation (Dauda et al. 2019). It can also pave the way for a low-carbon economy through the development of renewable energy (Kihombo et al. 2021) and accelerate energy transition (Lin and Zhu 2019). Many papers studied the relationship between environmental degradation and technological innovation (Rjoub et al. 2021; Umar et al. 2020; Ahmed et al. 2019). Even though the results are inconclusive, for example, Wang et al. (2020), Khan et al. (2019), and Yii and Geetha (2017) concluded that technological innovation improves environmental quality. Compared to other studies, Kirikkaleli (2020) and Ali et al. (2020a, b) reported that technology innovation deteriorates ecological quality.

According to the above explanations, the objectives of this paper are to examine the asymmetric impacts of renewable energy consumption, institutional quality, technological innovation, and GDP on carbon emissions using the method of moments quantile regression (MMQR) for the EU countries from 2000 to 2019. Although several researchers have studied the determinants of environmental degradation, the novelty of the present research is that few studies have paid attention to the position of the governance index as a proxy for institutional quality in CO_2 emissions. In most papers, democracy is considered as a proxy of institutional quality (You et al. 2020), but this study uses a governance index consisting of six elements: (1) government effectiveness, (2) corruption control, (3) rule of law, (4) supervision quality, (5) political stability, and (6) right to comment. Also, in this study, the method of moments quantile regression has been used to inquire about the asymmetric impacts of renewable energy, institutional quality, technological innovation, and GDP on carbon emissions. Using this method gives a complete image of the conditional distribution compared to traditional panel methods (FE-OLS, FMOLS, and DOLS techniques). This paper focuses on EU countries for some reasons. The European Union is one of the net importers of fossil fuels and the quality of the environment is an important issue for them, so they are trying to reduce CO_2 emissions (Shahnazi and Shabani 2021; Mongo et al. 2021). Greenhouse gas (GHG) emissions in EU countries decreased by 5.8% or almost 2 billion tons of carbon emissions in 2020. Despite the reduction of GHG emissions in EU countries in 2020, the global CO_2 emissions reached 31.5 GT, the average annual concentration of which increased to the highest volume of 412.5 parts per million in 2020, which is about 50% higher than at the beginning of the industrial revolution (IEA 2020). Also, according to Eurostat data, the renewable energy share in the energy consumed in EU countries in 2019 was 19.7%, which is 3% less than the target in 2020 (20%). In 2020, renewable energy accounted for 22.1% of the energy consumed in the EU, which was about 2% higher than the 2020 target of 20% (EPRS 2021). The leading country in the utilization of renewable energy is Sweden among the European Union, which accounted for 53% of its total energy consumption in 2019. Finland (46%), Latvia (41%), Denmark (37%), Austria (34%), Lithuania (33%), Croatia (32%), and Estonia (31%) were in the subsequent positions (WDI 2022). Thus, promoting the use of renewable energy sources can lead to the achievement of the goals of combating environmental degradation and global warming. In fact, this study seeks to answer this question: What factors cause carbon emissions and environmental degradation in EU countries? This paper is also in line with the United Nations Sustainable Development Goals (SDGs), namely, affordable and clean energy, climate action, and strong institutions (goal 7, 13, and 16), which can assist legislators in formulating long-term plans.

The results in this research show that renewable energy consumption, institutional quality, and technological innovation play a significant role in the improvement of environmental quality, while the increase in economic growth creates more environmental compression on EU countries. This study's results can help policymakers in designing effective environmental policies for EU countries to achieve environmental sustainability.

After a primary introduction, "Review literature" includes details about the relationship between variables and a literature review of the analysis. The methods and material used in the paper are stated in "Methods and material." "Results and discussion" indicates the results and discussion. Finally, "Conclusions and policy implications" summarizes the conclusions and policy implications.

Review literature

Theoretical literature

Factors affecting CO_2 emissions have attracted much attention in the literature of energy and environmental economics. Renewable energy use has been considered an important factor in the CO_2 function in papers. Governments promote to use of alternative energies because of energy shortage, global warming, climate change, and energy efficiency. So, studies in renewable energy are growing rapidly among researchers (Adebayo et al. 2022c). Renewable energy plays a significant role in countries that aimed to achieve sustainable development and increase environmental quality. Based on many studies, the use of renewable energy has a favorable effect on the long-run environmental consequences of emissions (Rodriguez-Alvarez 2021). A significant number of studies suggested that renewable energy helps in decreasing the degradation of the environment (Tufail et al. 2021; Adedoyin et al. 2021; Cheng et al. 2021a, b; Mahalik et al. 2021; Cevik et al. 2021).

Institutional quality is another factor in the carbon emissions function. Strong institutional frameworks have played a fundamental catalyst in achieving sustainable development. Effective institutions with efficient governments can increase environmental quality when environmental restrictions are applied rigidly and suitable legislation can improve air quality (Mehmood et al. 2021). Institutional weakness restricts the performance of government in devoting productive components, human and physical capital that eventually worsen the safety of the environment (Islam et al. 2021). Some studies have examined the link between institutional quality and CO_2 emissions (Apergis and Ozturk 2015; Ozturk and Al-Mulali 2015; Gholipour and Farzanegan 2018).

Another factor affecting CO_2 emissions is technological innovation. Technological innovation is an effective way to attain energy conservation and reduce pollution. It is useful for both traditional fossil energy and renewable energy. For fossil fuel energy, technological innovation can enhance energy efficiency in the production process and save energy consumption and then decrease air pollution. For renewable energy, technological innovation can improve the production process by gaining more knowledge and increasing the technological level of renewable energy and then promote the development of renewable energy which is free of CO_2 emissions (Chen and Lei 2018). By understanding the importance of technological innovation for CO_2 emission diminution, some scholars paid more attention to investigating the relationship between them (Bai et al. 2020; Cheng et al. 2019; Song et al. 2019; Chen et al. 2018).

Finally, the relationship between economic growth (GDP) and carbon emissions have been very important among researchers. Based on the environmental Kuznets curve (EKC) hypothesis, the interrelationship between economic growth and emissions can be classified into three stages (Grossman and Krueger 1991). The first stage is the scale effect, which represents the first step in the development of countries and emphasizes the importance of economic growth, so the production of waste and pollution increases. The next stage is the composition effect that indicates the second trajectory of countries and achieves some sort of economic growth and environmental consciousness is also awakened. In this stage, environmental degradation declines because the turning point threshold has been achieved. The last stage is a technique that can be used as a channel for increasing R&D activities on cleaner technologies and using renewable energy, especially from developed countries (Shahbaz and Sinha 2019; Soylu et al. 2021).

Empirical literature

In this subsection, previous papers are studied in four subsections. In the first part, the literature review on the relation between renewable energy usage and environmental degradation is discussed. In the following, previous studies about institutional quality and CO_2 emissions have been investigated. In the third subsection, the relationship among technological innovation and environmental degradation is discussed. Lastly, the literature about the relationship between GDP and environmental degradation has been reviewed.

Renewable energy and environmental degradation

Energy plays a vital role in economic production and renewable energy is one of the best substitutes for fossil fuels because it is a low-carbon energy source and environmentally friendly. A large number of scholars have perused the effects of renewable energy usage on carbon dioxide emissions. For example, Paramati et al. (2017) examined the relation between the use of renewable energy and CO_2 emissions in developing countries based on data from 1990 to 2012. The study used robust panel models. The outcomes show that renewable energy has harmful impacts on the environment. Dong et al. (2018a) have studied the relations between CO_2 emissions, renewable energy, population, and GDP in 128 countries from six regions for 1990–2014. The empirical results showed that use of renewable energy makes decreases in carbon emissions. In another study, Dong et al. (2018b) tested the dynamic impact of renewable energy on carbon emissions in China for the period 1965–2016. The results indicated that the effective use of renewable energy enhances environmental quality. A study has conducted by Lin and Zhu (2019) in Chinese provinces from 2000 to 2015 indicated that renewable energy has an important role in improving energy security. By using PSTR method, Alqaralleh (2021) demonstrated that use of renewable energy decreases CO_2 emissions in countries with high income for 2000–2018. Salahodjaev et al. (2022) investigated the link between renewable energy and CO_2 emission using the GMM method in Europe and Central Asia countries during 1990–2015. The results displayed that renewable energy declines carbon emissions in those regions. Khan et al. (2022) have estimated the relation between renewable energy and CO_2 emissions in low and high income countries from 2000 to 2019. The outcomes indicated that renewable energy consumption reduces carbon emissions. By using FMOLS, Rasheed et al. (2022) have examined the impacts of renewable energy on carbon emissions from 1997 to 2017. The results illustrated that renewable energy improve environmental quality in European countries. Adebayo et al. (2022a, b, c, d) used the quantile-on-quantile method to study the role renewable energy on environmental degradation in Sweden for 1965–2019. They demonstrated that the use of renewable energy has a negative effect on CO_2 emissions. With using ARDL model for Nigeria, Usman (2022) conducted that there is a positive link between renewable energy and environmental quality in Nigeria from 1990 to 2016. Awan et al. (2022) investigated the relation between renewable energy development and CO_2 emissions emerging countries from 1996 to 2015. The results illustrated that carbon emissions decrease when the use of renewable energy increases.

Institutional quality and environmental degradation

Institutional quality has become an important issue among policymakers, economists, and scientists recently. Many studies have examined this subject and its effects on environmental destruction. The efficient impact of institutions depends on whether quality institutions and good governance exist in society or not because robust rules enforce organizations to control the amount of CO_2 emissions and install suitable appropriate infrastructure. By contrast, weak institutions can allow companies to break environmental quality rules to increase their profit (Salman et al. 2019).

Several researchers have paid attention to the negative effect of institutional quality and CO_2 emissions (Wang et al. 2018; Ali et al. 2020a, b). For example, Abid (2016) investigated the importance of financial, economic, and institutional quality for the environment. The study tested this hypothesis in 58 Middle East and Africa and 41 European Union countries from 1990 to 2011 with the GMM system method. The empirical results show for sustainable development and a quality environment, policymakers should enhance the efficiency and role of domestic institutions. In another paper, Bhattacharya et al. (2017) studied the effect of institutional quality in reducing CO_2 emissions across 58 countries during 1991–2012 by using the GMM and OLS approaches. The results showed that institutional quality is important in reducing carbon emissions. Ali et al. (2019a, b) stated how institutional quality can reduce CO_2 emissions and the government should train people about preventing environmental degradation. The study used time series data from 1972 to 2014 by employing auto regressive distributed lag (ARDL) approach. Also, Salman et al. (2019) explored the effects of institutional quality on CO_2 emissions in East Asian countries (Indonesia, Thailand, and South Korea) for the time from 1990 to 2016 using FOLMS and DOLS methods. Findings show that domestic institutions can reduce CO_2 emissions. Arminen and Menegaki (2019) examined the relationship between corruption, as an institutional quality index, and CO_2 emissions in high-middle-income countries with simultaneous equations modeling during 1985–2011. The outcomes indicated that institutional quality did not have the effect on environmental degradation. By using FMOLS, ARDL, and DOLS models, Mahjabeen et al. (2020) explored the role of stability in institutions on environmental quality based on data in D-8 countries over the period from 1990 to 2016. The empirical outcomes show that there is a positive connection between institutional quality and CO_2 emissions. With using the QARDL method, Godil et al. (2020) displayed that there is a positive impact between institutional quality and CO_2 emissions in Pakistan from 1951Q1 to 2018Q4. By applying SYS-GMM method, Azam et al. (2021) have estimated the impact of institutional quality on CO_2 emissions by focusing on 66 developing countries in during 1991–2017. They found the positive relation between institutional quality and the environmental index. By using the finite mixture model, Wang and Yang (2022) concluded that government stability, bureaucracy quality, and law and order can effect on the CO_2 emissions. Yang et al. (2022) indicated the effect of institutional quality on carbon emissions in developing countries. They used the Driscoll–Kraay regression based on the data from 1984 to 2016. The outcomes show that an increase in institutional quality enhances CO_2 emissions.

Technological innovation and environmental degradation

Technological advancements have contributed to countries providing a pathway to decreasing carbon emissions and benefit countries' use of renewable resources. The role of technological innovation in environmental quality has also been investigated by several scholars (Khan et al. 2021). For example, Yii and Geetha (2017) investigated the nexus between technology innovation and carbon emissions in Malaysia from 1971 to 2013. For the sake of the analytical approaches, they implement VECM as well as TYDL Granger causality tests. Their results indicated that technology innovation has the negative effect on environmental quality. By using augmented mean group, Wang et al. (2020) estimated the impacts of technological innovations on carbon emissions in N-11 countries. Based on the results, technological innovation reduces CO_2 emissions. Rafique et al. (2020) evaluated the effects of technological innovation on environmental degradation in BRICS using the AMG and FMOLS approach from 1990 to 2017. The results illustrated that technological innovation increases environmental quality. Khan et al. (2020) have explored the nexus between technological innovations and environmental sustainability in BRICS over the time 1985–2014. AMG and FM-LS methods had been utilized. The outcomes confirmed that technological innovation diminishes emissions in BRICS. By using the PMG/ARDL method, Baloch et al. (2021) estimated the role of energy innovation on carbon emissions for OECD countries from 1990 to 2017. The empirical results show that energy innovation makes a quality improvement of the environment. Mohamued et al. (2021) analyzed the effects of innovations and oil prices on CO_2 emissions. This is a comparative study between oil-producing countries, European Union countries, China, and the United States of America for the period 1991–2015. The finding showed that innovation reduces carbon emissions in oil-importing economies, while innovation causes air pollution in oil-exporting economies. Lin and Ma (2022) investigated the relation between the technology innovation and environmental degradation in developing countries from 2006 to 2017 by using partially linear functional–coefficient models. The empirical results showed that technology innovations decrease carbon emissions. Raihan et al. (2022) studied the relation between technological innovation and carbon emissions in Malaysia from 1990 to 2019 by using the DOLS model and found that technological innovation enhances environmental quality. As stated several studies that show technological innovations can save energy and decrease carbon emissions but some other researchers believe that technological innovations cannot improve energy efficiency alone (Liu et al. 2019; Gu et al. 2019). For instance, Khan et al. (2019) demonstrated the impact of technological innovation on environmental quality in Pakistan by utilizing the dynamic ARDL method. Their results showed technological innovation hurt environmental quality in Pakistan. Adebayo et al. (2021a, b) used a non-linear ARDL approach to survey the link between carbon emissions and technological innovation in Chile based on data from 1990 to 2018. They found an ineffective effect of technological innovation on carbon emissions because technological innovation encourages economic motivation instead of green technology.

GDP and environmental degradation

Examining the relations between economic growth and carbon emissions is so important for policymakers and governments to formulate energy policies in sustainable ways (Mardani et al. 2019). For instance, Bekhet et al. (2017) explored the relation between carbon emissions and economic growth from 1980 to 2011. The results indicated that economic growth enhanced environmental degradation in Bahrain, Qatar, Oman, and Saudi Arabia. Mahmood et al. (2019) investigated the impacts of GDP on CO_2 emissions. The study employed 3SLS regression in Pakistan from 1980 to 2014. The results indicated that there was the KEC hypothesis. Moreover, GDP can help to form the EKC in Pakistan. Horobet et al. (2021) examined the effect economic growth on CO_2 emissions in EU countries for a period of 23 years (1995–2018). VECM analysis indicated there is a unidirectional link between GDP and carbon emissions. By using DOLS, FMOLS, and PMG approaches, Rahman et al. (2021) explored the relation between GDP and CO_2 emissions in industrialized countries during of 1979–2017. The results indicated that economic growth increase environmental quality. You et al. (2022) explored the impacts of economic growth on environmental degradation for the period 1996–2015. They used panel data from 95 countries. The findings showed that there is two-way causality between economic growth and carbon emissions. Weimin et al. (2022) tried to answer the question that inverted U-shaped hypothesis exists between economic growth and CO_2 emissions in top economies. They have used the data from 1990 to 2019 and have applied dynamic ordinary least squares panel method. The results displayed that economic growth increases environmental quality. Sikder et al. (2022) used the ARDL method to examine the impact GDP on CO_2 emissions for developing countries from 1995 to 2018. The results indicated that carbon emissions are affected by GDP growth. Chikezie Ekwueme et al. (2022) explored the nexus between economic growth and environmental sustainability in Asian countries over 20 years. The results demonstrated that economic growth enhances carbon emissions. By using the ARDL and NARDL methods, Sreenu (2022) investigated the impact of GDP on carbon emissions in India over the period 1990–2020. The results illustrated that economic growth causes more air pollution. With using panel quantile regression, Karimi Alavijeh et al. (2022) showed that the GDP's impact on carbon emissions is positive and significant in the most populous developing countries. Ahmed et al. (2022) highlighted the effect of economic growth on environmental quality. They used the CS-ARDL approach in OECD countries from 1971 to 2020. The results of the analysis showed that economic growth increases CO_2 emissions.

Although various studies have been conducted in different countries and regions to investigate the factors affecting environmental degradation and carbon emissions, but according to our knowledge, no study has investigated the impact of renewable energy along with technological innovation, institutional quality, and GDP on environmental degradation in EU countries. Furthermore, scholars have used different statistical methods to model the four groups as above. Nevertheless, the present paper used the new method of moments quantile regression (MMQR) to estimate the factors affecting environmental degradation in the EU. In other words, the use of MMQR for the analysis of EU-14 data on relevant variables is a major contribution of this study to existing literature.

Methods and material

Panel estimation methods (FE-OLS, FMOLS, DOLS, and MMQR)

This investigation adopts different methods of estimation, namely, fully modified ordinary least square (FMOLS), dynamic ordinary least squares (DOLS), and fixed effect ordinary least square (FE-OLS) for comparative purpose, and the novel method of moments quantile regression (MMQR) as its main estimation method. FMOLS method eliminates deviations from the issue of correlations between independent variables and error terms (Ozturk et al. 2021). This method includes individual intercepts, which allow for heterogeneous serial-correlation, across different individuals in the panel (Pedroni 2004; Anwar et al. 2021).

Introduced by Kao and Chiang (2001), the DOLS method results in an unbiased comparison between FMOLS and OLS estimations in a restricted sample. The foundation of DOLS method is the Monte Carlo simulation, to control endogeneity through the augmented of lag differences. The FE-OLS method is an enhancement over standard errors of Driscoll and Kraay, which was introduced by Driscoll and Kraay (1998). This statistical method is robust with heterogeneity, cross-sectional dependence, and autocorrelation up to a definite lag (Aziz et al. 2020).

Considering the differences across various individuals, the panel quantile regression technique was established by Koenker and Bassett (1978), estimating the conditional median or several quantiles of the response variables relevant to certain values of the exogenous variables. This technique provides a systematic strategy for studying how each determinant influences the dependent variable in the panel of countries across the entire conditional distribution of the dependent variable (Cheng et al. 2021a, b). However, due to the drawbacks of panel quantile regression, the method of moments quantile regression approach was established by Machado and Silva (2019), which takes fixed effects into account, to measure the distributional and heterogeneous effects of multiple quantiles (Adebayo et al. 2022a). The model of MMQR considers the estimation of location-scale conditional quantiles:

$$Y_{it} = \alpha_i + X_{it}^{'}\lambda + \left(\delta_i + Z_{it}^{'}\Phi\right) + U_{it} \tag{1}$$

In Eq. 1, the parameters (α, λ, δ, and Φ) are to be evaluated and $P\{\delta_i + Z_{it}^{'}\Phi > 0\} = 1.$ Z shows a k-vector of recognized parts of X. U_{it} is a random variable, and $X_{it}^{'}$ and U_{it} are independent. U_{it} is normalized to realization the conditions of moment ($E(|U|) = 1$ and $E(U) = 0$). Thus, Eq. 1 illustrates the following:

$$Q_Y\left(\Psi|X_{it}\right) = \left(\alpha_i + \delta_i q(\Psi)\right) + X_{it}^{'}\lambda + Z_{it}^{'}\Phi q(\Psi) \tag{2}$$

In Eq. 2, $\alpha_i + \delta_i q(\Psi) \equiv \alpha_i(\Psi)$ is the effect of distribution at quantile Ψ. The method of moments quantile regression of Eq. 2 is performed by calculating two fixed effects regressions and using a univariate quantile.

Compared to the linear methods including FMOLS and DOLS, and even over the ordinary panel quantile regression, the MMQR method offers a variety of advantages. To point out, one of the drawbacks of linear estimation techniques, which is covered by MMQR method, is that linear methods do not condition the distribution of data, and they only address the means. In fact, in the quantile method, the assumption must be dropped that the variables at the upper tails of the distribution behave as they do at the mean (Alqaralleh 2022). In addition, these methods fail to include unobserved heterogeneity across cross-sections in panel data. Moreover, the ordinary quantile regression suffers from a lack of non-crossing estimates when calculating estimators for multiple percentiles leading to an invalid distribution for the responses (Adebayo et al. 2022b). However, applying MMQR method, estimations do not encounter these issues. MMQR method treats endogeneity and heterogeneity simultaneously; hence, it can offer estimates for non-linear and asymmetric relations between variables (Gómez and Rodríguez 2020; Lingyan et al. 2022; Amegavi 2022).

Model and data

In line with Ajide and Mesagan (2022), Mujtaba et al. (2022), and Obobisa et al. (2022), the following function is specified to investigate the effects of renewable energy consumption, institutional quality, technological innovation, and GDP on environmental degradation in EU-14 countries (Fig. 2) (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, and Sweden):

$$CO2_{it} = f\left(REN_{it}, IQU_{it}, TECH_{it}, GDP_{it}\right) \tag{3}$$

In Eq. 3, CO_2, REN, IQU, TECH, and GDP represent carbon emissions, renewable energy consumption, institutional quality, technological innovation, and gross domestic product, respectively. The number of countries is indicated

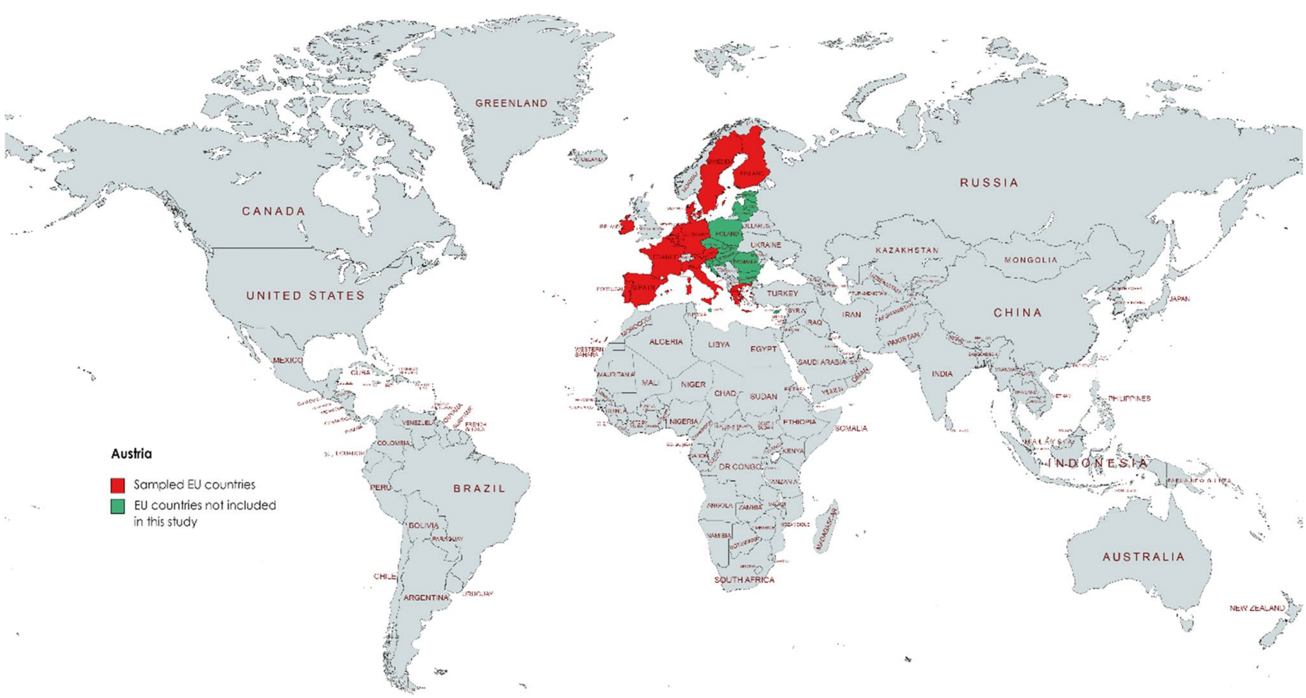

Fig. 2 Map of EU countries. The authors created this figure

by i (from 1 to 14) and t is stated the time period. Thus, Eq. 3 is set as follows:

$$CO2_{it} = \alpha_i + \beta_1 REN_{it} + \beta_2 IQU_{it} + \beta_3 TECH_{it} + \beta_4 GDP_{it} + \xi_t, \quad (4)$$

In Eq. 4, α_i defines the constant term. β_1, β_2, β_3, and β_4 display the long-run elasticities. ξ_t illustrates the error terms. The definition of different variables, symbols, and data source are displayed in Table 1.

In this paper, the goal of using renewable energy consumption, institutional quality, technological innovation, and GDP as a determinants of CO_2 emissions is stated. Following the researches of Saint Akadiri et al. (2020), Salahodjaev et al. (2022), and Rasheed et al. (2022), renewable energy consumption is incorporated in the framework. The relationship between renewable energy consumption and environmental degradation is expected to be negative (i.e., $\beta_1 < 0$). Further, as stated by Ali et al. (2019a, b) and Mehmood et al. (2021), institutional quality will reduce carbon emissions. Thus, institutional quality is expected to decrease environmental degradation (i.e., $\beta_2 > 0$). Also, the relation between technological innovation and environmental degradation is evaluated. As shown by Rafique et al. (2020), Raihan et al. (2022), and Lin and Ma (2022), technological innovation will increase the quality of the environment. Thus, technological innovation is expected to decrease environmental degradation (i.e., $\beta_3 > 0$). Finally, in line with the study of Alola (2019), Kirikkaleli et al. (2021), and Adebayo et al. (2021b), GDP is introduced into the model. The link between GDP and environmental degradation is expected to be positive (i.e., $\beta_4 > 0$).

Results and discussion

A descriptive of variables, correlations, and VIF statistics

The descriptive statistics of variables are represented in Table 2. The results show the minimum and the maximum value of CO_2 emissions starting from 3.405 to 25.604 for all 14 EU countries. The mean value of GDP is 42,780.180 with standard deviation of 19,461.63. Moreover, EU countries renewable energy consumption, institutional quality, and technological innovation have a mean value of 16.122, 1.306, and 1.971 with standard deviation of 12.940, 0.390, and 0.833, respectively. Jarque–Bera test shows the absence or presence of the data normality. According to the result of this test, all the variables have an absence of normality and asymmetric distribution. This finding is actually justifying the application of MMQR method (Sun et al. 2022).

Table 3 indicates the correlation matrix between the different variables. The outcomes show that there is a negative correlation between CO_2 and renewable energy consumption

Table 1 Description of variables

Variable	Symbol	Definition	Source
Carbon emission	CO_2	Carbon emissions (metric tons per capita)	WDI
Renewable energy	REN	Renewable energy consumption (% of total final energy consumption)	WDI
Institutional quality	IQU	Governance index*	WDI
Technological innovation	TECH	Research and development expenditure (% of GDP)	WDI
Gross domestic product	GDP	GDP per capita (constant 2015 US$)	WDI

(1) The estimation period is 2000–2019. (2) CO_2, REN and GDP variables are logarithmic. *Governance index (government effectiveness, corruption control, rule of law, supervision quality, political stability, and right to comment) are calculated through weighted average

Table 2 Summary of descriptive statistics (before logarithm)

Variables	CO_2	REN	IQU	TECH	GDP
Mean	8.594	16.122	1.306	1.971	42,780.180
Median	8.068	11.945	1.404	1.790	41,299.65
Minimum	3.405	0.850	0.185	0.527	17,796.26
Maximum	25.604	52.880	1.895	3.894	112,417.9
Skewness	2.183	0.977	−0.888	0.328	1.894
Std. Dev	3.809	12.940	0.390	0.833	19,461.63
Jarque–Bera	682.951***	47.775***	39.455***	16.206***	399.618***

***significance at the 1% level

**Significance at the 5% level

*Significance at the 10% level

Table 3 Correlation matrix and VIF statistics

Variables	CO_2	REN	IQU	TECH	GDP	VIF	1/VIF
CO_2	1.000					-	-
REN	−0.403***	1.000				2.99	0.334
IQU	−0.400***	0.218***	1.000			2.62	0.382
TECH	−0.093*	0.622***	0.613***	1.000		2.11	0.472
GDP	0.749***	−0.079	0.582***	0.004***	1.000	1.70	0.586
Mean	-	-	-	-	-	2.36	-

***significance at the 1% level

**Significance at the 5% level

*Significance at the 10% level

(−0.403), institutional quality (−0.400), and technological innovation (−0.093), but positive correlation with GDP (0.749). Interestingly, there is a positive correlation between renewable energy usage and institutional quality (0.218) and technological innovation (0.622) but negative relationship with GDP (−0.079). Further, there is a positive correlation between institutional quality and technological innovation (0.613) and GDP (0.582) and also a positive correlation between technological innovation (0.004) and GDP. It is noticeable that there is no high value of correlation coefficient among the variables (more than 0.8 in absolute values) which indicates that there is not much indication of multicollinearity problem. Also, the mean VIF is 2.36 (less than 5). So, there is no intense multicollinearity problem.

Cross-sectional dependence, unit root, and panel cointegration test

After descriptive analysis, we then test the possibility of cross-sectional dependence (CD) within the estimated panel. The reason of performing this test is twofold; one is cross-sectional dependence may change the accurate values of coefficient estimation and secondly cross-sectional dependence if arise as a finding of unobserved common factors may put some serious effects on the panel data efficiency gains if unobserved (Phillips and Sul 2003). Hence, this issue must be considered in order to reflect strong coefficient estimates. This study uses the Pesaran et al. (2004) CD test to measure cross-sectional dependence within the estimated panel. The findings of cross-sectional dependence test among selected EU countries demonstrated in Table 4. All the variables CO_2, REN, IQU, TECH, and GDP show significant *p* values at the 1% level; thus, the null hypothesis is not rejected, and there is the CD between the variables.

Based on the CD problem, the second-generation unit root test is used to review the variables stationary (Koengkan et al. 2022; Dogan et al. 2022). This paper used Pesaran (2007) panel unit root test and findings are illustrated in Table 4. The outcomes show all the variables are stationary at first difference.

Table 4 Results of CD and Pesaran CADF unit root test

Variables	CD test	CADF test	
		Level	First difference
CO_2	41.00***	−1.882	−2.546***
REN	41.71***	−1.560	−2.224**
IQU	24.95***	−2.023	−2.885***
TECH	10.82***	−1.073	−2.258**
GDP	26.33***	−1.812	−2.601***

(1) ***significance at the 1% level

**Significance at the 5% level

(2) The critical values for CADF test at the 10%, 5%, and 1% levels of significance are −2.140, −2.260, and −2.470, respectively

Table 5 Westerlund bootstrap panel cointegration results

Statistic	Value	*Z* value	*p* value
Gt	−10.859	−2.007	0.022
Ga	−9.856	0.611	0.730
Pt	−9.883	−2.313	0.010
Pa	−9.957	0.556	0.711

The null hypothesis is no cointegration and the alternative hypothesis is at least one of the cross-sectional units has cointegration (Gt and Ga) or cointegration for the panel as a whole (Pt and Pa)

Table 5 displays the results of the cointegration test proposed by Westerlund (2007) for cross-sectional dependence. This approach provides more consistent outcomes by minimizing the forge effects of cross-sections. The results confirm that measurable variables have a long run cointegration, inferring the rejection of null hypothesis and acceptance of alternative hypothesis. Thus, the empirical results are valid.

Method of moments of quantile regression results

The method of moments of quantile regression is used to investigate the relationships at various quantiles of carbon emissions in the 14 EU countries. Table 6 exhibits the results

Table 6 Results of method of moments quantile regression

Independent variables	Dependent variable (CO_2)										
			Quantiles								
	Location	Scale	Q10	Q20	Q30	Q40	Q50	Q60	Q70	Q80	Q90
REN	−0.087***	0.007	−0.099***	−0.096***	−0.092***	−0.090***	−0.088***	−0.085***	−0.082***	−0.080***	−0.076**
IQU	−0.023	−0.049***	−0.110***	−0.083***	−0.058**	−0.043**	−0.026**	−0.020*	−0.010	0.005	0.014
TECH	−0.035***	−0.034***	−0.095***	−0.077***	−0.059***	−0.049***	−0.037***	−0.024*	−0.014*	−0.001	0.018
GDP	0.544***	0.100***	0.370***	0.423***	0.473***	0.503***	0.538***	0.577***	0.614***	0.643***	0.701***
Obs	280	280	280	280	280	280	280	280	280	280	280
Post-estimation test for the panel quantile model											
F/Wald test			Chi2(4) = 107.71***	Chi2(4) = 314.43***		Chi2(4) = 452.37***		Chi2(4) = 312.73***		Chi2(4) = 160.61***	

***significance at the 1% level

**Significance at the 5% level

*Significance at the 10% level

of MMQR. The outcomes indicate that the effect of renewable energy consumption (REN) on CO_2 emissions is negative and significant in all the quantiles. Based on Table 6, the impact of REN on carbon emissions decreases in higher quantiles, so the effect of REN on 0.9 quantile of CO_2 emissions is less than other quantiles. This result indicates that renewable energy consumption plays a significant role in the quality of the environment in the 14 EU nations. Our results are consistent with Paramati et al. (2017) for developing countries, Kirikkaleli and Adebayo (2021a) for India, Rasheed et al. (2022) for European countries, Ehigiamusoe and Dogan (2022) for low-income countries, Anwar et al. (2022) for Asian countries, Mujtaba et al. (2022) for OECD, Usman (2022) for Nigeria, and Li and Haneklaus (2022) for G7 countries.

In addition, institutional quality (IQU) improves environmental quality in 0.1–0.6 quantiles, whereas at the highest qualities that is 0.7, 0.8, and 0.9 quantiles, the impact of institutional quality shows insignificant values. These results are consistent with Baloch and Wang (2019) and Hussain and Dogan (2021) for BRICS, Haldar and Sethi (2021) for developing countries, Jiang et al. (2022) for B&R nations, and Bletsas et al. (2022) for 95 countries, which claimed that institutional quality improves the environment and more corruption worsens the environment. It indicates that weak institutional quality leads to a degrading environment while strong institutional quality develops environmental standards. However, the results contradict with the findings of Ibrahim and Law (2016) for Sub-Saharan Arica, Godil et al. (2020) for Pakistan, and Islam et al. (2021) for Bangladesh. In addition to, Azam et al. (2021) stated that institutional quality has positive influence on carbon emissions in developing economics. Also, Arminen and Menegaki (2019) results on high-middle-income countries contradict our findings as they found that institutional quality did not have an effect on environmental degradation.

On the other hand, the findings show that the relation between technological innovation (TECH) and CO_2 emissions in all quantiles except the 0.8 and 0.9 quantiles is negative and significant. Therefore, increasing R&D expenditures can help technological innovations to reduce carbon emissions and prevent environmental degradation. Therefore, any progress in technological innovation will have a significant effect on the environmental quality of EU countries. The estimated impacts of technological innovation on CO_2 emissions are also supported by existing studies such as Yii and Geetha (2017) and Raihan et al. (2022) for Malaysia, Churchill et al. (2019) for G-7, Khan et al. (2020) for BRICS, Cheng et al. (2021a, b) for OECD, Obobisa et al. (2022) for African countries, Gu (2022) for Chinese cities, and Abid et al. (2022) for G8 countries. Also, Suki et al. (2022) indicated that technology innovation helps to reduce CO_2 emission in Malaysia. However, the findings of our study contradict the outcomes of Khan et al., (2019) for Pakistan and Adebayo et al., (2021a, b) for Chile. Adebayo and Kirikkaleli (2021) concluded that technological innovation increases carbon emissions in Japan.

Lastly, the effect of GDP on carbon emissions is positive and significant across all the quantiles and has an upward trend in study countries. Therefore, it can be seen that the increase in economic growth of countries creates more environmental compression on EU countries. Also, the positive impact of GDP on carbon emissions was confirmed by Salehnia et al. (2020) for MENA, Ozcan et al. (2020) for OECD, Razzaq et al. (2021) for top 10 GDP countries, Xue et al. (2022) for France, and Shpak et al. (2022) for Asia–Pacific region and United States, Also, Mentel et al. (2022) showed that GDP has the positive impact on carbon emissions in Sub-Saharan African countries. However, our results contradict the findings of Jebli and Youssef (2015) for Tunisia, Nathaniel and Iheonu (2019) for Africa, and Dehdar et al. (2022) for USA, which show that enhance in GDP decreases CO_2 emissions. Furthermore, the findings of Wald test demonstrate that the model estimator that this paper choose is adequate to perform this analysis.

Robustness check (results of the panel regression estimates)

As a robustness check for MMQR, the FE-OLS, FMOLS, and DOLS estimators have been used to examine the effects of renewable energy consumption, institutional quality, and technological innovation on environmental degradation. The outcomes of FE-OLS, FMOLS, and DOLS are shown in Table 7. From the results, it is clear that all the coefficient estimates obtained from the three methods are statistically significant, but they are different in terms of significant values. GDP is found as the most robust in all the three estimation techniques by means of coefficient size and statistical significance value. Put differently, a one-percent increase in GDP has a positive impact on CO_2 emissions by 0.380 in FE-OLS, 0.408 in FMLOS, and 0.430 in DOLS. In contrast, renewable energy shows a significant but negative impact on environmental degradation in 14 EU countries. In other words, a one-percent increase in renewable consumption decreases carbon emissions by − 0.142, − 0.162, and − 0.162 in FE-OLS, FMOLS, and DOLS techniques. In addition, it is observed that institutional quality has a negative and significant effect on carbon emissions in all three estimation techniques. That is to say that a one percent enhancement in institutional quality diminishes CO_2 emissions by − 0.101, − 0.071, and − 0.098 in all three estimation techniques. On the other hand, technical innovation has a significant and negative effect on carbon emissions, but the values of its coefficients are quite close to each other. One percent increase in technological innovation decreases the CO_2 emissions ranging from − 0.040, − 0.049, and − 0.044 in all three estimations, respectively.

Figure 3 represents the visual interpretation of the estimated variables related to 14 EU countries. It is quite obvious from the visuals that the coefficient of MMQR for all measurable variables are different, but the coefficients of FE-OLS, FMOLS, and DOLS regressions are constant. Therefore, it can be concluded that the use of MMQR approach provides comprehensive illustration of the related variables and gives a clear picture to assess the effect of coefficient and significance of independent variables on dependent variable.

Conclusions and policy implications

This paper studies the impact of significant determinants of carbon dioxide emissions, renewable energy consumption, institutional quality, technological innovation, and GDP for 14 EU countries over the period of 2000 to 2019, utilizing a variety of panel estimation methods such as FMOLS, DOLS, FE-OLS, and MMQR. Results obtained from MMQR method, which is the most robust and reliable technique in comparison with the other three methods revealed that renewable energy consumption has a mitigating

Table 7 FE-OLS, FMOLS, and DOLS results

Independent variables	Dependent variable (CO_2)					
	FE-OLS		FMOLS		DOLS	
	Coefficient	Prob	Coefficient	Prob	Coefficient	Prob
REN	− 0.142***	0.000	− 0.162**	0.019	− 0.136***	0.000
IQU	− 0.101***	0.001	− 0.071*	0.067	− 0.098**	0.049
TECH	− 0.040***	0.001	− 0.049**	0.046	− 0.044**	0.039
GDP	0.380***	0.000	0.408**	0.026	0.430***	0.003

***significance at the 1% level

**Significance at the 5% level

*Significance at the 10% level

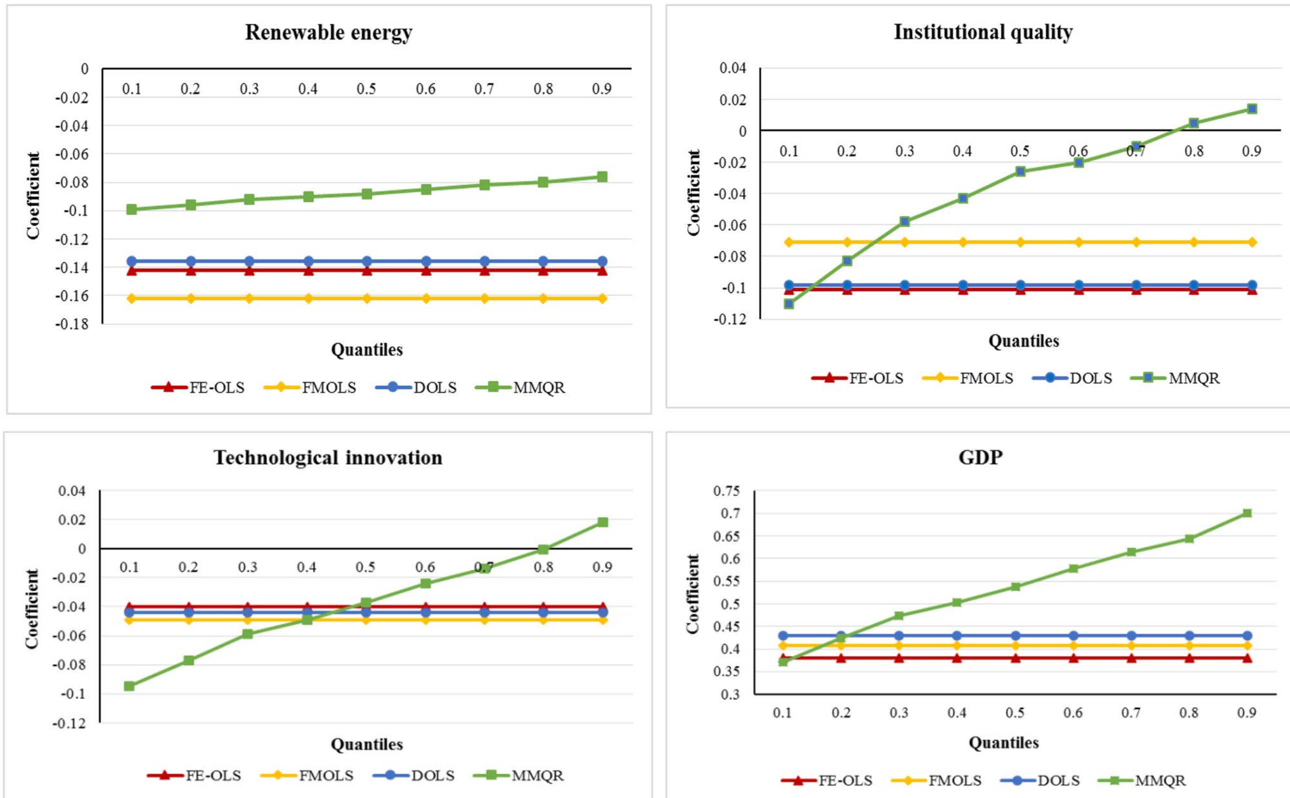

Fig. 3 Comparing coefficients of variables of renewable energy, institutional quality, technological innovation, and GDP in FE-OLS, FMOLS, DOLS, and MMQR

impact on CO_2 emissions, which is in line with the work of other researchers such as Ehigiamusoe and Dogan (2022), Mujtaba et al. (2022), Usman (2022), and Li and Haneklaus (2022). The same impact is witnessed when estimating the impact of institutional quality, which was approved by other researchers such as Hussain and Dogan (2021) and Haldar and Sethi (2021) for different groups of countries and time periods. Technological innovation has also lowered carbon emissions in the 14 EU countries studied. This finding is in line with those of Cheng et al. (2021a, b), Obobisa et al. (2022), and Abid et al. (2022).

However, GDP was found to have an increasing impact on the emissions of carbon dioxide. Other researchers including Razzaq et al. (2021), Shpak et al. (2022), and Mentel et al. (2022) also confirmed this finding for other regions and time periods.

The findings of this study offer several implications for environmental preservation policies. As Europe is aiming to become climate-neutral by 2050, it has been increasing the share of renewable energy consumption to more than double in 2020 compared to the 2004 levels, through setting targets that are legally binding for the member countries. The process was stimulated by a significant reduction in the use of fossil fuels during the global pandemic, and Sweden followed by Finland represented the highest share among all EU countries in 2020. This study reveals that renewable energies have a mitigating impact on carbon emissions in the EU member countries; however, it could be difficult for the energy market alone to deliver the required level of renewable energies to meet the 2050 targets, which means that national support plans and EU financing might be necessary (Potrč et al. 2021). Further investments in renewable energies, not only facilitate the mitigation of CO_2 emissions but also ensures the energy security for 14 EU countries, especially when there is geopolitical tension in oil and natural gas exporting countries such as the current instability in the energy market due to the Russia–Ukraine war, which has made the future of energy market unpredictable. Currently, it is expected that the energy generated from wind to significantly replace the shortage of fossil fuels during the winter in the EU.

Institutional quality has also shown a mitigating impact; however, in order to improve its magnitude, it is essential to provide a macroeconomic and regulatory environment that encourages business activities, such as start-ups and foreign investments that are sustainable and environmental friendly. The European Union should continue reinforcing its institutions not only on the supranational level but also on national, or municipal levels. In addition, strengthening the judicial system and continuing the fight against corruption have pivotal role in enhancing the quality of institutions. Reducing economic, institutional, technological, and educational gaps between developed nations and less-developed members will facilitate the path through achieving these goals (Dehdar et al. 2020).

It is advisable for the governments to constantly evaluate and measure their effectiveness through productive communications with the relevant stakeholders and investors, to ensure meeting the future environmental and energy targets. Further incentives and financial supports from the EU countries for research and development activities can enhance the impact of technological innovation in decreasing environmental degradation. Finally, policymakers should devise policies that help in promoting environmentally sustainable economic growth by imposing and accumulating environmental taxes, and by further emphasizing carbon permits and licenses.

Limitations and future recommendations

This paper, like other studies, has limitations. One of the limitations is that the current study only considers 14 European Union countries, while covering more countries could lead to a broader understanding on the environmental degradation in the EU. In addition, the present research takes CO_2 emissions as a proxy to measure the environmental degradations, while adding other hazardous gasses such as SO_2 or CH_4 could possibly add interesting insights to the findings.

In order to overcome the limitations, (1) future researches can expand this paper by adding other variables such as trade openness, foreign direct investment, total population, and industrialization. (2) Other scholars can repeat this study for other groups of countries such as BRICS, G-7, D-8, and MENA countries. (3) Researchers can use other econometric methods to investigate factors affecting environmental degradation in European Union. (4) Other studies can investigate on environmental policies considering a single-country analysis.

Author contribution N.K.A: methodology, software, and writing—review and editing. M.T.A.SH: conceptualization and writing—review and editing. N.N: writing—review and editing. S.Z: writing—review and editing. F.D: writing—review and editing. All authors read and approved the final manuscript.

Data availability The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate This paper does not contain any studies with human participants or animals performed by any of the authors.

Consent for publication The authors affirm the informed consent for publication of the article.

Competing interests The authors declare no competing interests.

References

Abdallh AA, Abugamos H (2017) A semi-parametric panel data analysis on the urbanization-carbon emissions nexus for the MENA countries. Renew Sustain Energy Rev 78:1350–1356. https://doi.org/10.1016/j.rser.2017.05.006

Abid M (2016) Impact of economic, financial, and institutional factors on CO2 emissions: evidence from Sub-Saharan Africa economies. Utilities Policy 41:85–94. https://doi.org/10.1016/j.jup.2016.06.009

Abid A, Mehmood U, Tariq S, Haq ZU (2022) The effect of technological innovation, FDI, and financial development on CO2 emission: evidence from the G8 countries. Environ Sci Pollut Res 29(8):11654–11662. https://doi.org/10.1007/s11356-021-15993-x

Adebayo TS, Kirikkaleli D (2021) Impact of renewable energy consumption, globalization, and technological innovation on environmental degradation in Japan: application of wavelet tools. Environ Dev Sustain 23(11):16057–16082. https://doi.org/10.1007/s10668-021-01322-2

Adebayo TS, Adedoyin FF, Kirikkaleli D (2021a) Toward a sustainable environment: nexus between consumption-based carbon emissions, economic growth, renewable energy and technological innovation in Brazil. Environ Sci Pollut Res 28(37):52272–52282. https://doi.org/10.1007/s11356-021-14425-0

Adebayo TS, Udemba EN, Ahmed Z, Kirikkaleli D (2021b) Determinants of consumption-based carbon emissions in Chile: an application of non-linear ARDL. Environ Sci Pollut Res 28(32):43908–43922. https://doi.org/10.1007/s11356-021-13830-9

Adebayo S, Rjoub H, Akinsola GD et al (2022a) The asymmetric effects of renewable energy consumption and trade openness on carbon emissions in Sweden: new evidence from quantile-on-quantile regression approach. Environ Sci Pollut Res 29:1875–1886. https://doi.org/10.1007/s11356-021-15706-4

Adebayo TS, Oladipupo SD, Rjoub H, Kirikkaleli D, Adeshola I (2022b) Asymmetric effect of structural change and renewable energy consumption on carbon emissions: designing an SDG framework for Turkey. Environ Dev Sustain 25:528–556. https://doi.org/10.1007/s10668-021-02065-w

Adebayo TS, Onifade ST, Alola AA, Muoneke OB (2022c) Does it take international integration of natural resources to ascend the ladder of environmental quality in the newly industrialized countries? Resources Policy 76:102616. https://doi.org/10.1016/j.resourpol.2022.102616

Adebayo TS, Rjoub H, Akadiri SS, Oladipupo SD, Sharif A, Adeshola I (2022d) The role of economic complexity in the environmental Kuznets curve of MINT economies: evidence from method of moments quantile regression. Environ Sci Pollut Res 29(16):24248–24260. https://doi.org/10.1007/s11356-021-17524-0

Adedoyin FF, Ozturk I, Agboola MO, Agboola PO, Bekun FV (2021) The implications of renewable and non-renewable energy generating in Sub-Saharan Africa: the role of economic policy uncertainties. Energy Policy 150:112115. https://doi.org/10.1016/j.enpol.2020.112115

Ahmed Z, Wang Z, Ali S (2019) Investigating the non-linear relationship between urbanization and CO2 emissions: an empirical analysis. Air Qual Atmos Health 12(8):945–953. https://doi.org/10.1007/s11869-019-00711-x

Ahmed Z, Ahmad M, Murshed M, Vaseer AI, Kirikkaleli D (2022) The trade-off between energy consumption, economic growth, militarization, and CO_2 emissions: does the treadmill of destruction exist in the modern world? Environ Sci Pollut Res 29(12):18063–18076. https://doi.org/10.1007/s11356-021-17068-3

Ajide KB, Mesagan EP (2022) Heterogeneous analysis of pollution abatement via renewable and non-renewable energy: lessons from investment in G20 nations. Environ Sci Pollut Res 29(24):36533–36546. https://doi.org/10.1007/s11356-022-18771-5

Ali HS, Zeqiraj V, Lin WL, Law SH, Yusop Z, Bare UAA, Chin L (2019a) Do quality institutions promote environmental quality? Environ Sci Pollut Res 26:10446–10456. https://doi.org/10.1007/s11356-019-04670-9

Ali R, Bakhsh K, Yasin MA (2019b) Impact of urbanization on CO2 emissions in an emerging economy: evidence from Pakistan. Sustain Cities Soc 48(April):101553. https://doi.org/10.1016/j.scs.2019.101553

Ali A, Kelley DJ, Levie J (2020a) Market-driven entrepreneurship and institutions. J Bus Res 113:117–128. https://doi.org/10.1016/j.jbusres.2019.03.010

Ali KA, Ahmad MI, Yusup Y (2020b) Issues, impacts, and mitigations of carbon dioxide emissions in the building sector. Sustainability 12(18):7427. https://doi.org/10.3390/SU12187427

Alola AA (2019) The trilemma of trade, monetary and immigration policies in the United States: accounting for environmental sustainability. Sci Total Environ 658:260–267. https://doi.org/10.1016/j.scitotenv.2018.12.212

Alqaralleh H (2021) On the nexus of CO2 emissions and renewable and nonrenewable energy consumption in Europe: a new insight from panel smooth transition. Energy Environ 32(3):443–457. https://doi.org/10.1177/0958305X2093768

Alqaralleh H (2022) Are the macroeconomic effects on oil price asymmetric? An asymmetric quantile regression approach. Int J Energy Sect Manage 16(5):1000–1014. https://doi.org/10.1108/IJESM-02-2021-0017

Amegavi GB (2022) The heterogeneous effects of government size and press freedom on corruption in sub-Saharan Africa: method of moment quantile regression approach. The International Journal of Press/politics 27(2):439–459

Anwar A, Siddique M, Dogan E, Sharif A (2021) The moderating role of renewable and non-renewable energy in environment-income nexus for ASEAN countries: evidence from method of moments quantile regression. Renew Energy 164:956–967. https://doi.org/10.1016/j.renene.2020.09.128

Anwar A, Sinha A, Sharif A, Siddique M, Irshad S, Anwar W, Malik S (2022) The nexus between urbanization, renewable energy consumption, financial development, and CO2 emissions: evidence from selected Asian countries. Environ Dev Sustain 24(5):6556–6576. https://doi.org/10.1007/s10668-021-01716-2

Apergis N, Ozturk I (2015) Testing environmental Kuznets curve hypothesis in Asian countries. Ecol Indic 52:16–22. https://doi.org/10.1016/j.ecolind.2014.11.026

Arain H, Sharif A, Akbar B, Younis MY (2020) Dynamic connection between inward foreign direct investment, renewable energy, economic growth and carbon emission in China: evidence from partial and multiple wavelet coherence. Environ Sci Pollut Res 27(32):40456–40474. https://doi.org/10.1007/s11356-020-08836-8

Arminen H, Menegaki AN (2019) Corruption, climate, and the energy-environment-growth nexus. Energy Econ 80:621–634. https://doi.org/10.1016/j.eneco.2019.02.009

Awan A, Abbasi KR, Rej S, Bandyopadhyay A, Lv K (2022) The impact of renewable energy, internet use and foreign direct investment on carbon dioxide emissions: a method of moments quantile analysis. Renew Energy 189:454–466. https://doi.org/10.1016/j.renene.2022.03.017

Azam M, Liu L, Ahmad N (2021) Impact of institutional quality on environment and energy consumption: evidence from developing world. Environ Dev Sustain 23(2):1646–1667. https://doi.org/10.1007/s10668-020-00644-x

Aziz N, Mihardjo LW, Sharif A, Jermsittiparsert K (2020) The role of tourism and renewable energy in testing the environmental Kuznets curve in the BRICS countries: fresh evidence from methods of moments quantile regression. Environ Sci Pollut Res 27(31):39427–39441. https://doi.org/10.1007/s11356-020-10011-y

Bai C, Feng C, Yan H, Yi X, Chen Z, Wei W (2020) Will income inequality influence the abatement effect of renewable energy technological innovation on carbon dioxide emissions? J Environ Manag 264:110482. https://doi.org/10.1016/j.jenvman.2020.110482

Baloch MA, Wang B (2019) Analyzing the role of governance in CO2 emissions mitigation: the BRICS experience. Struct Chang Econ Dyn 51:119–125. https://doi.org/10.1016/j.strueco.2019.08.007

Baloch MA, Ozturk I, Bekun FV, Khan D (2021) Modeling the dynamic linkage between financial development, energy innovation, and environmental quality: does globalization matter? Bus Strateg Environ 30(1):176–184. https://doi.org/10.1002/bse.2615

Balsalobre-Lorente D, Shahbaz M, Roubaud D, Farhani S (2018) How do economic growth, renewable electricity, and natural resources contribute to CO2 emissions? Energy Policy 113(October 2017):356–367. https://doi.org/10.1016/j.enpol.2017.10.050

Bekhet HA, Matar A, Yasmin T (2017) CO2 emissions, energy consumption, economic growth, and financial development in GCC countries: dynamic simultaneous equation models. Renew Sustain Energy Rev 70(2017):117–132. https://doi.org/10.1016/j.rser.2016.11.089

Ben Jebli M, Ben Youssef S, Apergis N (2019) The dynamic linkage between renewable energy, tourism, CO2 emissions, economic growth, foreign direct investment, and trade. Lat Am Econ Rev 28(1):1–19. https://doi.org/10.1186/s40503-019-0063-7

Bhattacharya M, Awaworyi Churchill S, Paramati SR (2017) The dynamic impact of renewable energy and institutions on economic output and CO2 emissions across regions. Renew Energy 111:157–167. https://doi.org/10.1016/j.renene.2017.03.102

Bletsas K, Oikonomou G, Panagiotidis M, Spyromitros E (2022) Carbon dioxide and greenhouse gas emissions: the role of monetary policy, fiscal policy, and institutional quality. Energies 15(13):4733. https://doi.org/10.3390/en15134733

Cevik EI, Yıldırım DÇ, Dibooglu S (2021) Renewable and non-renewable energy consumption and economic growth in the US: a Markov-switching VAR analysis. Energy Environ 32(3):519–541. https://doi.org/10.1177/0958305X20944035

Chen W, Lei Y (2018) The impacts of renewable energy and technological innovation on environment-energy-growth nexus: new evidence from a panel quantile regression. Renew Energy 123:1–14. https://doi.org/10.1016/j.renene.2018.02.026

Chen J, Cheng S, Song M (2018) Changes in energy-related carbon dioxide emissions of the agricultural sector in China from 2005 to 2013. Renew Sustain Energy Rev 94:748–761. https://doi.org/10.1016/j.rser.2018.06.050

Cheng C, Ren X, Wang Z, Yan C (2019) Heterogeneous impacts of renewable energy and environmental patents on CO2 emission-evidence from the BRIICS. Sci Total Environ 668:1328–1338. https://doi.org/10.1016/j.scitotenv.2019.02.063

Cheng CY, Chien MS, Lee CC (2021a) ICT diffusion, financial development, and economic growth: an international cross-country analysis. Econ Model 94:662–671. https://doi.org/10.1016/j.econmod.2020.02.008

Cheng C, Ren X, Dong K, Dong X, Wang Z (2021b) How does technological innovation mitigate CO2 emissions in OECD countries? Heterogeneous analysis using panel quantile regression. J Environ Manag 280:111818. https://doi.org/10.1016/j.jenvman.2020.111818

Chikezie Ekwueme D, Lasisi TT, Eluwole KK (2022) Environmental sustainability in Asian countries: understanding the criticality of economic growth, industrialization, tourism import, and energy use. Energy Environ. https://doi.org/10.1177/0958305X221091543

Churchill SA, Inekwe J, Smyth R, Zhang X (2019) R&D intensity and carbon emissions in the G7: 1870–2014. Energy Econ 80:30–37. https://doi.org/10.1016/j.eneco.2018.12.020

Dauda L, Long X, Mensah CN, Salman M (2019) The effects of economic growth and innovation on CO2 emissions in different regions. Environ Sci Pollut Res 26(15):15028–15038. https://doi.org/10.1007/s11356-019-04891-y

Dehdar F, Rasiah R, Dehdar MM (2020) How important is institutional quality to lower energy utilization: an analysis using a global panel of stable and unstable countries. Int J Bus Soc 21(3):1384–1401. https://doi.org/10.33736/ijbs.3360.2020

Dehdar F, Fuinhas JA, Karimi Alavijeh N, Nazeer N, Zangoei S (2022) Investigating the determinants of carbon emissions in the USA: a state-level analysis. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-022-23831-x

Dogan E, Chishti MZ, Karimi Alavijeh N, Tzeremes P (2022) The roles of technology and Kyoto Protocol in energy transition towards COP26 targets: evidence from the novel GMM-PVAR approach for G-7 countries. Technol Forecast Soc Chang 181:121756. https://doi.org/10.1016/j.techfore.2022.121756

Dong K, Hochman G, Zhang Y, Sun R, Li H, Liao H (2018a) CO2 emissions, economic and population growth, and renewable energy: empirical evidence across regions. Energy Econ 75:180–192. https://doi.org/10.1016/j.eneco.2018.08.017

Dong K, Sun R, Dong X (2018b) CO2 emissions, natural gas, and renewables, economic growth: assessing the evidence from China. Sci Total Environ 640–641:293–302. https://doi.org/10.1016/j.scitotenv.2018.05.322

Driscoll JC, Kraay AC (1998) Consistent covariance matrix estimation with spatially dependent panel data. Rev Econ Stat 80(4):549–560. https://doi.org/10.1162/003465398557825

Ehigiamusoe KU, Dogan E (2022) The role of interaction effect between renewable energy consumption and real income in carbon emissions: evidence from low-income countries. Renew Sustain Energy Rev 154:111883. https://doi.org/10.1016/j.rser.2021.111883

EPRS (2021) Renewable Energy Directive Revision of Directive (EU) 2018/2001 This. https://euagenda.eu/upload/publications/eprs-bri2021662619-en.pdf

Gholipour HF, Farzanegan MR (2018) Institutions and the effectiveness of expenditures on environmental protection: evidence from Middle Eastern countries. Constit Polit Econ 29(1):20–39. https://doi.org/10.1007/s10602-017-9246-x

Godil DI, Sharif A, Agha H, Jermsittiparsert K (2020) The dynamic nonlinear influence of ICT, financial development, and institutional quality on CO2 emission in Pakistan: new insights from QARDL approach. Environ Sci Pollut Res 27(19):24190–24200. https://doi.org/10.1007/s11356-020-08619-1

Gómez M, Rodríguez JC (2020) The ecological footprint and Kuznets environmental curve in the USMCA countries: a method of moments quantile regression analysis. Energies 13(24):6650. https://doi.org/10.3390/en13246650

Grossman GM, Krueger AB (1991) Environmental impacts of a North American free trade agreement. National Bureau Economic Res Working Paper Series 3914:1–57. https://doi.org/10.3386/w3914

Gu J (2022) Sharing economy, technological innovation and carbon emissions: evidence from Chinese cities. J Innov Knowl 7(3):100228. https://doi.org/10.1016/j.jik.2022.100228

Gu W, Zhao X, Yan X, Wang C, Li Q (2019) Energy technological progress, energy consumption, and CO2 emissions: empirical evidence from China. J Clean Prod 236:117666. https://doi.org/10.1016/j.jclepro.2019.117666

Haldar A, Sethi N (2021) Effect of institutional quality and renewable energy consumption on CO2 emissions− an empirical investigation for developing countries. Environ Sci Pollut Res 28(12):15485–15503. https://doi.org/10.1007/s11356-020-11532-2

Hasnisah A, Azlina AA, Taib CMIC (2019) The impact of renewable energy consumption on carbon dioxide emissions: empirical evidence from developing countries in Asia. Int J Energy Econ Policy 9(3):135–143. https://doi.org/10.32479/ijeep.7535

He X, Zhang T, Xue Q, Zhou Y, Wang H, Bolan NS, Jiang R, Tsang DCW (2021) Enhanced adsorption of Cu(II) and Zn(II) from aqueous solution by polyethyleneimine modified straw hydrochar. Sci Total Environ 778:146116. https://doi.org/10.1016/j.scitotenv.2021.146116

Horobet A, Popovici OC, Zlatea E, Belascu L, Dumitrescu DG, Curea SC (2021) Long-run dynamics of gas emissions, economic growth, and low-carbon energy in the European Union: the fostering effect of FDI and trade. Energies 14(10):2858. https://doi.org/10.3390/en14102858

Hussain M, Dogan E (2021) The role of institutional quality and environment-related technologies in environmental degradation for BRICS. J Clean Prod 304:127059. https://doi.org/10.1016/j.jclepro.2021.127059

Ibrahim MH, Law SH (2016) Institutional quality and CO2 emission–trade relations: evidence from Sub-Saharan arica. S Afr J Econ 84(2):323–340. https://doi.org/10.1111/saje.12095

IEA (2020) Data and statistics. Available online: https://www.iea.org (accessed on 11 May 2020)

Islam M, Khan MK, Tareque M, Jehan N, Dagar V (2021) Impact of globalization, foreign direct investment, and energy consumption on CO2 emissions in Bangladesh: does institutional quality matter? Environ Sci Pollut Res 28(35):48851–48871. https://doi.org/10.1007/s11356-021-13441-4

Jebli MB, Youssef SB (2015) The environmental Kuznets curve, economic growth, renewable and non-renewable energy, and trade in Tunisia. Renew Sustain Energy Rev 47:173–185. https://doi.org/10.1016/j.rser.2015.02.049

Jiang Q, Rahman ZU, Zhang X, Guo Z, Xie Q (2022) An assessment of the impact of natural resources, energy, institutional quality, and financial development on CO2 emissions: evidence from the B&R nations. Res Policy 76:102716. https://doi.org/10.1016/j.resourpol.2022.102716

Kao C, Chiang MH (2001) On the estimation and inference of a cointegrated regression in panel data. In Nonstationary panels, panel cointegration, and dynamic panels. Emerald Group Publishing Limited. https://doi.org/10.1016/S0731-9053(00)15007-8

Karimi Alavijeh N, Salehnia N, Salehnia N, Koengkan M (2022) The effects of agricultural development on CO2 emissions: empirical evidence from the most populous developing countries. Environ Dev Sustain 1–21. https://doi.org/10.1007/s10668-022-02567-1

Khan MK, Teng JZ, Khan MI, Khan MO (2019) Impact of globalization, economic factors, and energy consumption on CO2 emissions in Pakistan. Sci Total Environ 688:424–436. https://doi.org/10.1016/j.scitotenv.2019.06.065

Khan A, Muhammad F, Chenggang Y, Hussain J, Bano S, Khan MA (2020) The impression of technological innovations and natural resources in energy-growth-environment nexus: a new look into BRICS economies. Sci Total Environ 727:138265. https://doi.org/10.1016/j.scitotenv.2020.138265

Khan H, Weili L, Khan I, Oanh LK (2021) Recent advances in energy usage and environmental degradation: does quality institutions matter? Worldwide evidence. Energy Rep 7:1091–1103. https://doi.org/10.1016/j.egyr.2021.01.085

Khan H, Weili L, Khan I (2022) The role of institutional quality in FDI inflows and carbon emission reduction: evidence from the global developing and belt road initiative countries. Environ Sci Pollut Res 29(20):30594–30621. https://doi.org/10.1007/s11356-021-17958-6

Kihombo S, Ahmed Z, Chen S, Adebayo TS, Kirikkaleli D (2021) Linking financial development, economic growth, and ecological footprint: what is the role of technological innovation? Environ Sci Pollut Res 28(43):61235–61245. https://doi.org/10.1007/s11356-021-14993-1

Kirikkaleli D (2020) New insights into an old issue: exploring the nexus between economic growth and CO2 emissions in China. Environ Sci Pollut Res 27(32):40777–40786. https://doi.org/10.1007/s11356-020-10090-x

Kirikkaleli D, Adebayo TS (2021a) Do public-private partnerships in energy and renewable energy consumption matter for consumption-based carbon dioxide emissions in India? Environ Sci Pollut Res 28(23):30139–30152. https://doi.org/10.1007/s11356-021-12692-5

Kirikkaleli D, Adebayo TS (2021b) Do renewable energy consumption and financial development matter for environmental sustainability? New global evidence. Sustain Dev 29(4):583–594. https://doi.org/10.1002/sd.2159

Kirikkaleli D, Adebayo TS, Khan Z, Ali S (2021) Does globalization matter for ecological footprint in Turkey? Evidence from dual adjustment approach. Environ Sci Pollut Res 28(11):14009–14017. https://doi.org/10.1007/s11356-020-11654-7

Koengkan M, Fuinhas JA, Kazemzadeh E, Karimi Alavijeh N, de Araujo SJ (2022) The impact of renewable energy policies on deaths from outdoor and indoor air pollution: empirical evidence from Latin American and Caribbean countries. Energy 245:123209. https://doi.org/10.1016/j.energy.2022.123209

Koenker R, Bassett Jr G (1978) Regression quantiles. Econometrica: Journal of the Econometric Society 46(1):33–50. https://doi.org/10.2307/1913643

Lee CC, Ranjbar O, Lee CC (2021) Testing the persistence of shocks on renewable energy consumption: evidence from a quantile unit-root test with smooth breaks. Energy 215:119190. https://doi.org/10.1016/j.energy.2020.119190

Li B, Haneklaus N (2022) Reducing CO2 emissions in G7 countries: the role of clean energy consumption, trade openness and urbanization. Energy Rep 8:704–713. https://doi.org/10.1016/j.egyr.2022.01.238

Lin B, Ma R (2022) Green technology innovations, urban innovation environment and CO2 emission reduction in China: fresh evidence from a partially linear functional-coefficient panel model. Technol Forecast Soc Chang 176:121434. https://doi.org/10.1016/j.techfore.2021.121434

Lin B, Zhu J (2019) Determinants of renewable energy technology innovation in China under CO2 emissions constraint. J Environ Manage 247(June):662–671. https://doi.org/10.1016/j.jenvman.2019.06.121

Lingyan M, Zhao Z, Malik HA, Razzaq A, An H, Hassan M (2022) Asymmetric impact of fiscal decentralization and environmental innovation on carbon emissions: evidence from highly decentralized countries. Energy Environ 33(4):752–782. https://doi.org/10.1177/0958305X211018453

Liu H, Du K, Li J (2019) An improved approach to estimate direct rebound effect by incorporating energy efficiency: a revisit of China's industrial energy demand. Energy Econ 80:720–730. https://doi.org/10.1016/j.eneco.2019.02.012

Machado JA, Silva JS (2019) Quantiles via moments. J Econ 213(1):145–173. https://doi.org/10.1016/j.jeconom.2019.04.009

Mahalik MK, Mallick H, Padhan H (2021) Do educational levels influence the environmental quality? The role of renewable and non-renewable energy demand in selected BRICS countries with a new policy perspective. Renew Energy 164:419–432. https://doi.org/10.1016/j.renene.2020.09.090

Mahjabeen, Shah SZA, Chughtai S, Simonetti B (2020) Renewable energy, institutional stability, environment, and economic growth nexus of D-8 countries. Energy Strat Rev 29:100484. https://doi.org/10.1016/j.esr.2020.100484

Mahmood N, Wang Z, Hassan ST (2019) Renewable energy, economic growth, human capital, and CO2 emission: an empirical analysis. Environ Sci Pollut Res 26(20):20619–20630. https://doi.org/10.1007/s11356-019-05387-5

Mardani A, Streimikiene D, Cavallaro F, Loganathan N, Khoshnoudi M (2019) Carbon dioxide (CO2) emissions and economic growth: a systematic review of two decades of research from 1995 to 2017. Sci Total Environ 649:31–49. https://doi.org/10.1016/j.scitotenv.2018.08.229

Mehmood U (2021) Renewable-nonrenewable energy: institutional quality and environment nexus in South Asian countries. Environ Sci Pollut Res 28(21):26529–26536. https://doi.org/10.1007/s11356-021-12554-0

Mehmood U, Tariq S, Ul-Haq Z, Meo MS (2021) Does the modifying role of institutional quality remains homogeneous in GDP-CO2 emission nexus? New evidence from ARDL approach. Environ Sci Pollut Res 28(8):10167–10174. https://doi.org/10.1007/s11356-020-11293-y

Mensah CN, Long X, Boamah KB, Bediako IA, Dauda L, Salman M (2018) The effect of innovation on CO2 emissions of OCED countries from 1990 to 2014. Environ Sci Pollut Res 25(29):29678–29698. https://doi.org/10.1007/s11356-018-2968-0

Mentel U, Wolanin E, Eshov M, Salahodjaev R (2022) Industrialization and CO2 emissions in Sub-Saharan Africa: the mitigating role of renewable electricity. Energies 15(3):946. https://doi.org/10.3390/en15030946

Mohamued EA, Ahmed M, Pypłacz P, Liczmańska-Kopcewicz K, Khan MA (2021) Global oil price and innovation for sustainability: the impact of R&D spending, oil price, and oil price volatility on GHG emissions. Energies 14(6):1757. https://doi.org/10.3390/en14061757

Mongo M, Belaid F, Ramdani B (2021) The effects of environmental innovations on CO2 emissions: empirical evidence from Europe. Environ Sci Policy 118:1–9. https://doi.org/10.1016/j.envsci.2020.12.004

Mujtaba A, Jena PK, Bekun FV, Sahu PK (2022) Symmetric and asymmetric impact of economic growth, capital formation, renewable and non-renewable energy consumption on environment in OECD countries. Renew Sustain Energy Rev 160:112300. https://doi.org/10.1016/j.rser.2022.112300

Nathaniel SP, Iheonu CO (2019) Carbon dioxide abatement in Africa: the role of renewable and non-renewable energy consumption. Sci Total Environ 679:337–345. https://doi.org/10.1016/j.scitotenv.2019.05.011

Nazarko Ł, Žemaitis E, Wróblewski ŁK, Šuhajda K, Zajaczkowska M (2022) The impact of energy development of the European Union Euro Area Countries on CO2 emissions level. Energies 15(4):1–12. https://doi.org/10.3390/en15041425

Obobisa ES, Chen H, Mensah IA (2022) The impact of green technological innovation and institutional quality on CO2 emissions in African countries. Technol Forecast Soc Chang 180:121670. https://doi.org/10.1016/j.techfore.2022.121670

Ozcan B, Tzeremes PG, Tzeremes NG (2020) Energy consumption, economic growth and environmental degradation in OECD countries. Econ Model 84:203–213. https://doi.org/10.1016/j.econmod.2019.04.010

Ozturk I, Al-Mulali U (2015) Investigating the validity of the environmental Kuznets curve hypothesis in Cambodia. Ecol Ind 57:324–330. https://doi.org/10.1016/J.ECOLIND.2015.05.018

Ozturk I, Aslan A, Altinoz B (2021) Investigating the nexus between CO2 emissions, economic growth, energy consumption and pilgrimage tourism in Saudi Arabia. Econ Res-Ekon Istraz 35(1):3083–3098. https://doi.org/10.1080/1331677X.2021.1985577

Paramati SR, Sinha A, Dogan E (2017) The significance of renewable energy use for economic output and environmental protection: evidence from the Next 11 developing economies. Environ Sci Pollut Res 24(15):13546–13560. https://doi.org/10.1007/s11356-017-8985-6

Pedroni P (2004) Panel cointegration: asymptotic and finite sample properties of pooled time series tests with an application to the PPP hypothesis. Economet Theor 20(3):597–625. https://doi.org/10.1017/S0266466604203073

Pesaran MH (2007) A simple panel unit root test in the presence of cross-section dependence. J Appl Economet 22(2):265–312. https://doi.org/10.1002/jae.951

Pesaran MH, Schuermann T, Weiner SM (2004) Modeling regional interdependencies using a global error-correcting macroeconomic model. J Bus Econ Stat 22:129–181. https://doi.org/10.1198/073500104000000019

Phillips PC, Sul D (2003) Dynamic panel estimation and homogeneity testing under cross section dependence. Economet J 6(1):217–259. https://doi.org/10.1111/1368-423X.00108

Potrč S, Čuček L, Martin M, Kravanja Z (2021) Sustainable renewable energy supply networks optimization–the gradual transition to a renewable energy system within the European Union by 2050. Renew Sustain Energy Rev 146:111186. https://doi.org/10.1016/j.rser.2021.111186

Rafique MZ, Li Y, Larik AR, Monaheng MP (2020) The effects of FDI, technological innovation, and financial development on CO2 emissions: evidence from the BRICS countries. Environ Sci Pollut Res 27(19):23899–23913. https://doi.org/10.1007/s11356-020-08715-2

Rahman MM, Nepal R, Alam K (2021) Impacts of human capital, exports, economic growth and energy consumption on CO2 emissions of a cross-sectionally dependent panel: evidence from the newly industrialized countries (NICs). Environ Sci Policy 121:24–36. https://doi.org/10.1016/j.envsci.2021.03.017

Raihan A, Begum RA, Said MNM, Pereira JJ (2022) Relationship between economic growth, renewable energy use, technological innovation, and carbon emission toward achieving Malaysia's Paris agreement. Environ Syst Decis 42:586–607. https://doi.org/10.1007/s10669-022-09848-0

Rasheed MQ, Haseeb A, Adebayo TS, Ahmed Z, Ahmad M (2022) The long-run relationship between energy consumption, oil prices, and carbon dioxide emissions in European countries. Environ Sci Pollut Res 29(16):24234–24247. https://doi.org/10.1007/s11356-021-17601-4

Razzaq A, Fatima T, Murshed M (2021) Asymmetric effects of tourism development and green innovation on economic growth and carbon emissions in Top 10 GDP Countries. J Environ Plan Manag 66(3):471–500. https://doi.org/10.1080/09640568.2021.1990029

Rjoub H, Odugbesan JA, Adebayo TS, Wong WK (2021) Sustainability of the moderating role of financial development in the determinants of environmental degradation: evidence from turkey. Sustainability (Switzerland) 13(4):1–18. https://doi.org/10.3390/su13041844

Rodriguez-Alvarez A (2021) Air pollution and life expectancy in Europe: does investment in renewable energy matter? Sci Total Environ 792:148480. https://doi.org/10.1016/j.scitotenv.2021.148480

Saint Akadiri S, Alola AA, Olasehinde-Williams G, Etokakpan MU (2020) The role of electricity consumption, globalization and economic growth in carbon dioxide emissions and its implications for environmental sustainability targets. Sci Total Environ 708:134653. https://doi.org/10.1016/j.scitotenv.2019.134653

Salahodjaev R, Sharipov K, Rakhmanov N, Khabirov D (2022) Tourism, renewable energy and CO2 emissions: evidence from Europe and Central Asia. Environ Dev Sustain. https://doi.org/10.1007/s10668-021-01993-x

Salehnia N, Karimi Alavijeh N, Salehnia N (2020) Testing Porter and pollution haven hypothesis via economic variables and CO2 emissions: a cross-country review with panel quantile regression method. Environ Sci Pollut Res 27(25):31527–31542. https://doi.org/10.1007/s11356-020-09302-1

Salman M, Long X, Dauda L, Mensah CN (2019) The impact of institutional quality on economic growth and carbon emissions: evidence from Indonesia, South Korea, and Thailand. J Clean Prod 241:118331. https://doi.org/10.1016/j.jclepro.2019.118331

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. https://doi.org/10.1016/j.scitotenv.2018.07.365

Shahbaz M, Sinha A (2019) Environmental Kuznets curve for CO2 emissions: a literature survey. J Econ Stud. https://mpra.ub.uni-muenchen.de/id/eprint/86281

Shahnazi R, Shabani ZD (2021) The effects of renewable energy, spatial spillover of CO2 emissions and economic freedom on CO2 emissions in the EU. Renew Energy 169:293–307. https://doi.org/10.1016/j.renene.2021.01.016

Shahzad MK, Zahid A, Rashid T, Rehan MA, Ali M, Ahmad M (2017) Techno-economic feasibility analysis of a solar-biomass off-grid system for the electrification of remote rural areas in Pakistan using HOMER software. Renew Energy 106:264–273. https://doi.org/10.1016/j.renene.2017.01.033

Shpak N, Ohinok S, Kulyniak I, Sroka W, Fedun Y, Ginevičius R, Cygler J (2022) CO2 emissions and macroeconomic indicators: analysis of the most polluted regions in the world. Energies 15(8):2928. https://doi.org/10.3390/en15082928

Sikder M, Wang C, Yao X, Huai X, Wu L, KwameYeboah F, Dou X (2022) The integrated impact of GDP growth, industrialization, energy use, and urbanization on CO2 emissions in developing countries: evidence from the panel ARDL approach. Sci Total Environ 837:155795. https://doi.org/10.1016/j.scitotenv.2022.155795

Song M, Fisher R, Kwoh Y (2019) Technological challenges of green innovation and sustainable resource management with large scale data. Technol Forecast Soc Chang 144:361–368. https://doi.org/10.1016/j.techfore.2018.07.055

Soylu ÖB, Adebayo TS, Kirikkaleli D (2021) The imperativeness of environmental quality in China amidst renewable energy consumption and trade openness. Sustainability 13(9):5054. https://doi.org/10.3390/su13095054

Sreenu N (2022) Impact of FDI, crude oil price and economic growth on CO2 emission in India:-symmetric and asymmetric analysis through ARDL and non-linear ARDL approach.

Environ Sci Pollut Res 29:42452–42465. https://doi.org/10.1007/s11356-022-19597-x

Suki NM, Suki NM, Sharif A, Afshan S, Jermsittiparsert K (2022) The role of technology innovation and renewable energy in reducing environmental degradation in Malaysia: a step towards sustainable environment. Renew Energy 182:245–253. https://doi.org/10.1016/j.renene.2021.10.007

Sun Y, Bao Q, Siao-Yun W, ul Islam M, Razzaq A (2022) Renewable energy transition and environmental sustainability through economic complexity in BRICS countries: fresh insights from novel method of moments quantile regression. Renew Energy 184:1165–1176. https://doi.org/10.1016/j.renene.2021.12.003

Tufail M, Song L, Adebayo TS, Kirikkaleli D, Khan S (2021) Do fiscal decentralization and natural resources rent curb carbon emissions? Evidence from developed countries. Environ Sci Pollut Res 28(35):49179–49190. https://doi.org/10.1007/s11356-021-13865-y

Umar M, Ji X, Kirikkaleli D, Shahbaz M, Zhou X (2020) The environmental cost of natural resources utilization and economic growth: can China shift some burden through globalization for sustainable development? Sustain Dev 28(6):1678–1688. https://doi.org/10.1002/sd.2116

Usman O (2022) Modelling the economic and social issues related to environmental quality in Nigeria: the role of economic growth and internal conflict. Environ Sci Pollut Res 29(26):39209–39227. https://doi.org/10.1007/s11356-021-18157-z

Wang EZ, Yang M (2022) Green complexity and CO2 emission: Does institutional quality matter? Energy Econ 110:106022. https://doi.org/10.1016/j.eneco.2022.106022

Wang S, Liu X, Zhou C, Hu J, Ou J (2017) Examining the impacts of socioeconomic factors, urban form, and transportation networks on CO2 emissions in China's megacities. Appl Energy 185:189–200. https://doi.org/10.1016/j.apenergy.2016.10.052

Wang Z, Danish, Zhang B, Wang B (2018) The moderating role of corruption between economic growth and CO2 emissions: evidence from BRICS economies. Energy 148:506–513. https://doi.org/10.1016/j.energy.2018.01.167

Wang R, Mirza N, Vasbieva DG, Abbas Q, Xiong D (2020) The nexus of carbon emissions, financial development, renewable energy consumption, and technological innovation: what should be the priorities in light of COP 21 Agreements? J Environ Manag 271:111027. https://doi.org/10.1016/j.jenvman.2020.111027

WDI (2022) World Bank Indicators. https://data.worldbank.org/indicator/EG.FEC.RNEW.ZS

Weimin Z, Sibt-e-Ali M, Tariq M, Dagar V, Khan MK (2022) Globalization toward environmental sustainability and electricity consumption to environmental degradation: does EKC inverted U-shaped hypothesis exist between squared economic growth and CO2 emissions in top globalized economies. Environ Sci Pollut Res 29:59974–59984. https://doi.org/10.1007/s11356-022-20192-3

Westerlund J (2007) Testing for error correction in panel data. Oxford Bull Econ Stat 69(6):709–748. https://doi.org/10.1111/j.1468-0084.2007.00477

Xue C, Shahbaz M, Ahmed Z, Ahmad M, Sinha A (2022) Clean energy consumption, economic growth, and environmental sustainability: what is the role of economic policy uncertainty? Renew Energy 184:899–907. https://doi.org/10.1016/j.renene.2021.12.006

Yang B, Ali M, Hashmi SH, Jahanger A (2022) Do income inequality and institutional quality affect CO2 emissions in developing economies? Environ Sci Pollut Res 29(28):42720–42741. https://doi.org/10.1007/s11356-021-18278-5

Yii KJ, Geetha C (2017) The nexus between technology innovation and CO2 emissions in Malaysia: evidence from Granger causality test. Energy Procedia 105:3118–3124. https://doi.org/10.1016/j.egypro.2017.03.654

You W, Li Y, Guo P, Guo Y (2020) Income inequality and CO2 emissions in belt and road initiative countries: the role of democracy. Environ Sci Pollut Res 27(6):6278–6299. https://doi.org/10.1007/s11356-019-07242-z

You W, Zhang Y, Lee CC (2022) The dynamic impact of economic growth and economic complexity on CO2 emissions: an advanced panel data estimation. Econ Anal Policy 73:112–128. https://doi.org/10.1016/j.eap.2021.11.004