RESEARCH ARTICLE

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

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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.

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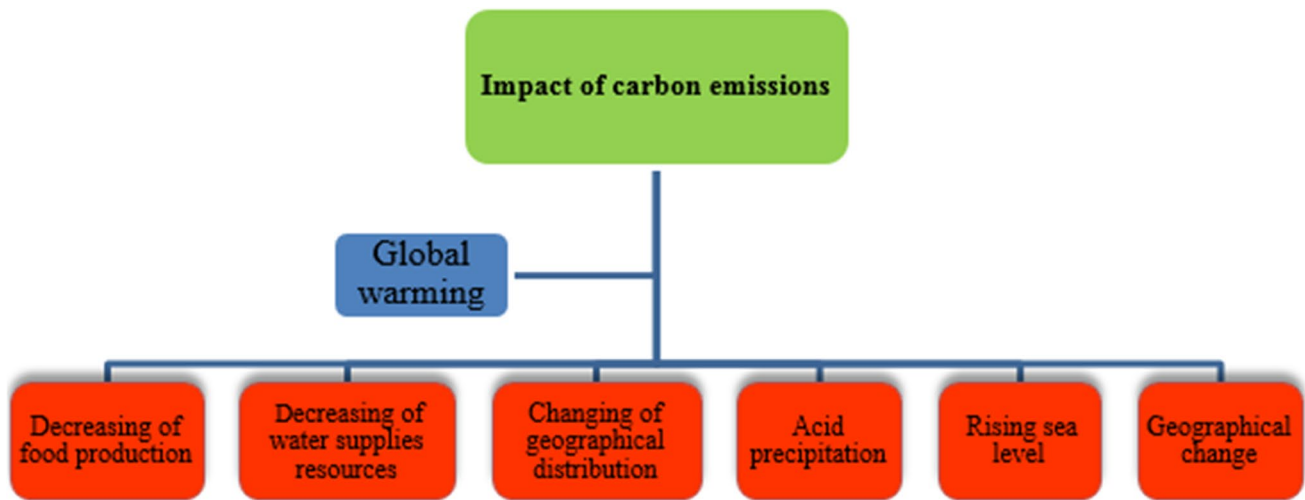
Fig. 1 Impacts carbon emissions on the environment. The authors created this figure

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
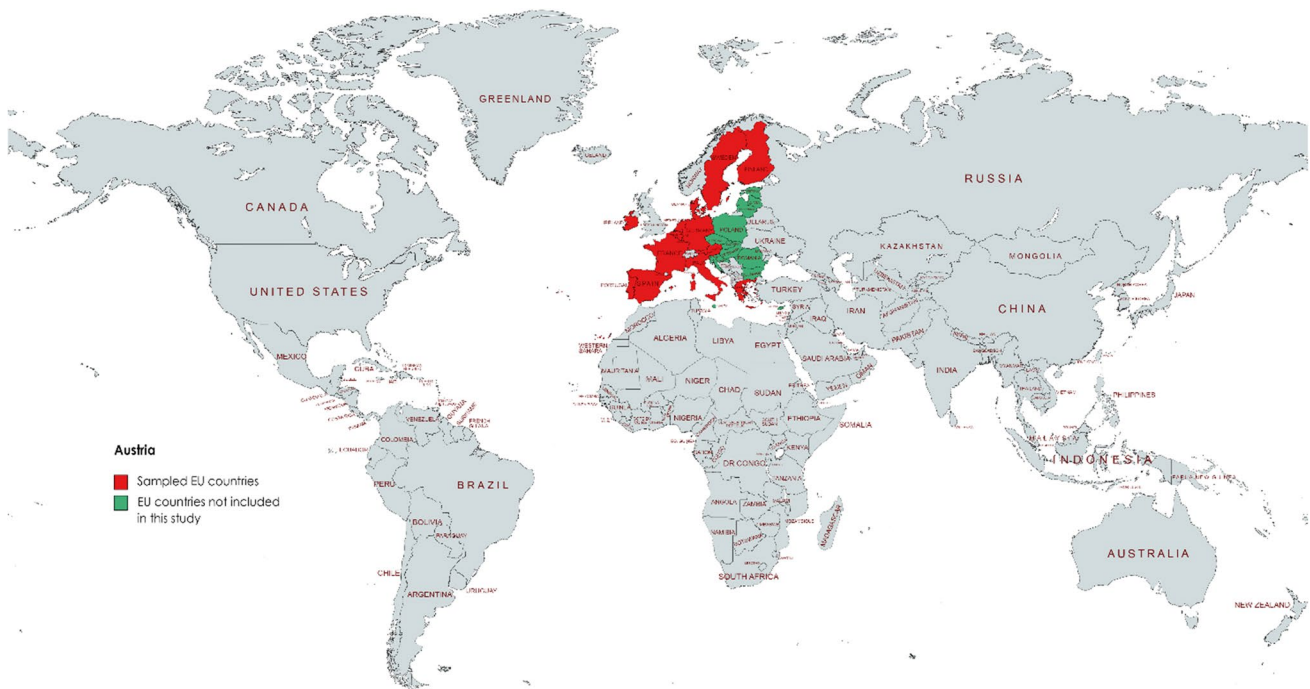

Fig. 2 Map of EU countries. The authors created this figure

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)										
	Location	Scale	Quantiles								
			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
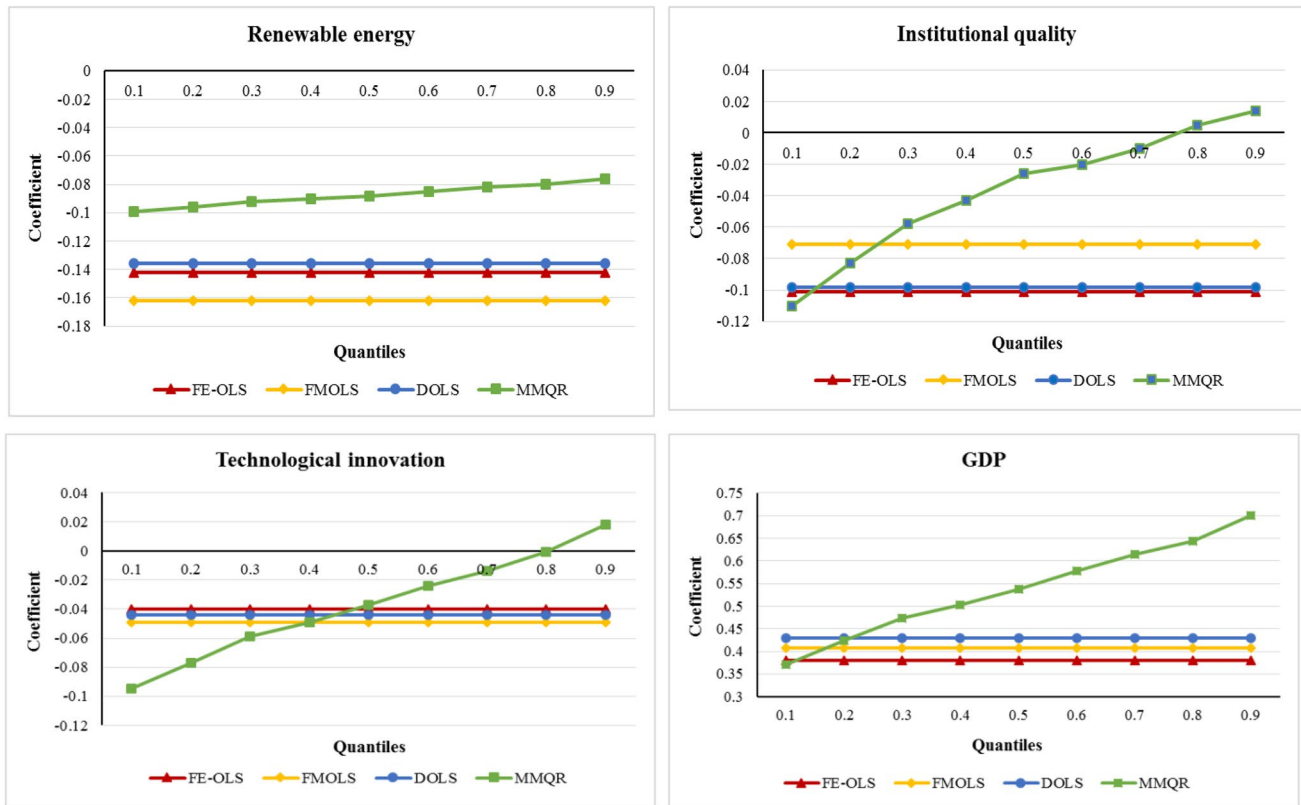
*Significance at the 10% level

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.

Declarations

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