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RESEARCH ARTICLE

Green technology, green electricity, and environmental sustainability in Western European countries

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Abstract

For Western European countries, many macroeconomic factors that have influenced environmental quality in several studies have been investigated. In this region, no empirical inquiry has explored the relationship between green technologies, renewable electricity, financial development, economic expansion, and eco-quality. To fill this gap, this inquiry is conducted to estimate the role of green technology innovation and green electricity on ecological balance in Western European countries. This study investigates how carbon dioxide emissions (CO_2E) may be influenced by its determinants (economic expansion, renewable energy, environmentally friendly technology) through some robust econometric techniques (second-generation panel unit root, Westerlund cointegration, FMOLS, and DOLS). Empirical findings confirm that renewable electricity and environmentally friendly technological innovations reduce CO_2E. However, the economic upsurge is positively correlated with CO_2E, suggesting that expanding the market has a deterioration effect on environmental quality. Policymakers in this region should allocate more resources to renewable electricity generation capacities and green technologies in order to minimize environmental damage. Further, the promotion of green and low-carbon energy development will contribute to a new form of global environmental governance.

Keywords Green technologies · Financial development · Environmental sustainability · Western European countries

Abbreviations

CO_2E	Carbon dioxide emissions
EU	European Union
kWh	Kilowatt-hour
GWh	Gigawatt-hours
NOX	Nitrogen oxides
SO_2	Sulfur dioxide
IRENA	International Renewable Energy Agency
R&D	Research and development
EGD	European Green Deal
FMOLS	Fully modified ordinary least squares
DOLS	Dynamic ordinary least squares
GDP	Gross domestic product
OECD	The Organization for Economic Cooperation and Development
ARDL	Autoregressive-distributed lag
EKC	Environmental Kuznets curve
BARDL	Bootstrapping autoregressive distributed lag
ETI	Environmental friendly technology
RE	Renewable electricity
FD	Financial development
AMG	Augmented mean group
CCEMG	Common correlated effect mean group
MG	Mean group

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Introduction

Climate change remains a topic of discourse as a comprehensive disaster, especially in the twenty-first century. A major contributing factor to carbon dioxide emissions (CO_2E) has been the overconsumption of nonrenewable energy. Moreover, climate change has posed a grave threat to human energy, food, and ecological security, posing a huge challenge to their survival (Chu et al. 2021; Kirikkaleli et al. 2022; Adebayo et al. 2022). Numerous studies have highlighted that constant consumption of energy is hazardous to the environment. The use of cleaner and more innovative technologies is essential to tackling these environmental challenges and lessening the emission of CO_2E in developed countries and developing countries alike. In addition, Ulucak and Khan (2020) assert that developing global clean energy sources requires reducing reliance on nonrenewable energy sources (coal, oil, and gas). Over the past few decades, the international community has become increasingly concerned with climate change. The international community has increasingly sought to set up a carbon–neutral and environmentally friendly model over the past few decades (Li et al. 2020). Further, many developed countries are increasing their supply of renewable energy as well as eco-innovation, which allows for the exchange of carbon-intensive energy sources and reduces the amount of pollution considerably. The carbon neutrality targets have been initiated by more than 130 countries and regions to achieve net-zero CO_2E by the twenty-first century, attaining a net-zero CO_2E. It is well established that decreasing greenhouse discharge is crucial for developing sustainable societies. Additionally, governments and non-governmental organizations have a responsibility to advance economic growth and enhance citizens' quality of life (Fan et al 2015).

Accomplishing carbon neutrality targets while simultaneously pursuing economic growth and development has become a global challenge for academics, environmental scientists, and politicians. Even though electricity is relatively clean and safe when used, it has an environmental impact when produced and transmitted (Adebayo et al. 2022). A plethora of studies have found that electricity is one of the biggest sources of CO_2E globally, for example, Akpan and Akpan (2012). Hence, it is imperative to understand how emissions (electricity in particular) generally impact the global environment. The studies of Mesagan and Olunkwa (2022) have emphasized how electricity power usage has been a contributing factor to elevated pollution levels following the windfall of oil during that period in the 1970s till date. Electricity generation from fossil fuels produces several pollutants which include NOX and SO_2 and principally carbon dioxide emissions which are dangerous to humans (Robinius et al. 2017). In the EU and USA, greenhouse gas emissions from the electricity sector are one of the biggest culprits of carbon emissions. The electricity sector comprises power plants that burn fossil fuels and fossil fuel–derived materials, Hence, pollution reduction in electricity generation is crucial for environmental protection. Accepting clean and renewable energy sources as a reliable alternative to fossil fuel is important for the lessening of global CO_2E. The international renewable energy agency (IRENA) predicted that by 2050, renewable energy sources would constitute more than 86% of electricity generation worldwide (Mostafaei et al. 2018). Further, the EU's gross electricity consumption grew to 37% in 2020 from 34% in 2019. As the economy recovered from the effects of the coronavirus pandemic and winter remained harsh, Germany (the largest electricity user in Western Europe) saw its electricity consumption increase in 2021, followed by other top global electricity consumers, including Belgium, France, and Italy which are contained in this study.

However, in spite of some progress in using clean energy, the majority of our electricity and fuel are still generated by dirty energy sources, such as coal, oil, and natural gas. Over two-thirds of global greenhouse gas emissions are attributed to fossil fuel combustion for heating, electricity, transport, and industry, according to the European Environment Agency. Hence, the answer for a reduction in CO_2E in these regions lies in renewable electricity. Increasing renewable electricity production in this region provides multiple opportunities to promote human health, protect the environment, mitigate climate change, and improve human welfare. Good monitoring, policy implementation, and possibly other targeted measures are necessary to achieve these goals.

In climate change discussions, energy plays an important role, since both economic growth and energy consumption need to be considered (Mohsin et al. 2020: Adebayo and Kirikkaleli 2021; Gyamfi and Adebayo 2022). Keeping growth and the environment in balance is today's challenge for policymakers. Economic expansion, CO_2E reduction, and zero-carbon economies can only be achieved by investing in R&D. EU economies rank among the world's best economies. The investment in energy can reduce the carbon intensity of the energy sector and stabilize greenhouse gas emissions at the same time as promoting economic growth. As a result of the previous study, an inverted U-shaped environmental Kuznets curve can be depicted as an illustration of how growth and environmental pollution interact in the literature. Accordingly, many empirical studies have argued that green growth is essential for sustainable development (Hao et al. 2021). Using eco-friendly alternative energy sources (biomass, hydro, solar) is necessary for neutralizing atmospheric CO_2E (Kirikkaleli and Sowah 2020). Nations, especially emerging nations, are often discouraged from changing their behavior to green alternatives because they are considered too expensive. But, when compared to the economic benefit attached, nations must invest in environmentally friendly and renewable technologies.

Is renewable electricity an effective vehicle that guarantees environmental stability in Western Europe? Is green electricity a veritable tool that can assist in the reduction of CO_2E in this region? Can climatic change be addressed without slowing down economic upsurge and financial development? These are the major concerns of most policymakers and environmental researchers in Western European countries. This study is motivated by the fact that most countries in this region (Western Europe) consume more electricity than countries in other parts of the EU. It is clear that electric power is a major contributor to CO_2E and electricity consumption continues to rise faster in recent times in the EU. For example, Germany is ranked as the highest net electricity producer in the EU in 2019, representing 20.8% out of the EU electricity generation. Next is France (19.7%) and Italy (10.2%), while Sweden 24.2% and Ireland 11.4% have realized an overall significant increase in energy generation (https://ec.europa.eu/eurostat/web/esgab/annual-reports). With the share of electricity in these countries constantly increasing, will the Paris climate agreement of temperatures below 1.5 °C in 2030 still be feasible? Although the European Green Deal (EGD) in December 2019 was launched to combat climate change, environmental risks, and ocean and forest pollution and further promotes low-carbon technologies, as well as reduces greenhouse discharges from the power sector, industry, and flights within the EU, we inquire again, by asking, is the European green deal achieving its goals in the West? How damaging is the high usage of electricity in manufacturing and production activities to the environment? Considering that most of the economies examined in this study are heavily industrialized and have heavy energy dependence, the issues raised are of utmost importance to environmental researchers.

With the use of advanced panel data methods, this empirical research is aimed at examining the role of renewable electricity and eco-friendly technologies in ten western European countries during 1990–2018. The following important aspects of this study contribute to the body of existing knowledge. In the past few decades, studies have investigated the dynamic relationship between CO_2E environmentally friendly technologies and economic growth (Adebayo et al. 2022; Awowusi et al. 2022; Kirikkaleli and Oyebanji 2022), but no study has examined the causal relationship between green electricity and CO_2E among high electricity users. Particularly, green electricity can be used as an alternative to conventional electricity in countries with high electricity consumption for countries such as Germany. A novel approach, second-generation panel unit roots and second-generation panel cointegration test, is also used to estimate this relationship. Finally, by examining the environmental impact of renewable electricity and eco-friendly technologies, this empirical study hypothesizes the implication of industrialization, globalization, and high electricity use on environmental quality and recommends the use of green electricity, which is lacking in the literature.

In the course of this study, three major contributions were made to the literature. By using panel data of high electricity users in rich economies in Western Europe, we examine the long-run effects of green technology and green electricity on emissions. To test for robustness, the approach also employs FMOLS and DOLS, which are the latest long-run panel techniques proposed by Westerlund (2007). Exploring the relationship between green electricity and CO_2E in these countries, it offers a comprehensive empirical analysis of the carbon trade relationship.

There are substantial policy implications to be gained from the findings of this paper for all countries in the study under review; for example, the international agencies in charge of energy and the regional economic blocks can create and implement energy policies that will ensure a secure and sustainable future for countries around the world. Additionally, this work is important for researchers, as it could open new directions for this research in the future. The rest of the paper is summarized below. Research reviews on relevant topics are provided in the “Literature review” section. It also describes the methods for collecting data, estimating outcomes, and analyzing the results. There is an empirical result section with findings and discussion and a conclusion and policy implication section with policy implications.

Literature reviews

The nexus between renewable electricity and CO_2E

Saint Akadiri et al. (2019) explored the interrelationship between globalization, electricity usage, GDP, and CO_2E. The outcome of the study demonstrated that renewable energy sources should be the prime importance. Hanif et al. (2020) showed that increased fossil fuel consumption, resource depletion, economic growth, and population growth pressure would cause an increase in CO_2E in Asia’s emerging market. The conclusion of this empirical study indicates that green energy sources like solar and wind must be promoted to stimulate and boost economic growth in emerging countries. Further, Bento and Moutinho (2016) explored the linkage between renewable and nonrenewable electricity production in Italy. The study employed data covering from 1960 to 2011. According to the results of this study, RE production and economic development are causally related in a unidirectional manner, and furthermore, the outcome indicates that the causality runs from GDP to RE, which explains why growth occurs. In addition, the results indicated a unidirectional causal relationship between nonrenewable electricity and renewable electricity, suggesting a conservation effect in Italy. Using data from twenty OECD countries covering the period 1990–2008, Ohler and Fetters (2014) investigated the interrelationship between renewable energy electricity production and GDP growth. According to the findings of this empirical study, renewable energy sources such as hydropower, waste, biomass, and wind power are crucial to affecting the growth levels of the countries under study, and growth in renewable electricity improves economic development as a result. In addition, a causal analysis of the variables reveals that economic growth and total renewable electricity are subject to a feedback effect. The study by Wang et al. (2023) emphasized that clean energy has a strong causal link with the environmental footprint in China.

Financial development, economic growth, and CO_2E

Usman and Balsalobre-Lorente (2022) indicated that environmental quality is accelerated by financial development in Pakistan. The study of Okeke (2022) further argue that financial development, fossil fuel consumption, and urban population are factors that contribute to polluted environments through the use of robust techniques like dynamic ARDL simulation and kernel-based regularized least-squares analysis for the case of Peru. A study by Al-Mulali et al. (2012) examines how CO_2E and energy consumption impact financial development and finds that energy consumption benefits financial development, which in turn increases CO_2E. In a similar vein, Jalil and Feridun (2011) studied the relationship between financial development and energy consumption and concluded that financial development contributed to high growth rates. Zhang (2011) asserts that financial institutions play a crucial role in reducing CO_2E. Research and investment in clean technologies such as renewable energy projects to increase environmental protection and reduce emissions are two ways in which financial institutions enhance the quality of the environment and promote environmentally friendly projects. Tamazian and Rao (2010) argue that financial development has negative effects on CO_2E, while Zhang (2011) asserts that financial development increases CO_2E. However, Acaravci and Ozturk (2012) pointed out that financial factors have no effect on CO_2E in Turkey.

Environmental friendly technologically innovation CO_2E

A mixed picture has emerged regarding the technology-carbon emission relationship. Some of them are discussed in this section. In comparison to current technologies, ecologically sound technologies contribute to pollution abatement that is beneficial to the environment (Quitzow 2015). According to the theoretical underpinnings of ecological innovation, environmental quality can be improved through environmentally sound technology by incorporating environmental regulations, cleaner production innovations, and reducing the environmental footprint of commercial activities (Diana et al. 2017). Technological innovation also led to a reduction in energy absorption and emissions among BRICS nations, according to Santra (2017). In the BRICS, Rafique et al. (2020) found that technological advancements reduce pollution. According to Sinha et al. (2020), technological development increases emissions in eleven countries. In 2001, Khan et al. concluded that technological innovation plays no role in environmental sustainability. According to Khan et al. (2020), new technologies reduce emissions in the BRICS region since they support energy-efficient technologies. The study of Mensah et al. (2018) highlights that technological advancement reduces emissions in OECD countries, but EKC is not valid for these nations. Research and development in the energy sector contribute to energy sector innovation, according to Loch et al. (2020). Adnan Khurshid et al. (2022) examined carbon taxes and environmental policy against the backdrop of technological innovation. Eco-friendly innovations and ecological policies support emissions both over the long and short term in selected 15 EU nations. The relationship between CO_2E and its determinants was also examined by Shahbaz et al. (2020) using a bootstrapping autoregressive distributed lag (BARDL) model. The outcomes of the study highlight that technological innovation adversely lessens emission significantly over the long term. This study further recommends that eco-friendly technologies should be encouraged in Pakistan. Futher, the study of Zhang et al. (2022) reveals that technological development has both favorable and adverse impacts on ecological sustainability.

Methodology

The study is aimed at establishing a link between green technologies, renewable electricity, financial development, economic expansion, and environmental quality in ten Western European countries as well as some high electric users in the EU between 1990Q1 and 2018Q4. Using some robust econometric techniques, this study examines this relationship and provides insightful policy recommendation.

Theoretical basis for selecting variables and defining models

The environmental Kuznets curve (EKC) presents the theoretical framework of the study. Mesagan et al. (2021) identify economic expansion as a core factor in determining pollution across countries. As indicated by the EKC, how income affects pollution in a country is an inverted U-shape. A lot of discussions has been conducted on Grossman and Krueger's (1991) EKC hypothesis, which suggests that economic advancement diminishes environmental quality, but contributes to it when a specified level of growth is reached. Khan et al. (2021) and Abid et al. (2021) underlined the importance of eco-friendly growth policies. Hence, GDP was incorporated into our study. Additionally, many research studies have argued that wealthy economies are capable of investing in ecological technological advancements that promote economic growth as well as help limit environmental pollution (Shao et al. 2021). Eco-technological innovation generally mitigates the unfavorable ecological influences of economic growth eco-friendly energy sources (Tao et al. 2021). There has also been discussion in the plethora of studies on how technological innovation can help develop environmental technologies. The study of Chen et al. (2022) hypothesizes that technological innovation can help achieve the Paris Agreement goals by reducing emissions from energy consumption (the use of relatively clean energy sources is also recommended in numerous studies, which can contribute to reducing air pollution). Hence, environmentally friendly technological innovation is integrated into our study. In addition, Murshed (2020) states that fossil fuel–based electricity deteriorates the environment by releasing hydrocarbons. There has been an assertion that burnt fossil fuels are leading to climate change because they emit harmful gases during the production of electricity. Thus, the quality of the atmosphere deteriorates (Murshed 2021). Energy sources like renewable electricity reduce fossil fuel extraction and greenhouse gas emissions by reducing the need to extract fossil fuels and reducing the amount of carbon dioxide produced (Belaid and Zrelli 2019). Renewable electricity is a major player in mitigating globally. Consequently, renewable electricity is included in our study. Lastly, there have also been numerous empirical investigations that have outlined the ambiguous impact of financial development across the globe (Xu et al. 2021). The study of Abokyi et al. (2019) hypothesized that financial development facilitates capital investments, which then generate output that, in turn, deteriorates the environment, especially in fossil fuel–dependent countries. Enhanced investments in green technologies can, on the other hand, minimize the negative effects on the environment with fiscal development (Charfeddine et al. 2019). Research and development can also benefit from a strong financial system because low-interest loans are available.

Data

Our study employs quarterly panel data variables covering between 1990 and 2018. The dependent variable is carbon emission (CO_2E) and the independent variables are renewable electricity (RE), financial development (FD), economic growth (GDP), and green environmental innovations. Variables are sourced from the database of World Bank (https://data.worldbank.org/) and OECD (https://data.oecd.org/). The study is aimed at exploring the linkage between CO_2E and renewable electricity (RE), financial development (FD), environmental friendly technology (ETI), and economic growth (GDP) (Table 1).

Table 1 Descriptive statistics

Variable	Mean	Std. Dev	Min	Max
LCO_2E	11.21209	1.595214	7.528332	13.76979
LGDP	26.55003	1.554302	22.55081	29.01113
ETI	18.91748	14.36098	0	62.67
RE	37.89349	34.41619	0.7235828	99.99055
FD	0.6414889	0.1210208	0.3391013	0.8555176

Empirical findings and discussion

This study investigates how CO_2E may be influenced by its determinants (economic expansion, renewable energy, environmentally friendly technology, and financial development). Under this subsection, we continue with the cross-section dependence tests, which provide a pointer for the econometric techniques that are to be used. Recent panel studies have widely accepted the CSD test since residuals are not cross-sectional independent in reality. The notion of "cross-sectional independence" is flawed when assessing macroeconomics because there is a considerable interconnection among countries. By using CSD tests, panel data difficulties can be overcome as well as robustness and reliability of estimators can be ensured. Here, two CSD tests were used. CSD could likely affect the reliability of the results of the first-generation tests; hence, the use of second-generation tests such as the cross-sectional enhanced IPS (CIPS) in determining the order of integration for green electricity, financial development, expansion growth, and green technologies for an environmental footprint for Western Europe.

$$\Delta Y_{i,t} = \gamma_i + \gamma_i Y_{i,t-1} + \gamma_i \overline{X}_{t-1} + \sum_{l=0}^{p} \gamma_{il} \Delta \overline{Y_{t-l}} + \sum_{l=1}^{p} \gamma_{il} \Delta Y_{i,t-l} + \varepsilon_{it} \tag{1}$$

where the lagged parameter is illustrated as $\overline{Y}_{t-1}$ and the first differences of $\overline{Y}_{t-1}$ symbolize $\Delta \overline{Y_{t-l}}$.

$$\widehat{\text{CIPS}} = \frac{1}{N} \sum_{i=1}^{n} \text{CADF}_i \tag{2}$$

Using the CIPS unit root test, we can verify the unit root properties of time series variables. The outcomes of the CIPS unit root test are reported in Table 2. The tests display that ETI and financial development are stationary at levels while LCO_2E, FD, LGDP, and RE variables are stationary at their first differences.

Table 2 Second generation panel unit root test

Variables	CIPS 1(0)	CIPS 1(1)
LCO_2E	−1.733	−4.679***
LGDP	−2.140*	−2.566***
RE	−1.886	−2.667***
ETI	−2.692**	——
FD	−2.116	−4.361***

*, **, and *** are for 10%, 5%, and 1% significance levels, respectively

Our second approach is to estimate the panel cointegration test. This test is based on the cointegrating relationship among the investigated parameters (for green electricity, financial development, expansion growth, and green technologies for environmental footprint), using the Westerlund method. This method addresses the common factor limitation problem that plagued the first generation of cointegration tests. Using an error-correction model cointegration test, the null hypothesis of no cointegration is explored. Tests determine if an error-correction term in a conditional panel error-correction model equals zero. According to the equation below, the *T*-statistics of the Westerlund cointegration test is as follows:

$$G_t = \frac{1}{N}\sum_{i-1}^{N}\frac{\acute{\alpha}_i}{SE(\acute{\alpha}_i)} \tag{3}$$

$$G_\alpha = \frac{1}{N}\sum_{i-1}^{N}\frac{T\acute{\alpha}_i}{\acute{\alpha}_i(1)} \tag{4}$$

The present study applies the Westerlund cointegration test in order to capture the cointegrating relationship among the investigated parameters, namely, green electricity, financial development, expansion growth, green technologies, and environmental sustainability. This method addresses the common factor limitation problem that plagued the first generation of cointegration tests. "The Westerlund panel cointegration test is a robust test to handle the CD and slope heterogeneity concerns in the data" (Li et al 2021a, b). The results from the Westerlund test, as indicated in Table 3, confirm long-term associations between CO_2E, GDP growth, green electricity, green technology, and financial development in ten selected western European countries. The validation of the long-term cointegrating linkages satisfies the assumption of performing a regression analysis to estimate the short- and long-term elasticities.

Table 3 Westerlund cointegration

Statistics	Value	*Z*-value	*P* value
Gt	−2.147	0.516	0.05
Ga	−4.473	2.404	0.33
Pt	−7.146	2.605	0.04
Pa	−5.218	0.488	0.03

Further, we proceed to our main estimator which is the augmented mean group (AMG). Eberhardt and Teal (2010) developed the AMG model as an alternative to the common correlated effect mean group (CCEMG) model by Pesaran (2006). The AMG uses a panel-average method to calculate unit-specific parameters. The AMG model's common dynamic effect is different from the mean group model (MG), which uses combined regression modeling augmented with year dummies. Moreover, Atasoy (2017) asserts that conventional panel models may be incompatible if the regressors are the cause of cross-section reliance. Therefore, using the AMG model for estimation is appropriate because the model captures cross-sectional dependence across members while allowing for unobserved correlations. The findings of the AMG estimator are reported in Table 4. The finding suggests that a 1% increase in renewable electricity will result in a reduction of carbon emission by −0.026% and it is statistically significant. Green electricity has a lowering effect on all the panels. Further, consistent with other pieces of literature. This study found that economic growth increases CO_2E (Olayungbo et al. 2022; Sun and Tang 2022; Su et al. 2022; Chen et al. 2019). Our study found that a 1% increase in economic growth will result in a 0.0975% increase in CO_2E; results on economic growth indicate an escalating effect on emissions in all the panels. Financial development has a favorable impact on carbon emission but it is statistically insignificant and energy consumption substantially increases emissions lastly. Overall, the results from AMG estimates suggest that in most cases, both green energy and financial development play a crucial role in the reduction of carbon emission role.

Table 5 shows the results of a robustness check (FMOLS and DOLS) that supports the main model developed in the study. The models are estimated by using the panel fully modified least squares (FMOLS) and DOLS technique. It is also a robust panel econometric technique for handling

Table 4 Panel estimators

Variables	AMG
LGDP	0.0975 ** (0.03)
FD	−0.060 (0.11)
RE	−0.026*** (0.01)
ETI	−0.0021 *** (0.001)

*, **, and *** are for 10%, 5%, and 1% significance level and this depicts the *P* values

Table 5 Panel robust estimators

Variables	FMOLS	DOLS
LGDP	0.139 ** (0.02)	0.124 *** (0.00)
FD	0.22 (0.81)	0.125* (0.08)
RE	0.0097*** (0.000)	−0.010*** (0.000)
ETI	−0.005*** (0.001)	−0.006** (0.003)

*,**, and*** are for 10%, 5%, and 1% significance level and this depicts the *P* values

Table 6 Dumitrescu and Hurlin causality analysis

	W-Stat	Zbar-Stat	Prob
LGDP causes LCO_2E	6.518***	5.614	0.000
RE causes LCO_2E	4.147**	2.532	0.011
ETI causes LCO_2E	8.085***	7.651	0.000
FD causes LCO_2E	2.624	0.552	0.580

*,**, and*** are for 10%, 5%, and 1% significance level

issues of heterogeneity in estimation (Pedroni 1995; Kao and Chiang 2001). In particular, this approach uses the long-run covariance estimates from cross-sectional estimates and reweights them to take into account heterogeneity. The outcome of the study has shown that a 1% increase in economic growth will result a 0.1391% and 0.124% increase in CO_2E, as demonstrated by FMOLS and DOLS, respectively. This study is in line and consistent with Chen et al.'s (2019) study that confirmed the validity of the EKC in 188 countries. Further, Ridzuan et al. (2017) endorsed an EKC in 174 nations; Sarkodie and Ozturk (2020) validated it in Kenya, and Pandey et al. (2020) validated it in Pakistan. As a result of a 1% increase in renewable electricity, the study shows a 0.0097% and 0.010% reduction of carbon dioxide emissions, based on the FMOLS and DOLS, respectively. In line with the study of Li et al. (2021a, b), this study also shows that a 1% increase in financial development was accompanied by 0.22% in FMOLS and 0.125% in DOLS, respectively. Finally, the decline in the CO_2E, due to green technologies, is demonstrated by a 1% rise in environmentally friendly technology by −0.005% and −0.006% by FMOLS and DOLS, respectively.

As a final step, the present study also employs the panel causality test of Dumitrescu and Hurlin (2012) to capture the causal effect of economic growth, renewable electricity, environmentally friendly technology, and financial development on CO_2E. As shown in Table 6, the outcomes of the Dumitrescu-Hurlin (DH) causality test report that the DH granger test finds that RE, GDP, and ETI cause CO_2E in Western European countries, indicating that RE, GDP, and ETI are important predictors of CO_2E in Western European countries. The outcomes can be supportive evidence for the long-run outcomes of the present study. The main findings of the present study are reported in Fig. 1.

Conclusion

Climate change and energy conservation are two of the most pressing environmental issues. Also, accelerating the decarbonization of gases and phasing out coal, Western European countries will have to develop a power sector based heavily on renewable resources. For this goal to

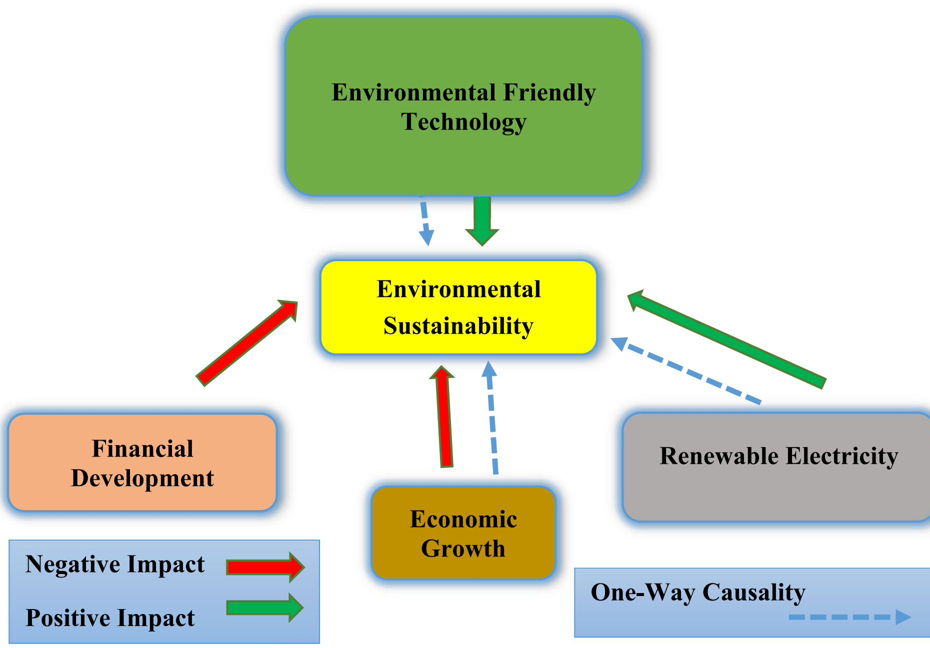

Fig. 1 Graphical illustration of the outcomes

be achieved, the European energy market must be fully integrated, interconnected, and digitalized. Sustainable solutions, environmental-friendly technologies, and disruptive innovation all play an important role in achieving the goals of the green deal. Developing and demonstrating novel eco-friendly technologies across sectors as well as within the single market are essential for the EU to maintain its leadership status in clean technologies, creating new value chains in western European countries that use more energy. Studying how green electricity contributes to CO_2E, is the major purpose of this study. The study examined the interrelationship between green electricity, GDP, financial development, environmental and technological innovation, and CO_2E, based on AMG, FMOLS, and DOLS and panel evidence from ten countries in Western Europe with the highest electricity usage. The findings of the study reveal that green electricity and environmental and technological innovation lower CO_2E while economic expansion and financial development amplifies.

As electricity is a major source of carbon dioxide emissions worldwide, this study attempts to suggest and recommend the necessity of green electricity in combating climate change. Furthermore, bidirectional causal relationships were revealed by the causality analysis. A number of relevant policies can be recommended in light of these findings. Environmental development objectives must be included in the economic growth plans of this region as a first step. Consequently, these economies can sustain their economic growth without compromising the environment. Ecologically sustainable consumption and production processes are essential for these nations to prosper economically and preserve the environment. As noted in the study, economic growth and financial development have a positive impact on CO_2; hence, for these selected Western European countries, we recommend that these countries should aim for domestic consumption levels in order to reduce the impact that economic growth has on CO_2E, especially in energy-intensive sectors. Further, to replace dirty resources in all sectors of their economies, these countries must use cleaner ones. These selected groups of 10 western European countries (especially Germany) should implement policies that facilitate the transition to renewables at national, regional, and global levels in order to enhance their renewable electricity generation. Energy infrastructure development should be invested in by the governments of the countries if they are to substantially increase their renewable electricity generation capabilities. Investing in research and development of renewable energy technologies that can provide large quantities of electricity from renewable resources is necessary. To conclude, the government should establish a public–private partnership to facilitate ecologically sustainable technologies within the region. The EU as a whole should also encourage ecologically sustainable technologies. Technological innovation that protects the environment can reduce adverse environmental impacts.

Within the selected countries of the EU, investments in technology may inhibit the development of pollution-intensive industries. Also, we recommend that the selected EU nations should integrate their financial development strategies with environmental welfare objectives to enhance their respective financial development policies. Compared to other countries, western European nations should allocate a relatively higher proportion of their domestic credit to clean private sector industries. The government should also consider providing subsidies for eco-friendly investment projects, which will further minimize negative environmental impacts related to financial development. One of the major flaws of this study is its focus on ten Western European countries. As a result, future research will be able to analyze the electricity usage in Western Europe, as well as the economies of European countries in general. A novel econometric approach and machine learning algorithms can further be used in future research to explore the linkage between green electricity and CO_2E.

Author contribution An investigation and data collection were conducted by Dervis Kirikkaleli and Modupe Oluyemisi Oyebanji. Dervis Kirikkaleli prepared the methodology and empirical findings as indicated in this paper, while Modupe Oluyemisi Oyebanji drafted the introduction and literature review. In addition, Dervis Kirikkaleli assisted in explaining the results. In conclusion, I confirm that all authors have reviewed and approved the final version of the paper.

Data availability The data that support the results of this research are accessible from the World Bank and OECD.

Declarations

Ethics approval No ethical authorization or informed consent is required for this research.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

We declare that this is an original paper, is not under consideration for publication by another journal, and has not previously been published.

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