Environmental Science and Pollution Research (2023) 30:24629–24640
https://doi.org/10.1007/s11356-022-24002-8

RESEARCH ARTICLE

Are the impacts of renewable energy use on load capacity factors homogeneous for developed and developing nations? Evidence from the G7 and E7 nations

Uzma Khan[1] · Aarif Mohammad Khan[1] · Mohammad Shahfaraz Khan[2] · Paiman Ahmed[3,4] · Ansarul Haque[5] · Rawnaq Ara Parvin[6]

Received: 19 June 2022 / Accepted: 31 October 2022 / Published online: 8 November 2022

Abstract

Both developed and underdeveloped economies worldwide are now more concerned than ever in respect of achieving environmental sustainability. Accordingly, the majority of the global economies have ratified several environment-related pacts to facilitate the tackling of global environment-related problems. Although these problems are assumed to be addressed using diverse mechanisms, limiting the use of fossil fuels has often been recognized as the ultimate enabler of environmental sustainability. Against this backdrop, this study aims to assess the environmental impacts associated with higher renewable energy use, controlling for economic growth and population size, in the context of the G7 and E7 countries using data from 1997 to 2018. Moreover, instead of using the traditional environmental quality proxies, this study tries to proxy environmental degradation with the load capacity factor levels of the countries of concern. The long-run associations among the study's variables are confirmed by outcomes generated from the cointegration analysis. Besides, regression analysis highlighted that integrating renewable energy into the energy systems while withdrawing from the use of fossil fuels can help to improve environmental quality by increasing the load capacity factor levels. In contrast, economic growth and population size expansion are evidenced to impose environmental quality-dampening impacts by reducing the load capacity factor levels. However, the findings, in the majority of the cases, are seen to differ across the groups of the G7 and E7 countries, especially in terms of the variations in the magnitudes of marginal environmental effects over the short and long run. Lastly, the causality analysis confirms the directions of the causal relationships among the variables of concern. Based on these results, a couple of policy interventions are recommended for improving environmental quality in the G7 and E7 countries.

Keywords Renewable energy · Load capacity factor · Environmental sustainability · G7 countries · E7 countries

Responsible Editor: Roula Inglesi-Lotz

✉ Ansarul Haque
ansarul.haque@ibrict.edu.om

1 College of Business Administration, Prince Sattam Bin Abdulaziz University, Alkharj, Saudi Arabia

2 Department of Business Administration, University of Technology and Applied Sciences, Salalah, Oman

3 Department of Law, College of Humanity Sciences, University of Raparin, Ranya, Iraq

4 International Relations and Diplomacy Department, Faculty of Administrative Sciences and Economics, Tishk International University, Erbil, Iraq

5 Business Studies Department, University of Technology and Applied Sciences, Ibri, Oman

6 Department of Sociology, Varendra University, Rajshahi, Bangladesh

Introduction

In the twenty-first century, improving the environment is of paramount importance since it is linked with sustainable economic performance in the future (Yuping et al. 2021; Rehman et al. 2021; Zhao et al. 2022). As a result, this utmost important agenda of enhancing the well-being of the environment has necessitated the withdrawal from the use of unclean energy to clean energy (Murshed 2021a; Khan et al. 2022). Notably, it is often prescribed that developing the renewable energy sector can facilitate the renewable energy transition process to expedite the attainment of the environmental welfare-enhancement objective (Hamid et al. 2021; Ahmed et al. 2022a; Bashir et al. 2022). Accordingly, the United Nations have recognized renewable energy as a facilitator of a safer future for the global economy whereby renewable energy transition can be anticipated to help the world nations to become more resilient to climate change-related problems (Nathaniel et al. 2021; Murshed et al. 2021a; Abbass et al. 2022). Besides, the "2030 Sustainable Development Goals" agenda has also manifested the pertinence of amplifying the global availability of low-cost renewable energy to reduce the environmental damages associated with energy use and economic growth (Ahmed et al. 2021; Molefe and Inglesi-Lotz 2022; Murshed et al. 2021b). Tackling environmental problems with the help of renewable energy is based on the understanding that the use of renewable energy resources, unlike fossil fuel consumption, does not trigger massive emissions of carbon dioxide and therefore does not impose significant environmental threats (Razmjoo et al. 2021; Sharif et al. 2019; Dogan and Ozturk 2017).

Nevertheless, despite its immense significance, the global renewable energy sector, as a whole, remains underdeveloped. The global energy system is heavily dominated by fossil fuels as renewable energy accounts for merely 20% of the primary energy mix (IEA 2021a). The situation is also dismal in the context of the global power sector since less than 30% of the electricity output generated worldwide comes from the combustion of renewable resources (IEA 2021b). These undesirable statistics give the idea that the task of combating the barriers that hinder the prospects of securing environmental sustainability through the renewable energy transition is equally difficult for both developing and developed countries. Besides, the fact that environmental problems are faced by all global economies, irrespective of their development categories, it is important to check whether renewable energy transition is a universal solution to environmental problems faced worldwide.

Against this backdrop, this study empirically compares the effects of renewable energy use on environmental quality across panels of developed and developing nations. In this regard, the analysis is conducted separately for the Group of Seven (G7) and Emerging Seven (E7) countries which are classified as leading developed and developing global nations, respectively.[1] Although the existing studies concerning the renewable energy-environmental quality nexus have either conducted similar analyses considering a mixed panel of developed and developing nations (Vo et al. 2020; Rehman et al. 2022; Ibrahim 2022; Chien et al. 2022) or have considered countries belonging to a particular development category (Dong et al. 2022; Yu et al. 2022; Agozie et al. 2022), limited evidence is available regarding a comparative empirical analysis. Such comparisons are essential to justify whether a universal renewable energy transition plan should be followed globally or whether dissimilar policies are needed for countries that are at different phases of development. Besides, another contribution of this study is in the form of identifying whether or not renewable energy use homogeneous exerts indirect environmental impacts by jointly influencing the environmental indicators with other major macroeconomic factors. In contrast, the available empirical studies in the related literature have mostly emphasized the direct environmental impacts of renewable energy (Afshan et al. 2022; Li et al. 2022; Xue et al. 2022). Lastly, this study is one of the few ones that use the load capacity factor[2] as the proxy of environmental quality which apart from emphasizing the level of environmental damage also provides a comprehensive account of environmental hardships by comparing the extent of environmental damage in relation to the ecological capacity to accommodate the damage. Contrastingly, the preceding studies have either used carbon dioxide emissions (Anwar et al. 2022; Xu et al. 2022) or ecological footprints (Ahmed et al. 2022b, 2022c; Huang et al. 2022) to quantify the environmental impacts associated with higher use of renewable energy.

The forthcoming sections present the following components of the study. The literature review is presented in the next section which summarizes the findings documented by the previous studies. Next, the methodology is presented which describes the empirical model and the estimation strategy followed in the study. Subsequently, the results from the empirical analysis are reported and interpreted accordingly. Lastly, the conclusion section provides the concluding remarks along with potential policy implications.

Literature review

This section has two major sub-sections. In the former, the conclusions drawn in prior studies on the renewable energy-environmental quality nexus for the developed countries are presented while the latter summarizes similar studies conducted on samples of developing countries.

Literature on renewable energy-environmental quality nexus or developed nations

Conventionally, carbon dioxide emissions were the mostly used indicator of environmental quality under the assumption that rising (declining) emission levels go on to degrade (improve) the quality of the environment (Balsalobre-Lorente et al. 2021; Usman et al. 2022a). In a study on the G7

[1] "The G7 countries include Germany, Italy, Canada, France, Japan, the USA, and the UK. The E7 countries include Brazil, India, China, Indonesia, Mexico, Russia, and Turkey."

[2] For an in-depth understanding of the load capacity factor, see Pata and Balsalobre-Lorente (2022) and Awosusi et al. (2022).

countries, Hao et al. (2021) considered annual data for the 1991–2017 period and found evidence that greater use of renewable energy improves environmental quality by lessening carbon dioxide emissions. Similarly, using annual data from 1994 to 2014 in the context of the G7 nations, Doğan et al. (2022) made similar conclusions and also pointed out that the imposition of stringent environmental taxes amplifies the carbon emission-inhibiting effects of renewable energy use. The negative correlation between renewable energy use and carbon emissions was also verified by Destek and Aslan (2020) for the G7 nations, Ponce and Khan (2021) for nine developed countries, Amin et al. (2020) for European nations, and Rahman and Vu (2020) for Australia. Likewise, Qin et al. (2021) showed that in the G7 countries higher investments in projects concerning renewable energy development result in lower emissions of carbon. In contrast, some studies have also found that promoting renewable energy consumption is not sufficient for reducing carbon emissions. Among these, Destek and Aslan (2020) commented that enhancing hydroelectricity use does not mitigate emissions in Germany, the USA, France, Canada, and Japan. Besides, the authors also asserted that solar power consumption is ineffective in explaining the variations in the carbon emission figures of the G7 nations. Similarly, Rahman and Vu (2020) also remarked that Canadian carbon emission levels are not influenced by the nation's renewable energy consumption levels.

In recently published studies, carbon emissions are no longer considered as comprehensive indicators of environmental quality. Rather, the ecological footprints are used as an alternative environmental indicator assuming that it takes into account different dimensions of environmental pollution (Zeraibi et al. 2021). "Based on numerous ecological demands, the ecological footprints are measured in terms of biologically productive land areas required for meeting the ecological demand and absorbing the ecological wastes and byproducts that are associated with the consumption of the ecological resources (Alvarado et al. 2022; Yasin et al. 2022)." In the context of the G7 nations, Chu and Le (2022) used data from 1997 to 2015 and revealed that renewable energy use contributes to bettering environmental quality by reducing ecological footprints in the long run. Similarly, using data from 1991 to 2016, Raza and Shah (2018) also found that renewable energy use and ecological footprints are negatively correlated; thus, the authors concluded that renewable energy use can be the technique effect that can aid the G7 countries to reduce their trade-offs between greater economic growth and higher ecological footprints. Identical conclusions were presented in the existing studies documented by Usman et al. (2020) for the USA and Alola et al. (2019) or 16 members of the European Union. On the other hand, while the majority of the existing studies have outlined the ecological footprint-inhibiting capacity of renewable energy, Murshed et al. (2022) opined that higher use of renewable energy rather amplifies the carbon footprint levels of the G7 countries. It is important to note that carbon footprints are a subset of total ecological footprints.

Although ecological footprints are comprehensive environmental indicators on their own, recent studies have argued that the load capacity factor, which is the ratio of the biocapacity to ecological footprints, goes one step further in providing the extent of environmental degradation in comparison with the natural biocapacity to handle/absorb the footprints (GFN 2022; Pata and Balsalobre-Lorente 2022; Awosusi et al. 2022). It is argued that a load capacity factor value of more than one indicates that the ecological footprints are less than the natural biocapacity to meet ecological demand and absorb ecological wastes; consequently, this surplus scenario can be interpreted as a situation of environmental sustainability (Pata and Balsalobre-Lorente 2022). Accordingly, a load capacity factor value lower than one can be interpreted as an unsustainable environmental situation (Pata and Balsalobre-Lorente 2022). In a related study on France, Pata and Samour (2022) mentioned that higher consumption of renewable energy does not significantly improve the environmental conditions since it fails to explain the variations in the French load capacity factor levels. In addition, the authors also claimed that nuclear energy consumption stimulates environmental well-being by increasing the level of load capacity factor in France. Similarly, Pata (2021) concluded that although higher renewable energy consumption guarantees a rise in the load capacity factor levels of the USA, it cannot establish similar environmental welfare-improving impacts in Japan.

Literature on renewable energy-environmental quality nexus or developing nations

Considering the cases of developing economies, several researchers have shared their insights on the effects of renewable energy use on their carbon emission levels. Aydoğan and Vardar (2020) employed annual data from 1990 to 2014 in the context of the E7 nations and found that enhancing the share of renewables in the energy mix of these underdeveloped nations is essential in reducing their carbon emission figures in the long run. Similar findings were discussed in the E7 context by Yunzhao (2022). In contrast, for the E7 nations between 1995 and 2018, Gyamfi et al. (2021) recorded empirical evidence regarding higher renewable electricity output resulting in higher emissions of carbon dioxide in the long run while no short-run impact of renewable energy in this regard could be established. Furthermore, Kurramovich et al. (2022) also mentioned that it is relevant to scale up investments in renewable energy-related projects for abating carbon emissions. Hence, it can be assumed that the repercussion of renewable energy use on carbon emissions is not homogenous for all underdeveloped economies. The related studies that have verified the carbon emission-mitigating role of renewable energy include Bouyghrissi et al. (2022) for Morocco; Du et al. (2022) for Turkey, Indonesia, Nigeria, and Mexico; and Shen et al. (2021) for Russia, Brazil, India, South Africa, and China. On the other hand, Yurtkuran (2021) claimed that the environmental benefits associated with renewable energy use are not realized in Turkey since the findings validated a positive correlation between Turkish renewable energy consumption and carbon dioxide emission levels.

Now regarding the studies emphasizing the renewable energy-ecological footprints nexus for the developing nations, in particular, Huang et al. (2022) recently utilized data from the E7 countries for the 1995–2018 period and revealed evidence that stimulating renewable energy consumption can contribute to lower down the long-run ecological footprints of these nations. Besides, conducting an empirical analysis by compiling data from 36 developing nations, Sahoo and Sethi (2021) reached the conclusion that the use of different types of energy yields mixed environmental impacts; precisely, the authors concluded that renewable energy consumption mitigates ecological footprints while non-renewable energy use amplifies ecological footprints in the long run. Likewise, Sharma et al. (2021) also questioned whether or not promoting renewable energy use can reduce the ecological footprint levels of developing countries located in Asia. Using advanced econometric tools, the authors unearthed that the rise in the ecological footprint levels in these countries was contained by stimulating the use of renewable energy across this part of the globe. The long-run ecological footprint-reducing effects of renewable energy use in South Asian nations were also highlighted in the study by Xue et al. (2021). Contrarily, Nathaniel et al. (2020) concluded that higher renewable energy consumption is not associated with lower ecological footprints in Colombia, Egypt, Indonesia, South Africa, and Turkey.

On the other hand, the corresponding literature in the case of developing nations is pretty limited. Among these, Pata and Balsalobre-Lorente (2022) found that higher economic growth, greater consumption of energy, and inbound tourist arrivals reduce the Turkish load capacity factor levels in the long run. Besides, for the case of Indonesia, Fareed et al. (2021) also pointed out the role of enhancing renewable energy use in stimulating load capacity factor enhancement-led environmental improvement. In another related study concerning China for the period between 1981 and 2016, Pata and Isik (2021) remarked that economic growth, intensification of energy use, and natural resource consumption are detrimental to environmental well-being since these factors were evidenced to reduce the load capacity factor level in China. Shang et al. (2022) considered a panel of Southeast Asian states and found that the load capacity factor levels of these countries are positively influenced by higher use of renewable energy and human development; contrarily, higher economic growth was evidenced to negatively influence the load capacity factor levels in the long run.

Methodology

Empirical model and data attributes

There are numerous models that provide the theoretical basis to empirically assess the determinants of environmental quality. Among these, the "environmental Kuznets curve (EKC)" hypothesis postulates an initially environmental quality-improving and an eventually environmental quality-reducing impact of economic growth (Murshed and Dao 2022; Jin et al. 2022; Murshed 2021b). Besides, the STIRPAT model also evaluates the effects of affluence/economic growth, population, and technological innovation (Ali et al. 2022; Zhu et al. 2022). Hence, linking these theoretical frameworks with the objectives of this study, the following model is considered:

$$\ln LCF_{it} = \beta_0 + \beta_1 \ln RE_{it} + \beta_2 \ln EG_{it} + \beta_3 \ln P_{it} + \varepsilon_{it} \quad (1)$$

where "the subscripts i and t refer to cross-sectional units and time, respectively," while the error term is denoted by ε. All the variables are transformed into their natural logs to convert the model into a double-log model; consequently, the parameters $\beta_1, \beta_2,$ andβ_3 are the elasticities of the dependent variable to one standard deviation shock to the respective independent variable. β_o represents the intercept parameter. The dependent variable ln*LCF* represents the natural logarithm of the annual load capacity factor level which is the proxy for environmental impact. Following Pata and Balsalobre-Lorente (2022), the load capacity factor is estimated by dividing the biocapacity level (consumption-based) by the ecological footprint level (consumption-based). Accordingly, positive (negative) signs of the elasticity parameters (i.e., $\beta_1, \beta_2,$ andβ_3) would indicate a rise (decline) in the difference between the biocapacity level and the ecological footprint level, thus indicating an improvement (aggravation) in the level of environmental well-being. The main independent variable of concern is ln*RE* which is the natural logarithm of the "annual share of renewable energy in the total final energy consumption level." In this regard, a higher (lower) value of this variable would indicate more (less) renewable energy penetration within the energy system.

Among the control variables, ln*EG* stands for the "natural logarithm of the economic growth level which is measured in terms of annual per capita real gross domestic product (GDP) level." Although the EKC hypothesis requires the model to include a squared term of the economic growth

Table 1 The description and sources of data

Acronym	Variable	Unit	Source
ln*LCF*	Load capacity factor (per capita biocapacity/ per capita ecological footprint)	Ratio	GFN (2022)
ln*RE*	Renewable energy consumption (share of total final energy consumption)	Percentage	World Bank (2022)
ln*EG*	Economic growth (per capita real GDP)	Constant 2015 US$	World Bank (2022)
ln*P*	Population size	Number	World Bank (2022)

"The prefix ln denotes natural log transformation"

Table 2 Descriptive statistics

Variable	Min	Max	Mean	St. Dev.	Skewness	Kurtosis
G7 countries						
ln*LCF*	−2.150	0.745	−1.031	0.822	0.875	2.119
ln*RE*	−0.163	3.122	2.023	0.748	−0.765	1.499
ln*EG*	10.308	10.995	10.552	0.174	0.705	2.582
ln*P*	17.214	19.605	18.217	0.654	0.778	2.914
E7 countries						
ln*LCF*	−1.361	1.275	−0.289	0.752	0.786	2.568
ln*RE*	1.157	3.901	2.883	0.876	−0.611	2.262
ln*EG*	6.501	9.393	8.457	0.790	−0.917	2.564
ln*P*	17.916	21.062	19.370	1.064	0.570	1.827

"The prefix ln denotes natural log transformation"

variable, this approach for assessing the non-linearity between economic growth and its environmental impact has recently been criticized (Jahanger et al. 2022). Hence, we do not include the squared term in our model. However, we evaluate the validity of the EKC hypothesis by predicting both the short-term and long-term marginal impacts of economic growth on the level of load capacity factor. Provided, the short-run elasticities verify adverse impacts while the long-run elasticities support favorable impacts of economic growth on the environment, the EKC hypothesis can be validated under the assumption that moving from the short- to the long-run results in a lower trade-off between economic gains and environmental losses. The other control variable ln*P* stands for the natural logarithm of the population size which is expected to explain how a larger population influences the ecological demand in comparison with the corresponding biocapacity for meeting that demand and absorbing the associated wastes.

In this study, we utilize annual data concerning the G7 and E7 nations from 1997 to 2018. Table 1 "displays the definitions, measuring scales, and sources of the study variables." Besides, the descriptive statistics for the variables are separately presented for the G7 and E7 nations in Table 2. It is evident that compared with the E7 countries, the G7 nations are more polluted; over the time period considered in this study, the mean value of the load capacity factor of the G7 countries was merely 0.532 as opposed to that of the E7 countries having an average load capacity factor level of 1.033 (GFN 2022). These contrasting statistics indicate that the G7 nations were in a state of ecological deficit (i.e., biocapacity < ecological footprint) while the E7 nations were somewhat neither ecologically deficit nor ecologically surplus (i.e., biocapacity < ecological footprint). Hence, it can be said that the G7 nations, despite being highly developed, are performing worse than the developing E7 nations in respect of controlling environmental pollution. Moreover, it is also evident from Table 2 that the energy mixes of the G7 countries were relatively more fossil fuel-intensive than the energy mixes of the E7 countries. Lastly, the E7 countries had larger population sizes compared with the sizes of the populations of the G7 countries. Besides, the variables for both the G7 and E7 panels are evidenced to exhibit both positive and negative distributions. Furthermore, all variables are seen to be platykurtic.[3]

Estimation strategy

In the first stage, the issue of cross-sectional dependency is tested following the assumption that since the G7 and

[3] "For ensuring brevity, the correlation matrices and variance inflation factor outputs are not reported. The related tables can be made available following a reasonable request to the corresponding author."

E7 countries are integrated multilaterally as well as bilaterally, the environmental responses to a particular shock in a possible environmental quality determinant can be similar across these countries. Under such circumstances, this problem may exist in the data which, in turn, would generate inefficient analytical outcomes. Hence, Pesaran's (2021) method is used to test for cross-sectional dependence. "This method predicts test statistics for the concerned variables (ln*LCF*, ln*RE*, ln*EG*, and ln*P*) considering the null hypothesis of cross-sectional independence" (Ozturk et al. 2019). Hence, the issue of cross-sectional dependency is confirmed only when the predicted test statistic is statistically significant. In the second stage, the slope homogeneity analysis is performed under the assumption that the slope coefficients predicted using the regression estimator can differ across the G7 and E7 nations due to the heterogeneous macroeconomic characteristics of these nations. In this regard, Pesaran and Yamagata's (2008) slope homogeneity analysis is conducted which "predicts two test statistics (delta and adjusted delta) considering the null hypothesis that the slope coefficients are homogeneous" (Le and Ozturk 2020).

In the third stage, the unit root analysis is performed to check in which order the concerned variables are integrated. Checking the integration order is important because not all regression models can accommodate variables with all types of integration orders. In this regard, considering the assumption that the issue of cross-sectional dependency exists in the data concerning the G7 and E7 countries, the cross-sectionally adjusted Im-Pesaran-Shin (CIPS) unit root estimator of Pesaran (2007) is used. This method considers the null hypothesis that the series of concerns are not integrated at the specified integration order; thus, for the variable to be integrated the corresponding test statistic needs to be statistically significant (Salahuddin et al. 2016). In the fourth stage, the relationships among the variables, in the long run, are tested using the cointegration analysis. The presence of such cointegrating relationships is essential in predicting the long-run marginal impacts of independent variables (ln*RE*, ln*EG*, and ln*P*) on the dependent variable (ln*LCF*). In this regard, Westerlund's (2007) cointegration estimator is utilized considering the issue of cross-sectional dependency. "Four test statistics (Gt, Ga, Pt, and Pa) are estimated considering the null hypothesis that no cointegrating relationship exists among the model's variables" (Rauf et al. 2018).

In the fifth stage, the regression analysis is executed using the "cross-section augmented autoregressive distributed lag (CS-ARDL)" estimator proposed by Chudik et al. (2016). Unlike conventional panel data regression estimators such as the dynamic ordinary least squares (DOLS), the CS-ARDL method accounts for cross-sectional dependency issues in the data (Mehmood et al. 2022). In addition, the issue of slope heterogeneity is also accounted for within this estimation technique (Mehmood et al. 2022). Both these data problems are tackled by the CS-ARDL estimator by augmenting additional lags of cross-sectional averages of the explanatory variables within the ARDL framework (Chudik et al. 2016). In addition, this technique can also predict short-run outcomes alongside long-run outcomes (Usman et al. 2022b). Regarding our model (shown in Eq. 1), it can be specified using the CS-ARDL model specification as follows:

$$\ln LCF_{it} = \sum_{j=1}^{a} \delta_{ij} \ln LCF_{i,t-j} + \sum_{j=0}^{b} \theta_{ij} X_{i,t-j} + \sum_{j=0}^{c} \vartheta_{ij} \overline{Z}_{t-1} + \omega_i + \mu_{it} \tag{2}$$

where $\overline{Z}_{t-1} = \left(\ln LCF_{i,t-j}, \overline{X}_{i,t-j} \right)$ are the cross-sectional means of the regressors [lagged dependent variable ($\ln LCF_{t-1}$) and the other explanatory variables including ln*RE*, ln*EG*, and ln*P*]; *a*, *b*, and *c* represent the different lags of the cross-sectional averages. Finally, in the sixth stage, the causality analysis is performed to check the directions of causations among the variables. In this regard, considering the assumption that the data set used in this study is cross-sectionally dependent and heterogeneous, Dumitrescu and Hurlin's (2012) method is employed. In this technique, "a causal association between a pair of variables is assessed by predicting a test statistic under the null hypothesis that the independent variable does not Granger cause the dependent variable" (Baloch et al. 2021).

Table 3 Cross-sectional dependency results

Variable	G7 countries	E7 countries
ln*LCF*	5.308* (0.000)	5.313* (0.000)
ln*RE*	− 1.734*** (0.083)	− 1.615*** (0.100)
ln*EG*	3.554* (0.004)	0.362 (0.718)
ln*P*	0.836 (0.403)	2.463** (0.014)

"* = significant at 1%; ** = significant at 5%; *** = significant at 10%; *p* values within ()"

Results

Firstly, this section displays the outcomes related to cross-sectional dependency for both the G7 and E7 nations. The related findings, as shown in Table 3, reveal that the data set considered in this study is subject to cross-sectional dependency; this finding is homogeneous for both the G7 and E7 panels. Notably, it can be seen that for the G7 panel, the test statistics for the variables ln*LCF*, ln*RE*, and ln*EG* are statistically significant. On the other hand, for the E7 panel, the test statistics for the variables ln*LCF*, ln*RE*, and ln*F* are evidenced to be statistically significant. These statistically significant test statistics confirm cross-sectional dependency

Table 4 Slope homogeneity results

Test statistics	G7 countries	E7 countries
Delta	6.947*	7.074*
Adjusted delta	7.903*	8.047*

"* = significant at 1%"

Table 5 Unit root results

Variable	G7 countries	E7 countries
ln*LCF*	−1.909	−1.555
Δln*LCF*	−5.147*	−4.900*
ln*RE*	−2.144	−2.599*
Δln*RE*	−4.606*	–
ln*EG*	–	−2.333**
Δln*EG*	−3.079*	–
ln*P*	−1.462	−1.433
Δln*P*	−3.173*	−2.272***

"Δ = first difference; * = significant at 1%; ** = significant at 5%; *** = significant at 10%"

Table 6 Cointegration results

Test statistics	G7 countries	E7 countries
Gt	−3.363** (0.023)	−3.380** (0.020)
Ga	−2.665 (0.883)	−2.750 (0.830)
Pt	−7.567*** (0.093)	−7.722*** (0.081)
Pa	−4.799 (1.000)	−5.239 (1.000)

"Bootstrapped replications = 10,000; ** = significant at 5%; *** = significant at 10%; *p* values within ()"

issues in the data. Following this analysis, the slope homogeneity test is conducted and the associated results are reported in Table 4. The findings confirm the presence of heterogeneous slope coefficients for both the G7 and E7 panels. Since both the delta and adjusted delta statistics are statistically significant, the issue of slope heterogeneity is verified for both the G7 and E7 countries.

In the next step, the unit root analysis is conducted by utilizing the CIPS test. The outcomes from the CIPS unit root analysis are reported in Table 5. Firstly, for the case of the G7 panel, the findings highlight that the variables ln*LCF*, ln*RE*, and ln*P* are integrated at the first difference while the variable ln*EG* is integrated at the level. Secondly, or the case of the E7 panel, it is found that the variables ln*LCF* and ln*P* are integrated at the first difference while the variables ln*RE* and ln*EG* are integrated at the level. Hence, in both cases, the findings confirm a mixed integration order of the variables of concern.

Table 7 Regression results

Regressors	G7 countries		E7 countries	
	Coefficient	Std. Err.	Coefficient	Std. Err.
Short-run results				
ln*RE*	0.110	0.095	0.123**	0.062
ln*EG*	−0.247*	0.091	−0.085*	0.020
ln*P*	−0.488	0.340	−6.311**	2.738
ECT(−1)	−0.459*	0.132	−0.311*	0.105
Long-run results				
ln*RE*	0.116**	0.079	0.279*	0.091
ln*EG*	−0.579*	0.130	−0.168*	0.024
ln*P*	−2.253**	1.119	−4.663**	1.968
Adj. *R*-squared	0.745		0.646	

"ECT(−1) = error-correction term; * = significant at 1%; ** = significant at 5%"

After the unit root analysis, we conduct the cointegration analysis using the method proposed by Westerlund (2007). As per the results concerning the cointegrating properties, Table 6 verifies that for both the G7 and E7 panels there are long-run relationships between the variables included in the model. This statement is verified by the statistical significance of the Gt and Pt statistics. Following the conclusion of the unit root and cointegration analyses, we perform the regression analysis utilizing the CS-ARDL modeling approach.

Table 7 presents the short- and long-run findings from the CS-ARDL analysis. Firstly, it is found that higher consumption of renewable energy improves environmental quality in both the G7 and E7 countries. However, the findings are dissimilar across the alternate panels of countries and also across the short and long run. For instance, in the short run, it can be seen that increasing the share of renewable in the aggregate energy consumption level enhances the load capacity factor level of only the E7 nations. However, in the long run, higher renewable energy consumption shares increase the load capacity factor levels of both the G7 and E7 countries. Moreover, it can also be observed that the long-run load capacity factor-enhancing effect associated with higher renewable energy consumption shares is comparatively larger for the E7 countries. This could be due to the relatively higher renewable energy consumption shares of the E7 countries which have enabled them to be more successful than the G7 countries in respect of environmental protection. Hence, this result supports the idea that enhancing renewable energy share as a means for reducing fossil fuel dependency is a credible mechanism for protecting the environment. This finding can be related to the conclusions drawn in the study conducted by Pata and Balsalobre-Lorente et al. (2021) in which the authors claimed that higher energy consumption in Turkey, which is mostly fossil fuel-based, is responsible for harming the environment by reducing the nation's load capacity factor level. Hence, in this regard, our finding of renewable energy contributing to increasing the load capacity factor levels of the G7 and E7 nations can be considered rational.

Secondly, the results displayed in Table 7 certify that economic growth is detrimental to environmental quality both in the G7 and E7 context; moreover, the impacts are also homogeneously distributed over the short and long run. Notably, the results indicated that enhancing the per capita national income levels in these countries makes sure that their ecological deficits are persistently enlarged whereby their load capacity factor levels are likely to monotonously decline. However, there are two additional findings to note. First, compared with the E7 countries, the marginal load capacity factor-reducing impact of economic growth is comparatively higher for the G7 countries. Given the fact that the G7 nations are developed while the E7 nations are developing, this particular finding advocate that it is relatively more difficult for the comparatively more developed nations to control the surge in their respective ecological footprint figures; consequently, it is cumbersome of the relatively more developed nations to limit the widening gaps between their respective biocapacity and ecological footprint levels. Second, we find that compared with the short-run impacts, the long-run negative impacts of economic growth on the load capacity factor levels, for both the G7 and E7 panels, are relatively larger. Intuitively, these results signal that the short-run adverse environmental impacts of economic growth are outweighed by the long-run adverse environmental impacts. As a result, it can be said that the results are contradicting the theoretical underpinnings of the EKC hypothesis which postulate that as economies persistently continue to grow, it is likely that those nations would be able to adopt clean growth policies whereby the environmental quality is like to improve with time. Hence, considering the corresponding short- and long-run results, we can claim that the EKC hypothesis for load capacity factor is invalid for both the G7 and E7 nations. These findings do not corroborate the results recorded by Pata and Samour (2022) in the context of France.

Lastly, the results shown in Table 7 reveal that growing population size induces intense ecological pressure to exert environmental problems in the G7 and E7 countries. The results provide evidence that in the G7 context a rise in the population size is associated with a decline in the load capacity factor level only in the long run but in the context of the E7 nations, the load capacity factor-reducing effect associated with population growth is verified for both the short and long run. The contrasting findings across the alternate panels of countries can be explained by the understanding that compared with the G7 nations the E7 countries are relatively more populated. However, the homogenous finding of population growth reducing load capacity factor levels implies that as the population sizes of the G7 and E7 countries expand, the demand for ecological resources tends to shoot up which is most likely not matched by the corresponding growth in the natural biocapacity level. As a consequence, the gap between the biocapacity and ecological footprint levels is likely to widen whereby the load capacity factor level is likely to decline further. Similar to our findings, the adverse environmental consequences accompanying growth in the population level of the USA were reported by Khan et al. (2021). In that study, the authors remarked that population growth inflicts environmental degradation in the USA by increasing the ecological footprint levels of this developed economy.

Table 8 Robustness analysis results

Panel	G7 countries		E7 countries	
Regressors	Coefficient	Std. Err.	Coefficient	Std. Err.
ln*RE*	0.555*	0.119	0.725*	0.210
ln*EG*	−0.211	0.203	−0.044**	0.021
ln*P*	−0.140**	0.068	−2.129*	0.549
Adj. *R*-squared	0.980		0.936	

"* = significant at 1%; ** = significant at 5%"

Besides, it is also evident from the error-correction terms that any disequilibrium in the current period is adjusted at a rate of around 46% and 31% for the G7 and E7 panels, respectively. On the other hand, the high adjusted *R*-squared figures confirm the goodness of fit for both the predicted models (G7 and E7 panels). Furthermore, the findings from the robustness analysis, checked using the panel DOLS method, are reported in Table 8. Overall, the findings are evidenced to be dissimilar whereby we can conclude that the findings are not robust to alternative regression estimators. The source of heterogeneous outcomes could be explained using the understanding that the CS-ARDL, unlike the DOLS estimator, the estimator is efficient in handling data sets with variables of mixed integration order and also neutralizes the potential impacts of endogenous covariates within the models. Lastly, after the regression analysis is completed, the panel causality analysis is performed to detect the directions of the causal links among the concerned variables.

Finally, the causality analysis is conducted using the method proposed by Dumitrescu and Hurlin (2012). As per the outcomes derived from the causality analysis, shown in Table 9, firstly we find that the level of load capacity factor and renewable energy shares of the G7 countries are bi-directionally associated while for the E7 countries a unidirectional causality extends from renewable energy share to load capacity factor. It can be argued that the reverse causality in the G7 context can lead to endogeneity concerns; however, the CS-ARDL model accounts for problems arising

Table 9 Causality results

Null hypothesis	G7 countries		E7 countries	
	Test Stat.	Causal direction	Test Stat.	Causal direction
ln*RE* does not Granger cause ln*LCF*	6.396*	ln*RE*↔ln*LCF*	4.803*	ln*RE*→ln*LCF*
ln*LCF* does not Granger cause ln*RE*	9.669*		2.733	
ln*EG* does not Granger cause ln*LCF*	3.792**	ln*EG*→ln*LCF*	6.496**	ln*EG*→ln*LCF*
ln*LCF* does not Granger cause ln*EG*	2.868		5.114	
ln*P* does not Granger cause ln*LCF*	6.737*	ln*P*→ln*LCF*	18.324*	ln*P*→ln*LCF*
ln*LCF* does not Granger cause ln*P*	3.664		2.061	

"Bootstrapped replications = 10,000; * = significant at 1%; ** = significant at 5%"

from the presence of endogenous covariates. Besides, the other causal findings reveal evidence of unidirectional causalities running from economic growth and population size to load capacity factor levels of both the G7 and E7 nations.

Conclusion and policies

Both developed and underdeveloped economies worldwide are now more concerned than ever in respect of achieving environmental sustainability. Accordingly, the majority of the global economies have ratified several environment-related pacts to express solidarity with the worldwide objective of limiting the rate of environmental degradation. Although environmental degradation is believed to be tackled using diverse methods, limiting the use of fossil fuels has often been recognized as the ultimate enabler of environmental sustainability. Against this backdrop, this study aimed to assess the environmental impacts associated with higher renewable energy use, controlling for economic growth and population size, in the context of the G7 and E7 countries. Besides, instead of using the traditional environmental quality proxies, this study tried to quantify the extent of environmental degradation in terms of changes in the load capacity factor levels of the countries of concern. The long-run associations among the study's variables were confirmed from the outcomes generated from the cointegration analysis. Besides, as per the findings from the regression, we found that integrating renewable energy into the energy systems while withdrawing from the use of fossil fuels can help to improve environmental quality while economic growth and population size expansion were evidenced to impose opposite environmental consequences. However, the findings, in the majority of the cases, differed across the groups of the G7 and E7 countries, especially in terms of the marginal environmental effects. Lastly, the causality analysis confirmed the directions of the causal relationships among the variables.

Considering these findings, it is deemed necessary for both the G7 and E7 nations to start executing policies that can minimize their dependency on fossil fuels. In this regard, these nations need to green their respective energy systems by transforming fossil fuel-intensive energy systems into renewable energy-intensive systems. Accordingly, the injection of funds for financing renewable energy development prospects is critically important because these policies would not only help to improve environmental quality but also lessen ecological demand, provide the scope for biocapacity expansion, and, thereby, enhance the load capacity factor levels. Secondly, considering the negative consequences of economic growth on the environment, greening the national output production processes is absolutely essential. This further calls for making more use of clean energy while limiting the use of fossil fuels. In this regard, the governments of the G7 and E7 countries can be expected to intervene in two significant forms. First, from the production side, the government should incentivize private investments in the power sectors so that private research and development financing can help to develop the renewable energy sectors of these countries. On the other hand, from the consumption side, the government should pass laws that would make renewable energy-intensive consumer appliances more affordable for the public even if it requires the government to extend cash and kind subsidies to the producers. Lastly, population control measures should also be undertaken so that the surging demand for ecological reserves can be contained.

Future studies should focus on conducting individual country analyses concerning the impacts of renewable energy use on the load capacity factor levels separately for each of the G7 and E7 nations. This is important because homogenous policies may not account for the country-specific heterogeneity in terms of the macroeconomic and demographic structures of these countries. Besides, further research can focus on controlling for other key macroeconomic variables to identify additional factors that can help these nations enhance their load capacity factor levels.

Author contribution UK and AMK wrote the original draft, conducted the econometric analysis, analyzed the findings, reviewed, and edited the final draft. MSK and PA conceptualized, compiled the literature review, and generated the graphical illustrations. AH and RAP wrote the original draft, compiled the literature review, and contributed in the methodology section.

Availability of data and materials The sources of data have been duly mentioned in the study.

Declarations

Ethics approval Not applicable.

Consent to participate Not applicable.

Consent for publication Not applicable.

Competing interests The authors declare no competing interests.

References

Abbass K, Qasim MZ, Song HM, Murshed M, Mahmood H (2022) A review of the global climate change impacts, adaptation, and sustainable mitigation measures. Environ Sci Pollut Res 29(28):42539–42559. https://doi.org/10.1007/s11356-022-19718-6

Afshan S, Ozturk I, Yaqoob T (2022) Facilitating renewable energy transition, ecological innovations and stringent environmental policies to improve ecological sustainability: evidence from MM-QR method. Renewable Energy 196:151–160

Agozie DQ, Gyamfi BA, Bekun FV, Ozturk I, Taha A (2022) Environmental Kuznets curve hypothesis from lens of economic complexity index for BRICS: evidence from second generation panel analysis. Sustainable Energy Technol Assess 53:102597

Ahmed Z, Adebayo TS, Udemba EN, Murshed M, Kirikkaleli D (2022a) Effects of economic complexity, economic growth, and renewable energy technology budgets on ecological footprint: the role of democratic accountability. Environ Sci Pollut Res 29(17):24925–24940

Ahmed Z, Ahmad M, Rjoub H, Kalugina OA, Hussain N (2022b) Economic growth, renewable energy consumption, and ecological footprint: exploring the role of environmental regulations and democracy in sustainable development. Sustain Dev 30(4):595–605

Ahmed Z, Murshed M, Ahmad M, Shah MI, Mahmood H, Abbas S (2022c) How do green energy technology investments, technological innovation, and trade globalization enhance green energy supply and stimulate environmental sustainability in the G7 countries? Gondwana Res 112:105–115. https://doi.org/10.1016/j.gr.2022.09.014

Ahmed Z, Cary M, Ali S, Murshed M, Ullah H, Mahmood H (2021a) Moving toward a green revolution in Japan: symmetric and asymmetric relationships among clean energy technology development investments, economic growth, and CO2 emissions. Energy Environ 0958305X211041780.

Ali S, Can M, Shah MI, Jiang J, Ahmed Z, Murshed M (2022) Exploring the linkage between export diversification and ecological footprint: evidence from advanced time series estimation techniques. Environ Sci Pollut Res 29(25):38395–38409

Alola AA, Bekun FV, Sarkodie SA (2019) Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in Europe. Sci Total Environ 685:702–709

Alvarado R, Tillaguango B, Murshed M, Ochoa-Moreno S, Rehman A, Işık C, Alvarado-Espejo J (2022) Impact of the informal economy on the ecological footprint: the role of urban concentration and globalization. Econ Anal Policy 75:750–767

Amin A, Altinoz B, Dogan E (2020) Analyzing the determinants of carbon emissions from transportation in European countries: the role of renewable energy and urbanization. Clean Technol Environ Policy 22(8):1725–1734

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

Awosusi AA, Kutlay K, Altuntaş M, Khodjiev B, Agyekum EB, Shouran M, ..., Kamel S (2022) A roadmap toward achieving sustainable environment: evaluating the impact of technological innovation and globalization on load capacity factor. Int J Environ Res Public Health 19(6):3288

Aydoğan B, Vardar G (2020) Evaluating the role of renewable energy, economic growth and agriculture on CO2 emission in E7 countries. Int J Sustain Energ 39(4):335–348

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

Balsalobre-Lorente D, Driha OM, Leitão NC, Murshed M (2021) The carbon dioxide neutralizing effect of energy innovation on international tourism in EU-5 countries under the prism of the EKC hypothesis. Journal of Environmental Management 298(C):113513. https://doi.org/10.1016/j.jenvman.2021.113513

Bashir MF, Ma B, Bashir MA, Radulescu M, Shahzad U (2022) Investigating the role of environmental taxes and regulations for renewable energy consumption: evidence from developed economies. Economic Research-Ekonomska Istraživanja 35(1):1262–1284

Bouyghrissi S, Murshed M, Jindal A, Berjaoui A, Mahmood H, Khanniba M (2022) The importance of facilitating renewable energy transition for abating CO2 emissions in Morocco. Environ Sci Pollut Res 29(14):20752–20767

Chien F, Hsu CC, Ozturk I, Sharif A, Sadiq M (2022) The role of renewable energy and urbanization towards greenhouse gas emission in top Asian countries: evidence from advance panel estimations. Renew Energy 186:207–216

Chu LK, Le NTM (2022) Environmental quality and the role of economic policy uncertainty, economic complexity, renewable energy, and energy intensity: the case of G7 countries. Environ Sci Pollut Res 29(2):2866–2882

Chudik A, Mohaddes K, Pesaran MH, Raissi M (2016) Long-run effects in large heterogeneous panel data models with cross-sectionally correlated errors. In *Essays in honor of Aman Ullah*. Emerald Group Publishing Limited. https://doi.org/10.1108/S0731-905320160000036013

Destek MA, Aslan A (2020) Disaggregated renewable energy consumption and environmental pollution nexus in G-7 countries. Renewable Energy 151:1298–1306

Doğan B, Chu LK, Ghosh S, Truong HHD, Balsalobre-Lorente D (2022) How environmental taxes and carbon emissions are related in the G7 economies? Renewable Energy 187:645–656

Dogan E, Ozturk I (2017) The influence of renewable and non-renewable energy consumption and real income on CO2 emissions in the USA: evidence from structural break tests. Environ Sci Pollut Res 24(11):10846–10854

Dong F, Li Y, Gao Y, Zhu J, Qin C, Zhang X (2022) Energy transition and carbon neutrality: exploring the non-linear impact of

renewable energy development on carbon emission efficiency in developed countries. Resour Conserv Recycl 177:106002
Du L, Jiang H, Adebayo TS, Awosusi AA, Razzaq A (2022) Asymmetric effects of high-tech industry and renewable energy on consumption-based carbon emissions in MINT countries. Renewable Energy 196:1269–1280
Dumitrescu EI, Hurlin C (2012) Testing for Granger non-causality in heterogeneous panels. Econ Model 29(4):1450–1460
Fareed Z, Salem S, Adebayo TS, Pata UK, Shahzad F (2021) Role of export diversification and renewable energy on the load capacity factor in Indonesia: a Fourier quantile causality approach. Front Environ Sci 434
GFN. (2022). Global Footprint Network. Available at https://www.footprintnetwork.org/ (Accessed on 15.10.2022)
Gyamfi BA, Adedoyin FF, Bein MA, Bekun FV (2021) Environmental implications of N-shaped environmental Kuznets curve for E7 countries. Environ Sci Pollut Res 28(25):33072–33082
Hamid I, Alam MS, Kanwal A, Jena PK, Murshed M, Alam R (2021) Decarbonization pathways: the roles of foreign direct investments, governance, democracy, economic growth, and renewable energy transition. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-022-18935-3
Hao LN, Umar M, Khan Z, Ali W (2021) Green growth and low carbon emission in G7 countries: how critical the network of environmental taxes, renewable energy and human capital is? Sci Total Environ 752:141853
Huang Y, Haseeb M, Usman M, Ozturk I (2022) Dynamic association between ICT, renewable energy, economic complexity and ecological footprint: is there any difference between E-7 (developing) and G-7 (developed) countries? Technol Soc 68:101853
Ibrahim RL (2022) Post-COP26: can energy consumption, resource dependence, and trade openness promote carbon neutrality? Homogeneous and heterogeneous analyses for G20 countries. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-022-21855-x
IEA (2021a) World energy balances: overview, IEA, Paris https://www.iea.org/reports/world-energy-balances-overview
IEA (2021b) Global energy review 2021b, IEA, Paris https://www.iea.org/reports/global-energy-review-2021b
Jahanger A, Usman M, Murshed M, Mahmood H, Balsalobre-Lorente D (2022) The linkages between natural resources, human capital, globalization, economic growth, financial development, and ecological footprint: the moderating role of technological innovations. Resour Policy 76:102569
Jin C, Razzaq A, Saleem F, Sinha A (2022) Asymmetric effects of eco-innovation and human capital development in realizing environmental sustainability in China: evidence from quantile ARDL framework. Economic Research-Ekonomska Istraživanja 35(1):4947–4970
Khan I, Hou F, Le HP (2021) The impact of natural resources, energy consumption, and population growth on environmental quality: fresh evidence from the United States of America. Sci Total Environ 754:142222
Khan S, Murshed M, Ozturk I, Khudoykulov K (2022) The roles of energy efficiency improvement, renewable electricity production, and financial inclusion in stimulating environmental sustainability in the Next Eleven countries. Renew Energy 193:1164–1176. https://doi.org/10.1016/j.renene.2022.05.065
Kurramovich KK, Abro AA, Vaseer AI, Khan SU, Ali SR, Murshed M (2022) Roadmap for carbon-neutrality: the mediating role of clean energy development-related investments. Environ Sci Pollut Res 29(23):34055–34074. https://doi.org/10.1007/s11356-021-17985-3
Le HP, Ozturk I (2020) The impacts of globalization, financial development, government expenditures, and institutional quality on CO2 emissions in the presence of environmental Kuznets curve. Environ Sci Pollut Res 27(18):22680–22697
Li L, Li G, Ozturk I, Ullah S (2022) Green innovation and environmental sustainability: do clean energy investment and education matter?. Energy Environ 0958305X221115096
Mehmood U, Agyekum EB, Uhunamure SE, Shale K, Mariam A (2022) Evaluating the influences of natural resources and ageing people on CO2 emissions in G-11 nations: application of CS-ARDL approach. Int J Environ Res Public Health 19(3):1449
Molefe T, Inglesi-Lotz R (2022) Examining the water–energy–food (WEF) nexus through an SDG lens for the big 5 African countries. Environ Dev Sustain. https://doi.org/10.1007/s10668-022-02650-7
Murshed M (2021) Can regional trade integration facilitate renewable energy transition to ensure energy sustainability in South Asia? Energy Rep 7(C):808–821. https://doi.org/10.1016/j.egyr.2021a.01.038
Murshed M (2021b) LPG consumption and environmental Kuznets curve hypothesis in South Asia: a time-series ARDL analysis with multiple structural breaks. Environ Sci Pollut Res 28(7):8337–8372
Murshed M, Dao NTT (2022) Revisiting the CO2 emission-induced EKC hypothesis in South Asia: the role of export quality improvement. GeoJournal 87(2):535–563. https://doi.org/10.1007/s10708-020-10270-9
Murshed M, Abbass K, Rashid S (2021a) Modelling renewable energy adoption across south Asian economies: empirical evidence from Bangladesh, India, Pakistan and Sri Lanka. Int J Financ Econ 26(4):5425–5450
Murshed M, Ahmed R, Kumpamool C, Bassim M, Elheddad M (2021b) The effects of regional trade integration and renewable energy transition on environmental quality: evidence from South Asian neighbors. Bus Strateg Environ 30(8):4154–4170
Murshed M, Saboori B, Madaleno M, Wang H, Doğan B (2022) Exploring the nexuses between nuclear energy, renewable energy, and carbon dioxide emissions: the role of economic complexity in the G7 countries. Renewable Energy 190:664–674
Nathaniel S, Nwodo O, Sharma G, Shah M (2020) Renewable energy, urbanization, and ecological footprint linkage in CIVETS. Environ Sci Pollut Res 27(16):19616–19629
Nathaniel SP, Alam M, Murshed M, Mahmood H, Ahmad P (2021) The roles of nuclear energy, renewable energy, and economic growth in the abatement of carbon dioxide emissions in the G7 countries. Environ Sci Pollut Res 28(35):47957–47972
Ozturk I, Al-Mulali U, Solarin SA (2019) The control of corruption and energy efficiency relationship: an empirical note. Environ Sci Pollut Res 26(17):17277–17283
Pata UK (2021) Do renewable energy and health expenditures improve load capacity factor in the USA and Japan? A new approach to environmental issues. Eur J Health Econ 22(9):1427–1439
Pata UK, Balsalobre-Lorente D (2022) Exploring the impact of tourism and energy consumption on the load capacity factor in Turkey: a novel dynamic ARDL approach. Environ Sci Pollut Res 29(9):13491–13503
Pata UK, Isik C (2021) Determinants of the load capacity factor in China: a novel dynamic ARDL approach for ecological footprint accounting. Resour Policy 74:102313
Pata UK, Samour A (2022) Do renewable and nuclear energy enhance environmental quality in France? A new EKC approach with the load capacity factor. Prog Nucl Energy 149:104249
Pesaran MH (2007) A simple panel unit root test in the presence of cross-section dependence. J Appl Economet 22(2):265–312
Pesaran MH (2021) General diagnostic tests for cross-sectional dependence in panels. Empirical Economics 60(1):13–50
Pesaran MH, Yamagata T (2008) Testing slope homogeneity in large panels. Journal of Econometrics 142(1):50–93

Ponce P, Khan SAR (2021) A causal link between renewable energy, energy efficiency, property rights, and CO2 emissions in developed countries: a road map for environmental sustainability. Environ Sci Pollut Res 28(28):37804–37817

Qin L, Kirikkaleli D, Hou Y, Miao X, Tufail M (2021) Carbon neutrality target for G7 economies: examining the role of environmental policy, green innovation and composite risk index. J Environ Manage 295:113119

Rahman MM, Vu XB (2020) The nexus between renewable energy, economic growth, trade, urbanisation and environmental quality: a comparative study for Australia and Canada. Renewable Energy 155:617–627

Rauf A, Liu X, Amin W, Ozturk I, Rehman OU, Hafeez M (2018) Testing EKC hypothesis with energy and sustainable development challenges: a fresh evidence from belt and road initiative economies. Environ Sci Pollut Res 25(32):32066–32080

Raza SA, Shah N (2018) Testing environmental Kuznets curve hypothesis in G7 countries: the role of renewable energy consumption and trade. Environ Sci Pollut Res 25(27):26965–26977

Razmjoo A, Kaigutha LG, Rad MV, Marzband M, Davarpanah A, Denai M (2021) A technical analysis investigating energy sustainability utilizing reliable renewable energy sources to reduce CO2 emissions in a high potential area. Renewable Energy 164:46–57

Rehman A, Ma H, Ozturk I, Murshed M, Dagar V (2021) The dynamic impacts of CO2 emissions from different sources on Pakistan's economic progress: a roadmap to sustainable development. Environ Dev Sustain 23(12):17857–17880

Rehman A, Alam MM, Ozturk I, Alvarado R, Murshed M, Işık C, Ma H (2022) Globalization and renewable energy use: how are they contributing to upsurge the CO2 emissions? A global perspective. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-022-22775-6

Sahoo M, Sethi N (2021) The intermittent effects of renewable energy on ecological footprint: evidence from developing countries. Environ Sci Pollut Res 28(40):56401–56417

Salahuddin M, Alam K, Ozturk I (2016) The effects of Internet usage and economic growth on CO2 emissions in OECD countries: a panel investigation. Renew Sustain Energy Rev 62:1226–1235

Shang Y, Razzaq A, Chupradit S, An NB, Abdul-Samad Z (2022) The role of renewable energy consumption and health expenditures in improving load capacity factor in ASEAN countries: exploring new paradigm using advance panel models. Renewable Energy 191:715–722

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

Sharma R, Sinha A, Kautish P (2021) Does renewable energy consumption reduce ecological footprint? Evidence from eight developing countries of Asia. J Clean Prod 285:124867

Shen Y, Li X, Hasnaoui A (2021) BRICS carbon neutrality target: measuring the impact of electricity production from renewable energy sources and globalization. J Environ Manage 298:113460

Usman O, Akadiri SS, Adeshola I (2020) Role of renewable energy and globalization on ecological footprint in the USA: implications for environmental sustainability. Environ Sci Pollut Res 27(24):30681–30693

Usman A, Ozturk I, Naqvi SMMA, Ullah S, Javed MI (2022a) Revealing the nexus between nuclear energy and ecological footprint in STIRPAT model of advanced economies: fresh evidence from novel CS-ARDL model. Prog Nucl Energy 148:104220

Usman O, Alola AA, Saint Akadiri S (2022b) Effects of domestic material consumption, renewable energy, and financial development on environmental sustainability in the EU-28: evidence from a GMM panel-VAR. Renewable Energy 184:239–251

Vo DH, Vo AT, Ho CM, Nguyen HM (2020) The role of renewable energy, alternative and nuclear energy in mitigating carbon emissions in the CPTPP countries. Renewable Energy 161:278–292

Westerlund J (2007) Testing for error correction in panel data. Oxford Bull Econ Stat 69(6):709–748

World Bank (2022) World development indicators. Available at https://databank.worldbank.org/source/world-development-indicators. Accessed on 16.10.2022

Xu D, Sheraz M, Hassan A, Sinha A, Ullah S (2022) Financial development, renewable energy and CO2 emission in G7 countries: new evidence from non-linear and asymmetric analysis. Energy Economics 109:105994

Xue L, Haseeb M, Mahmood H, Alkhateeb TTY, Murshed M (2021) Renewable energy use and ecological footprints mitigation: evidence from selected South Asian economies. Sustainability 13(4):1613

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? Renewable Energy 184:899–907

Yasin I, Naseem S, Anwar MA, Madni GR, Mahmood H, Murshed M (2022) An analysis of the environmental impacts of ethnic diversity, financial development, economic growth, urbanization, and energy consumption: fresh evidence from less-developed countries. Environ Sci Pollut Res. https://doi.org/10.1007/s11356-022-21295-7

Yu Z, Khan SAR, Ponce P, de Sousa Jabbour ABL, Jabbour CJC (2022) Factors affecting carbon emissions in emerging economies in the context of a green recovery: implications for sustainable development goals. Technol Forecast Soc Chang 176:121417

Yunzhao L (2022) Modelling the role of eco innovation, renewable energy, and environmental taxes in carbon emissions reduction in E−7 economies: evidence from advance panel estimations. Renewable Energy 190:309–318

Yuping L, Ramzan M, Xincheng L, Murshed M, Awosusi AA, Bah SI, Adebayo TS (2021) Determinants of carbon emissions in Argentina: the roles of renewable energy consumption and globalization. Energy Rep 7:4747–4760

Yurtkuran S (2021) The effect of agriculture, renewable energy production, and globalization on CO2 emissions in Turkey: a bootstrap ARDL approach. Renewable Energy 171:1236–1245

Zeraibi A, Balsalobre-Lorente D, Murshed M (2021) The influences of renewable electricity generation, technological innovation, financial development, and economic growth on ecological footprints in ASEAN-5 countries. Environ Sci Pollut Res 28(37):51003–51021

Zhao J, Sinha A, Inuwa N, Wang Y, Murshed M, Abbasi KR (2022) Does structural transformation in economy impact inequality in renewable energy productivity? Implications for sustainable development. Renewable Energy 189:853–864

Zhu C, Chang Y, Li X, Shan M (2022) Factors influencing embodied carbon emissions of China's building sector: an analysis based on extended STIRPAT modeling. Energy and Buildings 255:111607

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.