frontiers | Frontiers in Environmental Science

TYPE Original Research
PUBLISHED 09 January 2023
DOI 10.3389/fenvs.2022.1076859

OPEN ACCESS

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

RECEIVED 22 October 2022
ACCEPTED 18 November 2022
PUBLISHED 09 January 2023

CITATION
Wei S, Jiandong W and Saleem H (2023), The impact of renewable energy transition, green growth, green trade and green innovation on environmental quality: Evidence from top 10 green future countries.
Front. Environ. Sci. 10:1076859.
doi: 10.3389/fenvs.2022.1076859

The impact of renewable energy transition, green growth, green trade and green innovation on environmental quality: Evidence from top 10 green future countries

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This analysis investigates the impact of renewable energy consumption, green economic growth, green technology, green trade, and inward financial inflow on environmental quality in the world's top green future economies from 1990–2018. The analysis applied the Cross-sectional-Augmented Auto Regressive Distributed Lag (CS-ARDL) method. For robustness check, the current study used Augmented Mean Group (AMG) and Common Correlated Effect Mean Group (CCEMG) methods to identify the relationship between variables in the long-run analysis. The statistical findings show that green trade and inbound FDI significantly improve the environment quality, confirming the hypothesis of a "pollution halo." The results concluded that environmental quality is improving through trade liberalization in the short and long run. Green economic growth is stimulated through green energy (renewable energy use). These findings supported the theory of Core-macroeconomics. This analysis concluded that environmental quality is significantly improving through green technological innovation and growth. The bi-directional association between green growth and green technologies indicates that both promote a green and clean environment. The findings of this study significantly supported the theory of green competitiveness and the Porter hypothesis. The statistical results of green trade indicate that the reduction in CO2 emission enhances green economic growth. Thus, green trade is beneficial for these future green economies. The current analysis tries to establish helpful suggestions for policymakers on implementing practical policies addressing renewable energy sources, green growth projects, and green trade to improve environmental quality.

KEYWORDS

green growth, environmental degradation, renewable energy, green technological change, green trade

GRAPHICAL ABSTRACT
Graphical illustration of D-H panel test.

Introduction

Green growth is essential for economies to attain the sustainable development goals of a clean environment. To achieve green development, the contribution of technological change and clean energy for cleaner production of goods and services cannot be deniable (Wiebe & Yamano, 2016). Since the beginning of the industrial revolution in the early 1850s and 1950s, energy has played a critical role in the production process (Stern & Kander, 2012; Ellabban, et al.,2014). Energy consumption increases with the expansion of economic growth, improves the living standards of their inhabitants and deteriorates the environmental quality. Thus, green growth is crucial in minimizing environmental degradation problems such as extraordinary hazards, i.e., health issues in inhabitants, animals, and marine life, low agricultural productivity, global warming, rising sea levels, melting of glaciers, water scarcity, extreme weather, and unpredictable weather rainfalls. So, the contribution of renewable energy and technological innovation has become more significant in recent years. Thus, energy consumption has triggered a new era of debate among academics and policymakers; this topic has taken on extra importance in current climate agreements like the Paris Agreement (2015) and Conference on Parties (COP-26).

Environment-friendly innovation and using renewable energy sources are essential for improving the quality of the environment (Vural, 2020). It's also worth mentioning that renewable energy resources help to minimize CO_2 emissions, ensure sustainability, and lessen foreign reliance. Consequently, renewable energy resources appear critical in resolving energy security and environmental degradation issues (Saidi & Mbarek, 2016). Renewable energy contributes significantly to the energy supply and has the potential to improve the current energy mix, address market distortions, and diminish environmental degradation. That indicates that intensifying renewable energy sources has become a critical component of the global shift to a low-carbon society (Saleem et al., 2022). Moving fossil fuel to renewable energy sources can close the present and future energy gap, opening the route for decarburization, energy security, and improving economic growth (Shahbaz, et al., 2015). However, different studies concluded different findings and the insignificant association between the renewable energy-environment nexus (Alola et al., 2022). A significant and inverse association was found between the environment and renewable energy (Saleem et al., 2020; Chien et al., 2021a; Adebayo & Kirikkaleli, 2021; Soylu et al., 2021; Saleem et al., 2022).

This study aims to re-examine the halo/haven hypothesis under the umbrella of EKC by incorporating the impact of inbound FDI on CO_2 emissions. This investigation would significantly help attain targets of sustainable goals and policy inferences. Numerous existing literature concluded the inconclusive findings and followed both arguments (positive and negative) that environmental quality is significantly deteriorating by the FDI (due to irresponsible consumption and production, less environmental regulation, and low carbon taxes); on the other side, environmental quality is improving through FDI, e.g., technology transfer and use of renewable energy sources by developed countries (Ahmad et al., 2021b; Kisswani & Zaitouni, 2021). Furthermore, rapid development is found in International trade due to World Trade Organization (WTO) and globalization. Globally, trade continued to expand and develop internationally, and many countries heavily depend on international trade. Recently, it has been considered an integral part of the globe. Technological change can improve environmental quality, as advanced cleaner technologies to control pollution are imported from other countries and exported to other economies.

Based on the above-mentioned arguments, this study also examined more research questions. Thus, this study's research question is, "Does international trade stimulate green technology and green growth? The findings of many studies are inconclusive regarding the trade-environment nexus (Destek & Sinha, 2020; G. Wang et al., 2022a; Wang Q. et al, 2022). Various scholars described that environmental quality is deteriorating due to international trade, and host countries are suffering from emissions of pollutants; this is also related to the pollution haven effect" hypothesis introduced by (Sadiqa et al., 2022). On the other hand, a positive association was found between international trade and green growth (Cui et al., 2022). Thus, the statistical findings on the trade-environment nexus are inconclusive (as mentioned above), which requires more research to determine the role of green trade on environmental quality. In addition, Do these countries follow the pollution halo/heaven hypothesis by transferring green technology to the rest of the world through green trade?

Furthermore, are green growth and renewable energy significantly moving towards achieving environmental sustainability targets? These top energy transitional economies use green energy and technology to keep the world's average temperature below 2 degrees. Consequently, to extend the previous work thus, this analysis re-examines the contributions of green growth, renewable energy, green trade and innovation, and inward financial inflow environmental quality.

This analysis investigates the impact of renewable energy consumption, green economic growth, green technology, green trade, and inward financial inflow on environmental quality in the context of the world's top green future economies, namely, Iceland, Denmark, Netherlands, the United Kingdom, Norway, Finland, France, Germany, Sweden, and South Korea (Green future index, 2022). The following are imperative reasons for selecting these economies. First and foremost, they are all developed economies with highly advanced and knowledge-based industrial processes; as a result, these economies have a high use of energy. Second, these economies account for around 3% of all energy-related carbon emissions. Thus, this study aims to identify those factors contributing more to achieving a low-carbon-free economy. The rest of the world's economies take advantage through inbound foreign direct investment (FDI)/investment in clean products. Third, although many empirical analyses have been done on the environment, this area has much scope to reinvestigate. The debate on the environment–growth nexus required more research due to shortcomings and research gaps. Fourth, the findings related to environment-growth nexus are still inconclusive and could not reach definite elucidation (Destek & Sinha, 2020; G. Wang et al., 2022a; Q. Wang et al., 2022b). Fifth, various studies used technological change, not green technology, under environmental quality (Yu & Du, 2019; Chen & Lee, 2020; Saleem et al., 2020). Sixth, according to the author's knowledge, less attention has been given to identifying the impact of green technological innovation (Saleem et al., 2022). Thus this study tries to examine the role of green technology, green energy, and green trade in the context of the top 10 green future economies to identify the impact of these variables on a clean environment and its effects on the rest of the world. The scared empirical analyses on the green growth-green innovation-environment nexus were found in the existing literature. Seventh, the combined effect of green growth, innovation, green energy and trade is not discussed for top energy transitional economies. This study also tries to extend the prior analyses by using the above-mentioned variables under the umbrella of the EKC curve.

Finally, this study is based on three theoretical aspects, i.e., "The Porter hypothesis, the advanced model of H–O developed by (Siebert & Larrick, 1992), and Core macro-economic theory". The shocks of green innovation are significantly improving the quality of the environment, and sustainable growth targets can be achieved. The model (Siebert & Larrick, 1992) explained that unsustainable products (exports/production of pollution-concentrated) significantly deteriorate the environmental quality. Similarly, pollution is surging the economies' specialization in producing dirty products. The theory of Core macro-economic signifies that achieving sustainable environmental goals through clean energies such as renewable energy sources is crucial. In addition, this theory also describes that the consumption and production process should minimize the dependence on non-renewable energy sources.

Additionally, given the reasons mentioned above, the contribution of this study is to examine the co-integration links among renewable energy, green growth, green technological innovation, green trade, and environment nexus by using an annual balanced panel dataset for the top 10 energy transition nations from 1990 to 2015 through Westerlund (2007) co-integration model (G. Wang et al., 2022a). To solve the challenges of cross Section dependence (CSD) and stationary diagnostics, we use advanced econometric techniques such as unit root (second-generation) tests and cross-section dependency (CSD). Literature such as (Sinha et al., 2017) either ignored the CSD or relied on first-generation unit root tests, which are ineffective when considering the CSD. (Saleem et al., 2022). We also used different approaches and slope homogeneity (Pesaran, 2007; Pesaran & Yamagata, 2008). This study employed Westerlund (2007) approach to determine the long-run association between the factors. The model is tested using a Cross Section-Augmented mean group technique, followed by panel Augmented Distributed Lag (CS-ARDL). This analysis used Augmented Mean Group (AMG) and Common Correlation Estimation Mean Group (CCE-MG) techniques for robustness check. Dumitrescu and Hurlin (2012) employed the panel causality technique to identify the causal relationship between CO2 emission and green growth with other plausible determinants. We concluded that two-way dynamic causality was found between green economic development, renewable energy, green technology, green trade, inward financial investment, and environmental quality. Thus, this indicates that attaining a sustainable environment and growth can effectively be possible in top green future economies by exploiting renewable energy sources, green technology, inward financial investment, and green trade. As a result, this study will effectively provide valuable suggestions to various researchers and practical strategies for environmental–growth sustainability based on the theoretical framework and empirical evidence.

The following sections comprise the rest of this study: *Literature review Section* discusses the available literature. *Modeling and Data Section* delves deeply into modeling analysis, theoretical framework, and model construction. The results and discussion are presented in *Empirical Results and Discussion Section*, and the study concludes with a discussion of recommendations and policy implications in *Conclusion Section*.

Literature review

The literature on energy transition reasons, use of energy, and economic growth are examined for various nations, regions, and groups, methodologies, and variables, with time utilizing, are given below, widely discussed on the energy transition-economic growth nexus and with its plausible variables.

Literature review on the association between economic growth-renewable energy use and CO2 emissions

The first strand focuses on various countries' energy use and environmental degradation nexus. Verbong and Geels (2007) examined the Dutch power system's energy transition (renewable energy use) trends from 1960 to 2004. The authors discovered that the Dutch electricity system had undergone an energy transition since the 1960s and 1970s, but Europeanization and deregulation policies fueled it. Al-Mulali et al. (2015) used 1990–2013 data to examine the dynamic association between economic growth, pollution, and renewable energy use, in 23 European countries. They concluded a strong connection between economic growth and environmental degradation; however, solar and wind power have no substantial effect on environmental degradation. Numerous research studies examined the connection between renewable energy use, economic growth, and environmental quality. Such as, Gençer et al. (2020) used Environmental Modeling and Sustainable Energy System Analysis to examine renewable energy use and CO2 emissions. As a result, the energy transition from non-renewable to renewable energy) is a significant key to do, showing that environmental issues are becoming more complicated. Cardoso and González (2019) investigated the household energy transition and thermal efficacy in the setting of Argentina. The findings of their study concluded that not using energy-efficient strategies has many costs and negatively affects the environment. Kokkinos et al. (2020) examined Fuzzy Cognitive Map (FCM) modeling inducing the energy transition in sustainable environmental quality. They conclude that energy availability to urban residents impacts the growth of sustainable energy source sources. Poruschi and Ambrey (2019) investigated the cumulative impact on Australia's solar photovoltaic transformation (energy) environment between 2001 and 2015. They concluded that the environmental quality could decrease because more people are switching to solar panels for their energy needs. Song et al. (2020) investigated low-carbon energy and concluded that low-renewable energy strategies could be inversely related to the environment.

A study by Wang and Wang (2020) examined how the energy transition impacted 186 countries' economic growth and emissions from 1990 to 2014. Adedoyin and Zakari (2020) concluded that the energy transition harms growth and that decoupled economic growth from CO2 emission may benefit the economy. Suo et al. (2021) analyzed how China's renewable energy use to clean technologies and products would affect its economic growth. They used an ensemble energy system model to determine that the energy shift would slow down and even stop economic growth. These papers cover a wide range of subjects related to energy transition. Nevertheless, the study could not uncover any study that examined and synthesized these different indications of the energy shift. Based on the conclusions of this research, the energy transition is predicted to harm the economic growth of energy transition member nations.

Literature review on the association between energy consumption-economic growth and environmental degradation

The second strand of the literature argued that various other prior empirical analyses examined economic growth as an essential component of environmental degradation, e.g. (Adebayo & Kirikkaleli, 2021; Adebayo & Rjoub, 2022; Ahmad et al., 2021a; Anser et al., 2021; Bashir M. et al., 2022; Bashir M. A. et al., 2022; Bashir M. et al., 2022; S. Chen et al., 2019; Chien et al., 2021b; Chien et al., 2021a. Sadiq, et al., 2022; Fareed et al., 2022; Farhan Bashir et al., 2022; Sadiq et al., 2022; Shahbaz et al., 2014; Xia et al., 2022); concluded that non-renewable energy significantly increases the level of CO2 emission. Recently, Wan et al. (2022) and (Saleem et al., 2022) explored that GDP growth is deteriorating the environmental quality, and environmental quality is improving using renewable energy sources.

The connection between energy use and economic growth is well-known in the existing literature. Doğan et al. (2020) studied the association between growth and energy use in 32 European nations from 1995 to 2014. Their results showed that the use of energy fosters economic expansion. Many economic studies have examined the four main hypotheses about the energy-growth nexus (growth, conservation, feedback, and the neutrality hypothesis). Several arguments support the notion that energy use and economic growth are closely related (Bashir M. et al., 2022; Bashir M. A. et al., 2022; M. F. Bashir M. et al., 2022; Farhan Bashir et al., 2022; Sadiq et al., 2022; Shahbaz et al., 2013; Shahbaz et al., 2018; Xia et al., 2022). Energy consumption affects GDP directly or indirectly, depending on the income hypothesis.

The connection between energy use and economic growth is well known in the existing literature. Musthafah et al. (2014)

examined the impact of energy (non-renewable and renewable) utilization on the environment, and their findings concluded that heavy reliance on non-renewable energy significantly deteriorates the environmental quality. In contrast, environmental quality is improved considerably by using renewable energy sources in the OECD nations from 1980 to 2011. Energy consumption affects GDP directly or indirectly, depending on the income hypothesis. According to the energy-growth connection, environmental pollution may decrease by reducing waste and boosting its value, based on the conservation hypothesis. According to the feedback hypothesis, there is a correlation between energy consumption and GDP growth. Similarly, the neutrality hypothesis shows no relationship between growth and energy consumption.

Khan et al (2021) investigated the dynamic links between energy use, energy transition, and sustained economic growth for many IEA member countries from 1995 to 2015. Their findings conclude the long-run relationships between variables using advanced econometric techniques. On the other hand, energy transitions have a significant long-term impact on economic growth. In contrast, the economic sustainability-economic growth nexus found a strong association in the long and short-run analysis. Additionally, other studies by Al-Mulali et al. (2015) for various nations have incorporated growth-renewable energy relationship statistics. Recently (Saleem et al., 2020; Zheng et al., 2020; Agbede et al., 2021; Ahmad et al., 2021b; Nawaz et al., 2021; Rahman & Vu, 2021), (Li et al., 2021) also examined the growth-renewable energy relationship in their studies.

Based on the statistical results of previous literature, the study assumes that the use of energy (renewable and non-renewable) boosts GDP growth in high-energy-transition economies. Additional research is needed to resolve the gap in the literature, given the contradictory theoretical and empirical findings. Further research has examined the direct relationship between economic growth and CO2 emissions. Various econometric results in several studies can be dubious because slope heterogeneity and cross-sectional dependence were not considered. To fill this gap in the existing research studies, it is necessary to address this issue by utilizing improved methodology to investigate the influence of economic sustainability, non-renewable energy, energy transition, and renewable on GDP growth in the top ten energy transition economies. It is also essential to consider environmental and sustainable growth policies.

Nathaniel and Iheonu (2019) investigated the insignificant effect of renewable energy on environmental degradation found in the study of Africa. Hussain and Rehman (2021) concluded that environmental quality is improving due to the significant contribution of renewable energy, and population growth is positively related to ecological degradation in the case of Pakistan. Doğan et al. (2020) studied the association between growth and energy use in 32 European nations from 1995 to 2014. Their results showed that the use of energy fosters economic expansion. Many economic studies have examined the four main hypotheses about the energy-growth nexus (growth, conservation, feedback, and the neutrality hypothesis). Several arguments support the notion that energy use and economic growth are closely related (Shahbaz et al., 2013; Shahbaz et al., 2018). Shahbaz et al., (2020) examined the data of 38 nations highly dependent on renewable energy sources using the latest methodologies. They find that in OECD countries, renewable and fossil fuel energy use contributes to the growth of these nations. Additionally, other studies by Al-Mulali et al. (2015) have incorporated growth-renewable energy relationship statistics. Recently Zheng et al. (2020), Saleem et al. (2020), Ahmad et al. (2021b), Rahman and Vu (2021), Agbede et al. (2021), and Nawaz et al. (2021) also examined the growth-renewable energy relationship in their studies.

Literature review on the association between green innovation and environmental degradation

The third strand of the literature is related to technological change and its relationship with environmental degradation, which is associated with endogenous growth theory. The heavy reliance on non-renewable energy can be reduced through technological change and high investment in the energy transition. Thus, technological advancements in the energy sector can stimulate economic growth. Therefore, a Sustainable environment and development can be achieved through technological innovation (Saleem et al., 2022). The supposition related to technological innovation implies that long-run sustainable growth and less environmental destruction would be achieved through technological change and clean energy consumption. The technological innovation and environmental quality nexus are discussed in various studies (Álvarez-Herránz et al., 2017; Bekhet & Othman, 2018; Sarkodie & Ozturk, 2020; Hao, et al., 2021; Bilal I. et al., 2022; Bashir, 2022; Bilal D. et al., 2022; Saleem et al., 2022).

Literature review on the association between green trade and environmental degradation

The third literature has discussed the connection between environmental quality and trade. The available literature well documented the debate of international trade and environmental degradation nexus; the findings of their studies are inconclusive and could not reach a definite conclusion. For example, the first strand of existing studies concluded that the impact of trade on environmental quality is positive and trade significantly improves environmental quality, e.g., the findings of Hongxing et al (2021) examined the association of trade with an environment with other plausible variables for BRICS countries from 1995 to 2018. Dou et al. (2021) explored the interrelationship between environmental quality and trade; their findings concluded that environmental quality is less deteriorating due to exports, but CO2 emissions are surging due to imports. The opposite results are completed by Iqbal et al. (2021) in their analysis of Indonesia that the CO2 emission is increasing due to exports.

Similarly, J. Chen et al. (2022) concluded that trade is significantly deteriorating the environment of Asian economies from 2005 to 2020. Saleem et al. (2020) also concluded that trade negatively impacted the environment in Asian countries from 1980–2015. These inconclusive findings of existing literature induce the attention of researchers to re-investigate the relationship between trade and the environment and check the contribution of green trade (environment-friendly trade) to improving the quality of the environment. Ahmed et al. (2022) and Ahmed et al. (2022) explored that developing countries face severe environmental conditions compared to developed nations. Their findings suggested the important policy implications to developed countries and how they can transfer environment-friendly technologies to developing countries through trade.

Literature review on the association between inbound financial investment and environmental degradation

Prior literature shows two types of hypothesis statements regarding the FDI's effect: "Pollution heaven" and "Pollution halo" (Xia et al., 2022). According to the claim of the pollution heaven hypothesis, foreign organizations are willing to establish their industries in lower-cost developing countries and spread polluted productions, which to some extent, hampers the progress of local technologies; therefore, this lock-in situation takes to the low-ended global value chain (Bilal, Tan, et al., 2022b). Overall, serious pollution emissions have been induced by the flows of FDI into the pollutant industries. Studies like Baek (2016) and Shahbaz et al. (2018) report that FDI negatively influences emissions reduction to prove the pollution heaven hypothesis. Similarly, Bokpin et al. (2015) show that eco-friendly FDI inflow adversely affects the environmental sustainability of African countries. However, Wang et al. (2020b) show concern about China industries' carbon lock-in as they clarify that FDI enhances regional carbon lock-in. Whereas the 'pollution halo' hypothesis claims that international companies brought technological advancement to developing countries, these capital flows provide a crucial advantage for technical replication and innovation intent. The research (Tawiah et al., 2021) highlights that host countries' High-tech progress and economic development spurs due to FDI. Additionally, studies such as Adom et al. (2019) and Demena and Afesorgbor (2020) support the pollution halo hypothesis.

Based on contradicting empirical and theoretical analyses of the previous studies, resolving the inconsistency in the preliminary analysis thus, required more investigations in this regard. Numerous past literature could not identify the direct influence of various factors on economic growth, including the impact of CO_2 emission. Many studies cannot address the issue of slope heterogeneity and cross-sectional dependence, which can lead to spurious results. To fill the research gap in existing literature, it is necessary to address this issue by utilizing improved methodology to investigate the influence of economic sustainability, non-renewable energy, energy transition, and renewable on GDP growth in the top ten energy transition economies. It is also essential to consider environmental and sustainable growth policies. Thus this study incorporated different latest methodologies to address above mentioned problems by examining the impact of energy transitions, economic sustainability, technological innovation, and energy consumption in the top transitional energy economies. It is also essential to consider environmental and sustainable growth policies. Finally, we established a research hypothesis based on the literature mentioned above review (Bilal I. et al., 2022; Bilal, et al., 2022b).

H1: it is assumed that countries with the presence of renewable energy would substantially improve the quality of the environment.

H2: it is assumed that the use of environment-friendly technologies would substantially enlightening the environmental quality across countries.

H3: it is predictable that Inbound FDI significantly followed the direction of green development with green innovation and the transfer of green technologies.

H4: It is expected that trade will likely promote the green growth agenda by using environment-friendly technologies.

Modeling and data

Theoretical framework and model construction

This study addresses the theoretical background before beginning the econometric analysis, as it is essential to determine the model's significant variables. Countries can upsurge ecological sustainability and mitigate climate change by embracing fundamental changes in their energy sectors and implementing effective energy transitions (Millot et al., 2020). Non-renewable energy primarily relies on fossil fuel combustion, which results in the decomposition of hydrocarbons and subsequent air pollution. As a result, increased usage of this energy source is environmentally hazardous and a concern for sustainability. As a result, reducing energy usage is necessary for sustainable development and renewable energy. Renewable energy generation demands significant investment, a significant challenge for economic growth. As a result, the impact of renewable energy generation on GDP growth might be quite varied (Saleem et al., 2020; Bilal I. et al., 2022; Bilal D. et al., 2022).

This analysis discussed the theoretical framework under the "Theory of green competitiveness." This study follows the theory that throughout the manufacturing process, the level of CO2 emission can be reduced by using renewable energy sources. Renewable energy sources (electricity produced by wind, solar, and water) are environmentally friendly sources; this allows the producers to use carbon–neutral goods and services (Vaka et al., 2020). To improve the environment quality and achieve sustainable development targets, renewable energy sources' influential role cannot be deniable (Anwar et al., 2021). Thus, there is an inverse association between renewable energy sources and environmental destruction; many developed nations are significantly improving the quality of the environment by replacing their non-renewable energy sources with renewable energy sources (Sadiqa et al., 2022; Saleem et al., 2022).

Recently, economies have been diverting their focus from conventional economic growth to green economic growth because traditional economic growth has escalated the depletion of natural resources and has negative environmental footprints. In this scenario, apart from the conventional theories of growth, modern growth theories focus on technological innovation to pace the path of green transformation (Acemoglu et al., 2016; Aghion et al., 2016). In the view of the traditional economic approach laissez–fair equilibrium will be achieved but may result in the degradation of the environment. "Can transformation in technology be helpful in the warfare of climate change"? This question is the need of the present time to underline the importance of technological innovation in decreasing environmental emissions, as well as less dependence on non-renewable energy sources and more and more reliance on renewable energy, uses (Aghion et al., 2016).

Similarly, Green growth is an effective policy for reducing carbon emissions (Acemoglu et al., 2016). On the other side of the story, due to the flourishing awareness about green output, many economies have been encouraged to develop a green economy framework for resources and a friendly environment in the means of energy conservation specifically (Song et al., 2019) thus, in the explanation of green growth path the salient role of renewable energy, non-renewable energy sources, and innovation in green technology cannot be ignored. Recently the well-debated topic is the "growth-environment nexus," especially for scholars and policymakers who are highly focused on achieving environmental sustainability goals (Hao et al., 2021).

Based on the above-mentioned theoretical framework, this study tries to identify the association between environmental quality and green growth, renewable energy, green trade, inward financial investment, and green innovation under the Environmental Kuznets Curve EKC umbrella. This well-known inverted U-shaped theory (EKC) was designed by Grossman and Krueger (1995), describing the association between environment and economic growth. This theory argues that rapid economic growth significantly deteriorates the quality of the environment, but green growth improves the quality of the environment. Based on this theoretical framework of EKC (Bashir M. A. et al., 2022), this study identifies the association between environmental quality with green growth and other plausible variables in the following equation.

$$CO_{2it} = \beta_1 + \beta_2 GREN_{it} + \beta_3 (GREN_{it})^2 + \beta_4 REW_{it} + \beta_5\, GTEC_{it} + \beta_6\, GTRD_{it} + \beta_7 FINF_t \epsilon_{it} \tag{1}$$

The study converts all variables to their natural logarithms to provide elastic interpretations. Eq. 1 is presented in its logarithmic form in the equation.

$$LnCO_{2it} = \beta_1 + \beta_2 LnGREN_{it} + \beta_3\, Ln(GREN_{it})^2 + \beta_4 LnREW_{it} + \beta_5\, LnGTEC_{it} + \beta_6\, LnGTRD_{it} + \beta_7 + \epsilon_{it} \tag{2}$$

Where β1 represents the slope of coefficient, time starts from 1990 to 2018, β2, β3, β4, β5, β6, parameters of green growth (GREN), the square of green growth $(GREN)^2$, renewable energy consumption (REW), green technological change (GTEC), green trade (GTRD), and Inward Financial inflow (FINF).

We used carbon emissions (CO2 per capita) to measure environmental destruction. This study tries to evaluate the role of green growth, the square of green growth under the premises of EKC. Moreover, various other variables are also significantly improving the quality of environments, such as renewable energy, green technological innovation, and international green trade. Economic growth and development can be enhanced through energy use. Non-renewable energy sources are the main contributors to environmental degradation, but renewable energy sources significantly improve the environment's quality. Thus, this study incorporated renewable energy consumption (the main contributor to minimizing ecological destruction) in EKC's model (Shahbaz et al., 2017; Saleem et al., 2020). Technological innovation can significantly improve the environment's quality (W. Chen & Lei, 2018; Saleem et al., 2022). The green Keynesianism hypothesis indicates the significance of environmental quality and technological innovation. According to this theory, environmentally friendly technologies can minimize environmental destruction. Environmental friendly technology

TABLE 1 Statistical description of data.

Variables	Description	Units	Sources
CO2	Carbon emissions	metric tonnes per capita)	(WDI, 2021)
GREN	Green growth is measured as "production based CO2 emission"	in percentage points %	(OECD, 2021)
REW	Renewable energy use	Total final energy consumption in percentage	(WDI, 2021)
GTEC	The patent in related environmental technologies."	% of all technologies	(OECD, 2021)
GTRD	"Share of export of environmental goods to total export"	in percentage (%)	(OECD, 2021)
FINF	Inward Financial inflow (FDI net inflow)	% of GDP)	World Bank (2021)

and green trade can replace the "dirty" technologies and improve the quality of the environment (Cohen & Tubb, 2018; Sadiqa et al., 2022).

Data

Description of data

This analysis examines the role of green growth with other vital variables on the quality of the environment for the top 10 green future index countries (namely Iceland, Denmark, Netherlands, the United Kingdom, Norway, Finland, France, Germany, Sweden, and South Korea) from 1990 to 2018. Green growth is essential to achieve sustainable development targets. Furthermore, there is an inverse association between ecological destruction and green growth as these countries are the world's top green future countries, showing tremendous progress in this regard and moving towards clean and green environmental policies. By adoption of green policies and green technological innovations, there countries are also transferring green innovation to developing nations through FDI and trade. Table 1 represents the data descriptions. The data on CO2 emissions and inward financial investment is gathered from the World Development Indicator (WDI, 2021). The expected sign of inbound financial inflow-environmental quality is negative. If an inverse association between CO2 emissions and inbound FDI was found, it accepted the pollution halo hypothesis. Still, it acknowledged the pollution haven hypothesis if CO2 emissions and inbound FDI are positively associated. The data on green growth (GREN), renewable energy use (REW), green technology (GTEC), and green trade (GTRD) is obtained from OECD (2021) statistics. To check the existence of EKC, this study incorporated the square of green growth. Renewable energy is an environment-friendly energy source, and environmental quality is improving using renewable energy sources. Thus it is concluded that there is a negative association between CO2 emissions and renewable energy sources. There is a positive association between trade liberalisation and environmental destruction, but green trade significantly improves the quality of the environment and is inversely related to environmental destruction. Similarly, green growth and technological innovations are inversely related to environmental destruction.

Methods

Cross-section dependence unit root test

This approach determines the cross-sectional dependence (CSD) between several plausible model variables. Furthermore, various other determinants are linked to CSD. If the problem of CSD is not considered during the estimate, spurious results will be attached (Flores, 2019; Westerlund, 2007). To identify the cross-section dependence (CSD), we applied Pesaran (2015) test.

The equation of the CSD test can be written below,

$$CSD_{\text{Adjusted one}=}\sqrt{2T/N(N-1)}\left(\sum_{i=1}^{N-1}\sum_{k=i+1}^{N}\hat{\Omega}_{ik}\right)\frac{(T-J)\hat{\Omega}_{ik}{}^{2}-E(T-J)\hat{\Omega}_{ik}{}^{2}}{V(T-J)\hat{\Omega}_{ik}{}^{2}} \tag{3}$$

Where N stands for ∞, and sufficiently large T mean of the CSD test is exactly zero for fixed values of N and T (using panel data, including heterogeneous/homogeneous analysis).

Tests of slope homogeneity

The study employed the Pesaran and Yamagata (2008) test to determine the slope homogeneity of the model. This test can determine whether the data analysis is heterogeneous or homogeneous. This analysis determined the slope homogeneity using the Pesaran and Yamagata (2008) statistics. Thus, this test would determine the homogeneity and heterogeneity of panel data. In the empirical study, it is impossible to overstate the significance of the slope homogeneity test.

The following equation is used to determine the model's slope homogeneity.

$$S=\sum_{i=0}^{N}(\beta_i-\beta_{WFE.})\frac{'x_i'M_{\tau x_i}}{\partial^2}(\beta_i-\beta_{WFE}) \tag{4}$$

$$\Delta=N^{I/2}(2k)^{1/2}\left(\frac{1}{N}S-k\right) \tag{5}$$

Where S indicates the delta tide and Δ indicates the adjusted delta tide.

Panel unit root tests

Non-stationarity in data analysis was also dealt with in recent empirical studies (Cheung et al., 2019; Jiang, et al., 2020). This research also investigated the characteristics of the unit root of all the variables. The second-generation stationary technique will identify the unit's root problem (Pesaran, 2007). The test allows for the presence of CSD in the research (Shahzad et al., 2021; Saleem et al., 2022). The CIPS (augmented cross-sectional IPS) test detects the stationary issue of various factors. The study used Pesaran (2007) (augmented cross-sectional IPS) to detect a unit root problem. The test developed by Bai and Carrion-I-Silvestre (2009) addresses the stationary nature of data when many structural fractures are discovered throughout the analysis.

Cointegration tests

Co-integration is the long-run relationship between the model's various variables (Yoo & Kwak, 2010). This method can examine different factors for the presence of long-run relationships. Westerlund (2007) developed the contemporary panel co-integration test, which we used in our study to identify robust disclosures. Westerlund (2007) can deal with CSD data non-stationarity and heterogeneity in panel data analysis.

$$\alpha_1 (L)\Delta y_{it} = y2it + \beta_i \left(y_{it} - 1 - \alpha'_i X_{it}\right) + \lambda_i (L) v_{it} + \eta_{it} \tag{6}$$

$$\text{Where, } \delta_{1i} = \beta_i (1)\hat{o}_{21} - \beta_i \lambda_{1i} + \beta_i (1)\hat{o}_{2i} \text{ and } y2i = \beta_i \lambda_{2i} \tag{7}$$

The equation of Westerlund co-integration statistics is given below,

$$G_t = 1\big/N\, \Sigma_{i=1}^{N}\, \alpha'_i \big/ SE\left(\alpha'_i\right) \tag{8}$$

$$G_a = 1/N\, \Sigma_{i=1}^{N}\, T\alpha'_i / \left(\alpha'_i (1)\right. \tag{9}$$

$$P_t = \alpha'_i \big/ SE\left(\alpha'\right) \tag{10}$$

$$P_a = T\alpha' \tag{11}$$

Where the value of group statistics is shown as Ga and Gt, and panel statistics are represented by P_t and P_a. The null hypothesis represents no co-integration, and the alternative hypothesis indicates the long-run association between the variables.

Cross-section augmented autoregressive distributed lags

The CS-ARDL technique establishes a relationship between environmental deterioration and plausible variables of the model. This CS-ARDL technique resolves the issues of slope heterogeneity, endogeneity, and CSD (Chudik & Pesaran, 2013). This test compresses various descriptive elements with unexplained components and a small sample size that is unpredictable and sensitive. Moreover, The study used energy security theory, and this analysis established the analytical framework (described in the theoretical framework). Thus, based on the theoretical framework, this analysis concluded that rapid technological progress and innovation in the energy industry geared toward the widespread use of renewable energy could benefit environmental quality. This study rewrites the model in the following manner:

$$CO2_{it} = f\left(GREN_{it}, REW_{it}, GTEC_{it}, GTRD_{it}, FINF_{it}\right) \tag{12}$$

Following the theoretical framework, this study examined the renewable energy (REW), green growth (GREN), square of green growth $(GREN)^2$, renewable energy consumption (REW), green technological change (GTEC), green trade (GTRD) and Inward financial inflow (FINF).

The equation given below defines the model of CSD-ARDL.

$$\Delta GREN_{it} = \Omega_i + \sum_{l=0}^{m} \Phi_{1il} \Delta GREN_{t-1} + \sum_{l=0}^{m} \Phi_{2il} X_{i,t-i} \tag{13}$$

$$\Delta GREN_{it} = \Omega_i + \sum_{l=0}^{m} \Phi_{1il} \Delta GREN_{it,t-1} + \sum_{l=0}^{m} \Phi_{2il} X_{i,t-i} + \sum_{l=0}^{m} \Phi_{3il} Y_{it-1} + \epsilon_t \tag{14}$$

Where, GREN is related to the dependent variable (environmental degradation), Y represents the average value of dependent variables and X indicate the importance of imperative determinants such as $GREN_{it,}$ REW_{it}, $GTEC_{it}$, $GTRD_{it}$, $FINF_{it}$, l, and m related to the lag values of the green growth.

The following Eq. 8 represents the long-run analysis of CS-ARDL through the mean group estimator as given below,

$$\pi\, CS - ARDL,\ i = \sum_{l=0}^{m} \Phi_{1il},\ m\big/1 - \sum_{l=0}^{m} \tag{15}$$

For the moment, the following equation shows the mean group of the analysis.

$$\pi\, MG = 1\big/N - \sum_{l=1}^{N} \pi i \tag{16}$$

Nevertheless, this analysis shows the analysis of the short-run coefficients in the equation given as below,

$$\Delta GREN_{it} = \varnothing_i \left[GREN_{it,t-1} - \pi X_{i,t}\right] + \sum_{l=0}^{m} \Phi_{1il} \Delta GREN_{it,t-1} + \sum_{l=0}^{m} \Phi_{2il} X_{i,t-i} + \sum_{l=0}^{m} \Phi_{3il} Y_{it-1} + \epsilon_t \tag{17}$$

Eq. 18 represents the short-run co-efficient of CS-ARDL analysis. GDP is related to the dependent variable (environmental degradation), Y represents the average value of dependent variables and X indicates the importance of imperative determinants such $GREN_{it,}$ REW_{it}, $GTEC_{it}$, $GTRD_{it}$, $FINF_{it}$, l, and m related to the lag values of the GDP growth.

TABLE 2 Test of residual cross-section dependence.

Test	Statistic	*p*-value	Null hypotheses	Conclusion
LnGREN	17.834	0.000***	No CSD in residuals	Reject
LnREW	15.245	0.001***	No CSD in residuals	Reject
LnGTEC	14.875	0.000***	No CSD in residuals	Reject
LnGTRD	20.78	0.000***	No CSD in residuals	Reject
LnFINF	22.89	0.000***	No CSD in residuals	Reject

Note: rejection means that the null hypothesis is rejected at a 1% significance level.

TABLE 3 The heterogeneity and homogeneity testing of slope co-efficient.

Model: $CO_{2it} = ß_1 + ß_2 GREN_{it} + ß_3 (GREN_{it})_2 + ß_4 REW_{it} + ß_5 GTEC_{it} + ß_6 GTRD_{it} + ß_7 FINF_{it} + \mathcal{E}_{it}$

Delta (*p*-value)	Adjusted—Delta (*p*-value)
25.008[a]	47.096[a]
0	0

[a]Note: represents the level of significance at 1%.

TABLE 4 Statistical analysis of Panel unit root test.

Variable names	At level		First differences	
	CIPS	MIP	CIPS	MIP
CO2	−0.065	0.158	−4.702***	−8.651**
LnGREN	−3.002***	−8.001**	—	—
LnREW	−0.497	−0.67	−0.806	6.430***
LnGTEC	3.842***	−6.856***	—	—
LnGTRD	−8.561***	−4.423***	—	—
LnFINF	−7.875***	−5.537***	—	—

Notes: where ***and ** represents the 1% and 5% level of significance.

Panel causality test

Dumitrescu and Hurlin (2012) test examines the correlation between green growth-CO2 emissions nexus with other control variables such as renewable energy, green growth, the square of green growth, green technological change, green trade, and Inward Financial inflow.

Empirical results and discussion

Table 2 shows the empirical results of the CSD test. In the panel data analysis, Pearson LM normal, Friedman chi-square, Pearson CD normal, and Breusch-Pagan chi-square tests were used, and the presence of CSD was confirmed. This analysis rejected the null hypothesis (no CSD) and agreed with the alternative hypothesis (existence of CSD). Pesaran (2015) concluded that all the values of variables were found to be statistically significant in the analysis. The statistical findings confirmed that cross-sectional dependence between the economies and these nations is interconnected. The analysis results suggested that if any shock is experienced in any economy, it will also be observed in other countries. Due to this interdependence of these economies, the spillover effect can be observed in these countries.

TABLE 5 Statistical findings of panel co-integration Test (Westerlund, 2007).

Statistics	Value	Z-value
G_t	−4.082[a]	−3.690[a]
G_a	−6.785[a]	−3.236[a]
P_t	−7.065[a]	−4.150[a]
P_a	−8.045[a]	−5.793[a]

[a]Notes: where represents the 1% level of significance.

Furthermore, after performing the CSD test, it is essential to perform the slope homogeneity test; as a result, the study used Pesaran and Yamagata (2008) method. Table 3 represents that the null hypothesis was rejected, whereas the alternative hypothesis was confirmed. The acceptance of the alternative hypothesis confirmed the heterogeneity of the slope coefficients. Various methodologies and stationarity tests are used in this analysis to under-consider the problems of heterogeneity and cross-sectional dependence.

Table 4 provides the statistical results of the unit root with the help of CIP and MIP methods. To detect the unit root problem under the observation of null and alternative hypotheses, the study observed that a few variables failed to attain stationarity in panel data. The null hypothesis was rejected for the set of variables. The dependent variable is not stationary at the level. The statistical findings concluded that except for renewable energy use reaming, all are stationary at level.

The statistical findings are summarized in Table 5 using the Westerlund (2007) approach for determining the presence of co-integration in the assessment. The results indicated that the study rejected the null hypothesis, and the alternate hypothesis was accepted (presence of co-integration). Thus, the analysis establishes a long-run relationship between the variables and supports the study's hypothetical testing. Furthermore, under the dependent variables (CO2), Westerlund (2007) found a long-run association between variables.

The present analysis applied the CS-ARDL test to determine the impact of renewable energy, green growth, and square of green growth, green technological change, green trade and

TABLE 6 Statistical findings of CS-ARDL.

Model

CO2it = ß1+ß2GRENit+ß3(GRENit)2+ß4REWit+ß5GTECit+ß6GTRDit+ß7FINFit+Ɛit

Variables	Short-run analysis		Long run-analysis	
	Co-efficient	Standard deviation	Co-efficient	Standard deviation
LnGREN	−0.258***	0.000	−0.464***	0.001
Ln(GREN)2	−0.608***	0.008	−1.523***	0.003
LnREW	−0.088***	0.002	−0.662***	0.004
LnGTEC	−0.332***	0.001	−1.270***	0.007
LnGTRD	−0.350**	0.009	−0.481***	0.009
LnFINF	−0.387**	0.003	−0.802**	0.008
ECT(-1)	−0.601***	—	—	—

Notes: where *** and ** represents the 1 %and 5% level of significance.

Inward Financial inflow on CO2 emissions. Table 6 indicates the long-run and short-run results for the world's top 10 green future economies. The findings suggest that a 1% rise in green growth may result in a 0.26% and 0.46 decline in environmental degradation in these economies in the short and long run, respectively, implying that green growth may considerably improve the quality of the environment. Similarly, the results of GREN square indicate that if a 1% change is found in a square of GREN, it leads to a 0.61% and 1.5% decline in CO2 emissions. This study confirmed the existence of concave EKC for these top green future economies. Thus statistical findings concluded that environmental quality is improving through green growth. These results are consistent with Saleem et al. (2022) and Ahmed et al. (2022).

Similarly, a 1% increase in REW can minimize CO2 emissions by 0.09% in top green energy countries in the short run. But in the long run, the contribution of renewable energy use, a 1% increase in REW, minimizing the CO2 emissions by 0.66% in these countries. Studies confirm these results by Kihombo et al. (2021) Jahanger et al. (2022) and Pata and Balsalobre-Lorente (2022). Moreover, to minimize the destruction of environmental quality, enhancement of sustainable production through renewable energy sources with technological innovation are prerequisites for green growth of the economies. The findings are also endorsed by Anser et al. (2021), Saleem et al. (2022), Yaqoob et al. (2022), Sadiqa et al. (2022), Mughal et al. (2022). Furthermore, green innovation significantly improves the environment's quality through energy-efficient technologies, innovative environmentally friendly technologies, and efficient utilization of natural resources by effective machinery, etc. These results are consistent with the line of (Hao et al., 2021) some work (Chen & Lee, 2020; Usman & Hammar, 2021) concluded that the association between technological innovation and environmental degradation is not conclusive. The preliminary analysis of Toebelmann and Wendler (2020) analyzed that environmental destruction is minimized due to technical advancement. The findings of Saleem et al. (2022) examined that worldwide convergence of clean energy innovations is possible due to technological innovation development in various economies. The statistical findings of this study concluded that environmental quality is improving through green technological innovations in these economies. More precisely, the results indicate that 0.33 and unit 1.27 unit decrease was found in CO2 emissions in the short-run and long-run, respectively, as there was 1 unit change found in technological change. The findings of our study are endorsed by the studies of (Shahbaz et al., 2020; Chien et al., 2021b; Hao et al., 2021; Saleem et al., 2022).

The statistical findings show an inverse relationship between environmental degradation and green trade. A one % change increase in GTRD leads to a 0.35 and 0.48% decrease in environmental degradation at a 1% significance over the short and the long run, respectively. These findings are consistent with the line of Hashmi and Alam (2019), which concluded that environmental patents economies promote green products. Considering the role of green trade by top green future economies in promoting environmentally friendly products, these findings provide a new addition to the existing literature. Since environmental quality is significantly improving by extensive consumption of green products through international green trade, the import and export of green products can be enhanced through international trade. Thus, under these circumstances, the

10.3389/fenvs.2022.1076859

TABLE 7 AMG and CCEMG (Long run) for robustness check.

Dependent variable (GDP)	Augmented mean group (AMG.)		Common correlated effect mean group (CCEMC)	
Variables	Co-efficient	Standard deviation	Co-efficient	Standard deviation
LnGREN	−0.458***	0.06	−1.215***	0.06
LN(GREN)2	−0.765***	0.001	−1.876***	0.004
LnREW	−0.186***	0.001	−0.864***	0.001
LnGTEC	−0.554***	0.069	−1.467***	0.069
LnGTRD	−0.681**	0.072	−0.442***	0.083
LnFINF	−0.567**	0.073	−0.763**	0.085

Notes: where *** represents the 1 %and 5% level of significance levels.

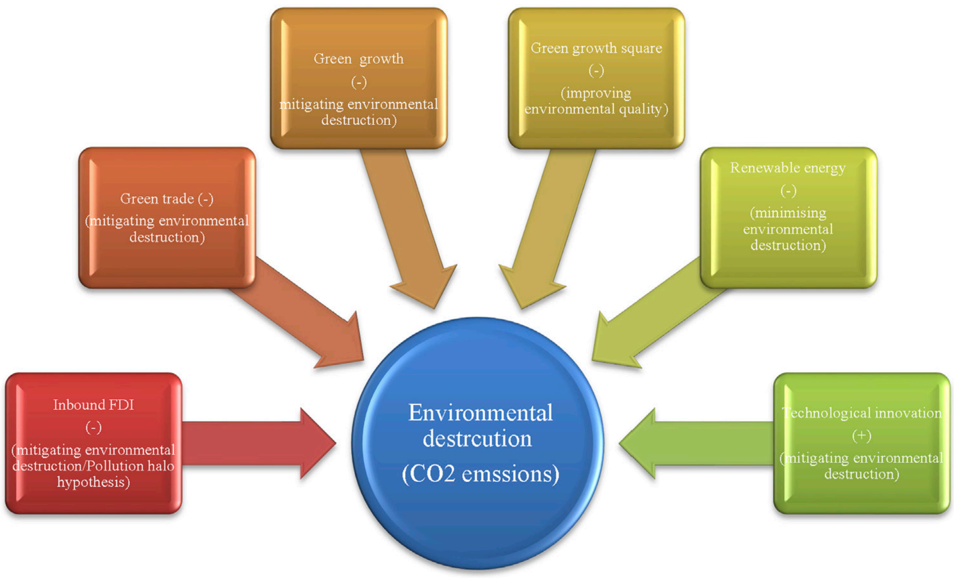

FIGURE 1
Graphical representation of statistical findings.

economies are trying to adopt environmentally protected measures to improve the quality of the environment.

Furthermore, the statistical findings of various studies concluded that exports lead to knowledge, competitiveness, and specialization. Specialization in cleaner goods can be achieved through environmentally friendly and exports of green products by nations that improve the environmental quality and enhance sustainable activities of industries (Ahmed et al., 2021a). The findings of our study are consistent with the work of (Ahmed et al., 2021b; J. Chen et al., 2022).

More precisely, the results indicate that 0.39 and unit 0.80 unit increases were found in CO2 emissions in the short-run and long-run, respectively, as a 1 unit change was found in inbound financial inflow. The negative relationship found between environmental degradation and FINF; this inverse association indicates that the pollution haven hypothesis is rejected, and these economies are following the Pollution halo hypothesis. The transfer of green/eco-friendly technologies and clean energy technologies are significantly improving the environmental quality of the host countries (Albornoz et al., 2009; Sadiqa et al., 2022). The short and long-run statistical findings of the inbound FDI-CO2 emissions nexus show that environmental quality is significantly improved by the inbound FDI in these economies, as these economies have strict environmental regulations. Consequently, these future green economies are committed to minimizing the destruction of the

TABLE 8 The statistical findings of the Dumitrescu Hurlin panel test.

S.no.	Hypothesis	W-stat	Z- stat	*p*-value	Statistical results	Decision
1	GRENϕCO2	3.877	2.806	0.011	Yes	Unidirectional causality
	CO2ϕGREN	0.983	0.104	3.510	No	
2	GREN2ϕCO2	4.847	3.616	0.001	Yes	Unidirectional Causality
	CO2ϕGREN2	0.931	0.454	7.501	No	
3	REW ϕ CO2	5.098	4.125	0.000	Yes	Bidirectional causality
	CO2ϕ REW	3.322	2.902	0.012	Yes	
4	GTECϕCO2	4.166	3.980	0.001	Yes	Bidirectional causality
	CO2ϕ GTEC	5.789	4.045	0.002	Yes	
5	GTRDϕCO2	6.612	5.009	0.010	Yes	Unidirectional
	CO2ϕGTRD	0.267	0.837	3.014	No	
6	FINFϕ CO2	3.759	0.043	0.869	No	Unidirectional causality
	CO2ΦFINF	5.825	4.092	0.000	Yes	
7	GRENϕGREN2	6.890	5.965	0.000	Yes	Bidirectional causality
	GREN2ϕGREN	8.815	7.725	0.000	Yes	
8	GRENϕREW	7.708	6.152	0.001	Yes	Bidirectional causality
	REWϕGREN	6.458	5.187	0.000	Yes	
9	GRENϕGTEC	5.768	4.152	0.000	Yes	Bidirectional causality
	GTECϕGREN	8.458	7.187	0.000	Yes	
11	GRENϕGTRD	6.025	4.025	0.000	Yes	Bidirectional Causality
	GTRDϕGREN	5.075	4.025	0.001	Yes	
12	GRENϕFINF	8.436	7.234	0.000	Yes	Bidirectional causality
	FINFϕGREN	7.543	6.754	0.000	Yes	
13	REWϕGDP2	6.207	5.815	0.000	Yes	Bidirectional causality
	GDP2ϕ REW	3.889	2.677	0.013	Yes	
14	REWϕGTEC	4.546	3.578	0.001	Yes	Bidirectional causality
	GTECϕREW	9.077	8.235	0.000	Yes	
15	REWϕGTRD	1.546	−0.578	0.556	No	Unidirectional causality
	GTRDϕREW	9.077	8.235	0.000	Yes	
16	REWϕFINF	8.293	7.498	0.000	Yes	Bidirectional
	FINFϕREW	9.809	8.677	0	Yes	
17	GTECϕGTRD	6.207	5.815	0	Yes	Bidirectional causality
	GTRDϕGTEC	4.889	3.677	0	Yes	
18	GTECϕFINF	1.946	−0.778	0.656	No	Unidirectional causality
	FINFϕGTEC	8.077	7.235	0	Yes	
19	FINFϕGTRD	6.207	5.815	0	Yes	Bidirectional causality
	GTRDϕFINF	7.889	6.985	0	Yes	

environment and investing in foreign investment in adopting clean technologies to improve the quality of the environment. Therefore, with investments to clean up the environment, these economies accepted the "pollution halo" hypothesis. This primary analysis concluded that these economies (as these countries are playing an important role in FDI of the world) are positively contributing to minimize the level of CO2 emissions (Christoforidis & Katrakilidis, 2021) results of our study endorsed by the findings of studies (Demena & Afesorgbor, 2020; Zubair et al., 2020). The Error of correction technique (ECT) (-1) indicates the speed of adjustment, the findings of ETC (-1) concluded that at a 1% level of significance, 60% (as dependent variables) respectively, modification required to move towards the equilibrium point of the research study for top green future economies.

Furthermore, a proactive strategy for renewable energy development, green growth and technological innovation with a long-term threshold to minimize environmental degradation and consistency with resource endowments could be encouraged a sustainable environment by the governments of these countries. Among the top energy transitioning and green growth economies, a collaboration mechanism involving technological innovation, supportive initiatives, and arrangements of collective sustenance must be strengthened. Furthermore, by establishing power plants and supporting solar and wind energies, good cooperation between energy transition countries may reduce the threat of energy shortages. For long-term sustainable development, these economies must continue their green innovation policy, promoting green technologies and transferring renewable energy sources to the rest of the world.

Robustness checks

The AMG and CCEMC methods are used to evaluate long- and short-run heterogeneous non-causality between the variables to check the robustness of the study's results. The reliability of statistical data is demonstrated in Table 7, where the results are gathered using the joint correlated effect mean group and augmented mean group methods. The AMG and CCEMC discovered that GREN values were inversely related to CO2. The square GREN is significantly inversely correlated with environmental destruction under the AMG and CCEMC and confirmed the existence of EKC. Furthermore, the inverse association found between REW, GTEC, GTRD and FINF and study observed that these variables are significantly improving the quality of these economies.

The statistical findings of this study are illustrated in Figure 1. The results indicate that green growth significantly improves the quality of these future green growth economies. Similarly, the findings of green trade, renewable energy use, the inflow of FDI, and technological innovation show a negative association between environmental degradation and the factors mentioned above.

Table 8 represents the Dumitrescu Hurlin panel test findings to test the causality between the variables. The Dumitrescu Hurlin panel test is applied in this analysis to gauge the causality between the variables. Table 8 shows the causal relationship between renewable energy consumption, green economic growth, green technology, green trade, and inward financial inflow. The statistical findings indicate that the two-way causality established between GRENϕGTRD, GRENϕGREN2, CO2ϕ REW, GRENϕREW, GRENϕGTEC, REWϕFINF, GTECϕGTRD, REWϕGTEC and FINFϕgGTRD. The unidirectional association between FINFϕGTEC, REWϕGTRD, FINFϕ CO2, GRENϕ CO2, GREN2ϕ CO2, GTRDϕCO2. Hereafter, findings designate that GDP growth can be increased through policy shock to the GREN, GREN2, REW, GTRD, FINF, and GTEC. The estimation describes that any policy shock in the factors mentioned abovewill be significantly essential to improve the quality of the environment of these economies. The findings of technological change are endorsed by Saleem et al. (2022), (Hao et al., 2021). The adoption of renewable energy sources leads to a significant contribution to any country's economy.

The graphical illustration of Graphical abstract represents those mentioned above is bi-directional and unidirectional associations with CO2 emissions.

Conclusion

This analysis contributes to the literature on the environmental sustainability of the economies, and the role of green growth, green trade, green innovation and inbound inflow are discussed under the premises of EKC. This analysis investigated the data of the world's top 10 green future economies (these countries moving towards green and clean developmental paths) for the period of 1990–2018 to identify these green variables' role in improving the environment's quality. The analysis applied the Cross-Sectional-Augmented Auto Regressive Distributed Lag (CS-ARDL) method. The study depends on cross-sectional dependence and augmented cross-sectional IPS (CIPS) for empirical analysis objectives; the CIPS test is used to detect the stationary issue, examine slope heterogeneity, Westerlund (2007), and for robustness check, this analysis used AMG and CCEMG tests.

This comprehensive analysis of the green growth-environmental quality nexus provides policymakers and researchers guidance on achieving sustainable environmental and development goals. Moreover, our core variable is green growth; thus, the carbon neutrality targets can be achieved through green growth projects. However, green trade, inbound financial inflow, and technological innovation can improve the environment's quality. Consequently, statistical findings show that green trade and inbound FDI significantly deteriorate the environment quality, confirming the "Pollution halo hypothesis." The results concluded that environmental quality is improving through trade liberalization in the short and long run. Green economic growth is promoted through green energy as dependency on non-renewable energy sources can significantly deteriorate the quality of the environment. Still, environmental sustainability can be achieved through renewable energy sources.

Moreover, natural resources can deteriorate less through the production of green products and renewable sources. These findings supported the theory of Core-macroeconomics. This analysis concluded that environmental quality is significantly improved by green technological innovation and growth, as the bi-directional association between green growth and green technologies indicates that both promote a green and clean environment. The findings of this study significantly supported the theory of green competitiveness and the Porter hypothesis. The statistical findings of green trade indicate that the reduction in CO2 emission enhances green economic growth; thus, green trade benefits these future green economies. This analysis confirmed the argument of composition effect by the modified H-O model of (Siebert & Larrick, 1992).

The use of renewable energy and technological advancement are crucial for achievement of environmental sustainability.

The current analysis tries to establish helpful suggestions for policymakers on implementing practical policies addressing renewable energy sources that improve environmental quality.

Environmental resources and economic growth can be sustainable through green technological innovation. Environmental resources can be preserved through an efficient supply chain process (Anser et al., 2021). Furthermore, to improve the quality of the environment and boost economic activities, society needs to import sustainable capital products. Thus, to stop the rising temperature of the earth, academics must report negative externalities. These countries are using the policies of "emissions cap trade" through restrictions imposed on emissions inventory; thus, these economies can provide technical assistance to developing nations to control CO2 emissions. As Kudratova et al (2018) identified, green projects provide greater profit than traditional projects. Thus, economies must invest more in boosting environmentally friendly technologies through research and development projects and focus on environmental management innovation. These economies follow the pollution halo hypothesis; thus, more investment should be allocated for transferring green technologies through inbound FDI in host countries. Inbound FDI can significantly overcome the issue of environmental degradation and can attain environmental sustainability through clean technologies. The current analysis used few green indicators but for, future analyses are recommended to identify more variables like green financing, carbon taxes and research and development expenditure (R&D) to minimise the CO2 emissions especially for developing and transitional economies. This research is important step towards to provide the contribution of green growth for the top future green growth economies in the existing literature. The contribution of green growth in improving the quality of environment varies from country to country, thus country specific research can be done on this topic by using these (used in this study) important variables. Furthermore, developing economies can used data regarding green growth and various other factors by researchers for further investigation to minimise the global climate change effects. To measure the environmental degradation impact, few variables are under consideration; thus, this study's limitation, so researchers can also add ecological footprint and other proxies of environmental destruction.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: data can be obatined from https://www.oecd.org/and world bank dats, http://data.worldbank.org/. Requests to access these datasets should be directed to https://www.oecd.org/ and world bank dats, http://data.worldbank.org/.

Author contributions

HS: Conceptualization, Writing, Editing, Data Analysis and Original draft. SW Writing, data collection. WJ, Writing, Review of Manuscript.

Conflict of interest

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

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