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RESEARCH ARTICLE

Exploring renewable energy, financial development, environmental quality, and economic growth nexus: new evidence from composite indices for environmental quality and financial development

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Abstract

The association between trade, financial development, consumption of renewable energy, environmental quality, foreign direct investment, and economic growth is important for sustainable growth and environmental strategies. Hence, this research unveils this association in selected low- and high-income economies from 1996 to 2020. Unlike most of the previous literature, this study uses a composite environmental quality index, a composite financial development index, and a composite trade share measure to better represent environmental quality, financial development, and trade openness, respectively. The Continuously Updated Fully Modified and Continuously Updated Bias Corrected estimators along with the Dumitrescu Hurlin causality method are utilized to scrutinize the nature of the linkage between the modeled variables. The long-run estimation provided that consumption of renewable energy and environmental quality augment economic growth in high-income nations, while both these variables do not contribute to the economic growth in low-income countries. Financial development upsurges economic growth in high- as well as low-income nations. Interestingly, trade openness boosts economic growth in high-income countries, while in low-income countries, it obstructs economic growth. In causal linkage, the conservation hypothesis for low-income countries and the feedback hypothesis for high-income countries are confirmed in the context of consumption of renewable energy and economic growth association. The supply-leading hypothesis for low-income countries and the feedback hypothesis for high-income countries are supported regarding the financial development–economic growth nexus. Moreover, one-way causality from growth to environmental quality and bidirectional causality between environmental quality and economic growth for low- and high-income countries are established, respectively. Lastly, exhaustive environmental and economic policies are directed.

Keywords Composite environmental quality index · Composite financial development index · Economic growth · Renewable energy

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Introduction

As we know, economic growth is an important tool for understanding the development of countries; hence, it has attracted a considerable focus from the development and environmental economists (Fakher et al. 2021a, 2021b). This is because achieving higher economic growth requires more natural resources and energy consumption (especially fossil fuels) which play a vital role in improving the standard of living and economic development of a country (Murshed et al. 2022; Ali et al. 2021). However, the adverse environmental consequences of such consumption include global warming and resulting climatic changes. Notably, energy consumption is a critical determinant of climate change, as all forms of non-renewable energy consumption have an adverse environmental contribution to air, water, and land (Irfan et al. 2021, 2022). In this context, global warming and conventional fossil-fuel depletion have augmented the value of renewable energy (RE) (Abbasi et al. 2022). Using appropriate sources of energy for improved economic growth with less environmental issues is a major challenge for every nation (Ahmed et al. 2021a). Environmental deterioration can directly or indirectly affect the economic and social status of human beings. For instance, environmental degradation can lead to the decline of productivity (economic status) and increase health disorderliness (social status) (Udemba et al. 2020). As a matter of fact, limiting environmental deterioration is essential to avoid its negative impacts on human health and economic development (Hao et al. 2021; Ahmad et al. 2022).

Given that access to socio-economic growth and development requires energy use as well as its expansion, energy has become an essential requirement for development and energy security has become a challenge for economies. The manufacturing activities drastically need energy due to continuous industrial growth. The path of industrialization has replaced the human workforce with machines, and energy-intensive production technologies demand much more energy resources day by day (Ahmed et al. 2021b; Ahmed et al. 2022; Hanif et al. 2019). Rising economic growth, population growth, and industrialization have stimulated energy use in developing countries, and more demand for energy in upcoming years is expected since these nations plan to accelerate their development (Sandberg et al. 2019). This means more environmental pollution and health problems are possible in the upcoming years.

The energy crisis as well as the dependency of humans on energy and its environmental consequences have led to the development of various technologies across the world. The intensification of this crisis has thus made countries move toward alternative energy sources, such as renewable energy, and also motivated them to formulate strategies for minimizing energy use and exploitation of resources. In addition, the use of clean energy to reduce environmental pollution itself is enough reason to consume clean sources of energy more than conventional sources of energy. In this context, the consumption of renewable energy (CRE) has become a proper substitute for fossil fuels to mitigate environmental deterioration (Iqbal et al. 2021; Ponce et al. 2021). In the view of researchers, many fossil fuel sources will be depleted in the next 40 years (Fakher et al. 2021a). Moreover, the increased use of renewable resources will mitigate global warming. Limited natural reserves along with the negative environmental effects of fossil fuels have stimulated the importance of renewable energy resources as a significant replacement for fossil fuels. Global attention toward ecological issues, desire to obtain sustainable development, strengthening of environmental groups, and implementation of energy security programs have expanded clean energy projects (Kassi et al. 2019). At this time, there are concerns about the high primary costs of renewable energy which hinder further promotion and progress of the clean energy sector. Also, the lack of financial supply channels, insufficient investments in small and medium-sized enterprises, and incomplete governmental policies obstruct the development of this sector (Kassi et al. 2020). Hence, it is vital to investigate the effect of renewable energy on economic progress and unfold the causal direction between clean energy and growth. Evidently, the causal association between these variables can follow neutrality, conservation, growth, and feedback hypotheses, and each of these hypotheses requires different policy implications.

Besides, different strategies have been thus proposed to achieve economic growth including economic openness policy and increasing foreign direct investment (FDI). Regarding the formulation and development of growth models in the economic literature, investment and capital supply are regarded as the basic economic issues by scholars. To achieve balanced growth, finding optimal resources of financial supply in various sectors at the micro-level is critical. FDI is thus regarded as one of the vital financial channels. FDI can effectively contribute to accelerating economic growth, creating jobs, improving production techniques, strengthening and expanding main financial and global resources, increasing research and development, nurturing competitiveness, and boosting domestic technology (Fan and Hao 2020).

Investigating the impact of renewable energy, financial development, and environmental quality on the economic growth of high- and low-income nations is imperative due to various reasons. According to the data provided by the World Bank (2020), high-income nations have an enormous

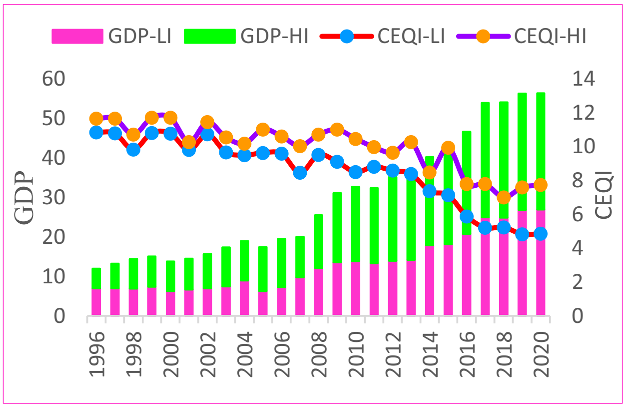

Fig. 1 Trend of GDP along with composite environmental quality index (CEQI) for selected low- and high-income economies. Source: World Bank (2020)

60.87% contribution to global GDP and they produce more than 36% of global CO_2 emissions. This indicates a major share of high-income nations in global environmental deterioration and climate change. On the other hand, low-income nations have a very limited contribution (less than 1%) to global economic growth and CO_2 emissions. Even though high-income nations are the main contributor to global environmental pollution, low-income nations are also motivated to acquire high growth for improving the standard of life of common people. In this context, low-income nations need to adopt environmentally friendly energy sources to avoid the negative effects of promoting growth and ensure energy security. On the other hand, high-income nations are required to adopt cleaner sources of energy to reduce their high contribution to environmental pollution. Also, the relationship between certain variables can vary according to the income level (Al-Mulali et al. 2015). Besides, Fig. 1 clearly shows that achieving desirable economic growth and development in these economies has led to adverse ecological consequences.

Therefore, it is interesting to investigate renewable energy, environmental quality, and economic growth nexus with respect to the income groups (low- and high-income economies) to formulate sustainable growth strategies. Hence, this research work will provide interesting outcomes for policymakers to achieve sustainable growth and implement environmental policies for pollution control.

Given the necessity of developing environmental indices for policymaking in line with sustainable principles, this study took several steps to measure and evaluate the linkage between economic growth and environmental quality using a holistic index based on environmental indicators, including Environmental Vulnerability (EVI), Ecological Footprint (EFI), Environmental Sustainability (ESI), Environmental Performance (EPI), Adjusted Net Saving (ANS), and Pressure on Nature (PN). Given the contradictory results of published studies on various environmental indices and economic growth connections, the consideration of the type of variables adequately representing environmental quality is an important issue. In many studies, only one variable or index has been used to depict environmental quality. However, such proxies cannot represent every aspect of environmental pollution and thus cannot accurately represent environmental quality. Hence, the main objective of this work is to investigate the linkage between economic growth, financial development (FD), consumption of renewable energy (CRE), foreign direct investment (FDI), composite trade share (CTS), and composite environmental quality index (CEQI) in selected low- and high-income economies from 1996 to 2020.

Three main novelties differentiate our research from the existing studies. Firstly, the present study used a holistic index (i.e., a composite index covering all aspects of environmental pollution), which is introduced by Fakher et al. (2021b), to resolve the aforementioned issues and unfold the linkage between selected variables and environmental quality. Undoubtedly, using this composite index will provide a solid foundation for formulating environmental policies to effectively control pollution. Secondly, a composite financial development index (CFDI), based on six financial development indicators, is established following the principal component analysis (PCA) suggested by Imamoglu (2019) and Shujah-ur-Rahman et al. (2019) to analyze the connection between variables under analysis and FD. Lastly, the Continuously Updated Fully Modified (CUP-FM) method is applied which provides trustworthy long-run results for panel data robust against heteroscedasticity, endogeneity, fractional integration, and cross-sectional dependency. For robustness of long-run panel results, the study employed the Continuously Updated Bias Corrected (CUP-BC) approach which also presents similar advantages (Ahmed et al.2020a).

The rest of the study is classified as follows: The "2" section presents the literature review. The "3" section presents the data, methodology, and model specification. The "7" section provides the empirical results. The "8" section contains the conclusions and policy recommendations.

Literature review

Here, this section will explain briefly the results of previous empirical studies under six study strands. The first strand of literature is associated with the environmental degradation–economic growth nexus. Technically, the past literature on economic growth–environmental deterioration nexus has advocated three hypotheses including the unidirectional hypothesis, feedback hypothesis, and neutrality hypothesis. Given this background, various studies have investigated the connection between environmental deterioration and economic growth without uniform outcomes. For example, the statistical outcomes of Malik (2021) and Vo and Ho (2021) supported the existence of bidirectional causality (feedback hypothesis) between economic growth and environmental degradation. On the contrary, using a sample of BRICS economies from 2000 to 2019 with the autoregressive distributed lag (ARDL) estimation, Li et al. (2022) disclosed findings supporting the unidirectional hypothesis (unidirectional causality) between economic progress and environmental pollution. Likewise, this outcome is confirmed by the study of Regmi and Rehman (2021) while others revealed evidence supporting the existence of the neutrality hypothesis between economic development and environmental pollution (e.g., Guoyan et al. 2022; Eyuboglu and Uzar 2022; Abdouli and Hammami 2020).

The second strand of literature deals with the interrelationship between FDI and environmental quality which presents equivocal and ambiguous outcomes. Accordingly, there are two different controversies on FDI–environmental quality nexus. The first controversy is related to *Pollution Halo Hypothesis*, in which FDI is likely to improve environmental standards by providing cleaner technologies and better environmental management systems. In some previous empirical investigations, the presence of a positive connection between environmental quality and FDI has been verified (e.g., Marques and Caetano 2020; Abdouli and Omri 2021; Dou and Han 2019). Conversely, the second controversy refers to *Pollution Haven Hypothesis* in which FDI dwindles environmental quality. In such studies, the presence of a negative effect of FD on environmental quality has been reported (e.g., Khan and Ozturk 2020; Udemba et al. 2020; Fakher 2019; Shahbaz et al. 2019). However, Akadiri and Ajmi (2020) stated that FDI does not influence CO_2. Some investigations also concentrated on the cause-effect relationship among these two variables. In this context, Xie et al. (2020), Abdouli and Hammami (2020), and Abdouli and Omri (2021) support *bidirectional causality* implying the presence of the feedback hypothesis, while Shahbaz et al. (2019), Fakher (2019), Khan and Ozturk (2020), Udemba et al. (2020), and Abdouli and Omri (2021) support *unidirectional causality*. Furthermore, Akadiri and Ajmi (2020) indicate the *neutrality hypothesis*.

The third strand of existing economic literature deals with a wide range of mixed outcomes regarding the relation between FDI and growth. From the empirical perspective, several investigations are indicating paradoxical findings. Firstly, numerous researches verify the positive influence of FDI on economic growth (e.g., Boateng et al. 2021; Bolívar et al. 2019; Fakher and Abedi 2017). Among these studies, Boateng et al. (2021) divulged outcomes supporting a one-way causality connection from FDI to economic expansion. In a similar work, Bolívar et al. (2019) and Fakher and Abedi (2017) revealed unidirectional causality. Secondly, several studies validated the two-way causality linkage between FDI and economic progress (e.g., Marques and Caetano 2020; Osei and Kim 2020; Abdouli and Omri 2021; Bakari and Sofien 2019; Sokhanvar 2019). Similar to these studies, Abdouli and Hammami (2020) found bidirectional causality between FDI and economic progress, implying the presence of the feedback hypothesis. Thirdly, some investigations have indicated that FDI does not impact economic growth. For example, Goh et al. (2017) and Curwin and Mahutga (2014) do not find any link between growth and FDI.

The fourth strand of existing literature is associated with the trade openness–economic growth nexus which is still unresolved and remains one of the most challenging issues (Destek and Sinha, 2020). For instance, we can refer to Majumder et al. (2020) and Bakari and Sofien (2019) who indicated a positive connection between economic growth and trade openness. Similar to these researches, Amna Intisar et al. (2020) illustrated that trade openness and economic extension have bidirectional causality in Western Asia and unidirectional causality in Southern Asia. However, some scholars found a negative and significant relationship between trade and economic expansion (for example, Nabi et al. 2022; Raghutla 2020; Zameer et al. 2020). Among these scholars, a unidirectional causality link from economic growth to trade openness is confirmed by Nabi et al. (2022) and a two-way causality linkage between trade openness and economic progress is authenticated by others. In addition, some investigations have indicated that there is no connection between growth and trade openness (Saidi and Mbarek 2017; Chandia et al. 2018).

The fifth strand of existing literature is related to the growth and FD nexus. The association between these variables grabbed many researchers' attention (Chen et al. 2021; Deng and Zhao 2022). These studies can be grouped into four classifications including the *demand-following hypothesis*, *supply-leading hypothesis*, *two-way causality* or *feedback effect hypothesis*, and *neutral hypothesis*. Among such researchers, we can refer to Osei and Kim (2020) and Combes et al. (2019) who indicated the *supply-leading hypothesis* depicted by the causality from FD to economic growth. In similar works, Abdouli and Hammami (2020) have pointed out a unidirectional causality from financial development to economic growth in the case of Lebanon and Oman, implying the presence of the supply-leading hypothesis. However, in some other papers, the *demand-following hypothesis* is found which revealed that economic growth causes FD (Cheng et al. 2021; Nyasha and Odhiambo 2018). In line with the results of these studies, Abdouli and Hammami (2020) have disclosed unidirectional causality from economic growth to financial development for Iraq, indicating the demand-following hypothesis. In various researches, the *two-way causality* or *feedback hypothesis* between financial development and economic growth was confirmed; for instance, Kassi et al. (2020) and Ponce et al. (2021) suggested this hypothesis. Additionally, Opoku et al. (2019) authenticated the *neutrality hypothesis* supporting no linkage between growth and FD.

The sixth strand of existing literature is associated with the economic growth–CRE nexus. Renewable energy has been determined as one of the sustainable energy cornerstones for the future, so it is significant to find out the relation between economic growth and the CRE. Therefore, numerous studies have been undertaken in this field, and no consensus has been reached regarding the findings. Some of the studies are suggestive of *bidirectional causality* between economic growth and CRE (e.g., Alola et al. 2019; Saint Akadiri et al. 2019; Aydin 2019; Zafar et al. 2019). As a matter of fact, these studies reveal the *feedback hypothesis* between CRE and growth. Similar to these academic works, Saadaoui and Chtourou (2022) have found evidence of a bidirectional causality connection between CRE and economic extension. However, others revealed a *unidirectional causality* between economic growth and CRE (e.g., Valadkhani and Nguyen 2019; Alvarado et al. 2019; Rasoulinezhad and Saboori 2018). In these studies, Armeanu et al. (2019) and Rasoulinezhad and Saboori (2018) depicted *conservation hypotheses*. Similar to these studies, the empirical work of Eyuboglu and Uzar (2022) divulged a causality from negative shocks of economic growth to negative shocks of CRE in South Africa, Thailand, and Turkey. However, Alvarado et al. (2019) and Valadkhani and Nguyen (2019) supported the *growth hypothesis*. Alternatively, the investigations by Papieża et al. (2019), Tuna and Tuna (2019), Ozcan and Ozturk (2019), and Fan and Hao (2020) demonstrated *no causality linkage* between economic growth and the CRE, thus establishing the *neutrality hypothesis*.

Data, strategy, and model specification

Data

In this study, panel data of economic growth (measured in constant 2010 US dollar), environmental quality (measured as a composite environmental quality index), FDI (net inflows as a percent of GDP), trade openness (measured as composite trade share), financial development (measured as a financial development composite index), and consumption of renewable energy (measured as the total energy consumption percentage) have been used for selected low- and high-income countries (see Appendix A) from 1996 to 2020. As we stated in the "1ntroduction" section, new composite indices are used for environmental quality and financial development. These indices are composite indicators that contain information related to six environmental and financial development indicators, as claimed by Fakher et al. (2021b)[1] and Kassi et al. (2020), respectively. The calculation of the composite index of environmental quality and financial development is discussed in Appendix B. The data regarding foreign direct investment, economic growth, financial development, and trade openness have been collected from the World Bank[2] (2020). The data related to renewable energy is sourced from the Energy Information Administration (EIA). The datasets relating to environmental indices are collected from many sources, for instance, World Bank (2020) for ANS and PN; Columbia University Center for International Earth Science Information Network (CIESIN) and Yale Center for Environmental Law and Policy[3] (YCELP) for ESI and EPI; South Pacific Applied Geoscience Commission (SOPAC) and the United Nations Environment Programme (UNEP) for EVI; and Global Ecological Footprint Network (GFPN 2020) for EFI.

Economic strategy

The intended model in this paper is a panel equation. In the econometrics of the panel, in general, it is assumed that the used data have cross-sectional independence. Therefore, the first stage in the econometric analysis of the panel data is the determination of the cross-sectional independence of the data. For this purpose, several tests have been provided, such as the Lagrange multiplier (LM) test propounded by Breusch and Pagan (1980), general CD tests, and the scaled CDLM suggested by Pesaran (2004). In this study, the Pesaran *CD* test and Breusch and Pagan LM test have been used as follows:

$$CSD_{lm} = T_{ij} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}^{2} \quad (1)$$

$$CSD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}^{2} \right) \quad (2)$$

where T indicates the time period and N stands for denotes the number of cross-sections.

Whenever a cross-sectional affinity has been approved in panel data, the use of conventional panel unit root methods will increase the probability of occurrence of false unit root results. To solve this concern, the cross-sectional IPS (CIPS) test that has been presented by Pesaran (2007) is employed. In order to formulate this test, considering dependence

[1] For a comprehensive discussion on the index methodology, see Fakher et al. (2021b).

[2] See https://data.worldbank.org.

[3] See https://epi.envirocenter.yale.edu/.

between the sections, Pesaran has used the cross-sectional Augmented Dicky–Fuller regression (ADF) which is assessed by using the OLS method for the *i*-th section. Due to its ability to account for cross-sectional dependence as well as heterogeneity, this test is very popular in the recent literature (Ahmed et al. 2020a). Therefore, the CIPS test is specified based on the following equation:

$$\Delta Z_{it} = \delta_i + \lambda_i z_{it-1} + \beta_i \overline{z}_{t-1} + \sum_{j=0}^{n} \varphi_{ij} \Delta \overline{z}_{it-1} + \sum_{j=0}^{n} \alpha_{ij} \Delta z_{it-1} + \mu_{it} \tag{3}$$

where $\overline{Z}$ is the average cross-section. The test statistics of CIPS can be calculated by taking the cross-sectional average of t_i (N, T) (Ahmed et al. 2020a) as follows:

$$CIPS = \frac{1}{N} \sum_{i=1}^{N} t_i(N, T) \tag{4}$$

After scrutinizing the unit root properties of studied variables, Westerlund's (2007) cointegration test is employed to examine the presence of panel cointegration association between modeled variables. Additionally, in order to verify the outcomes of cointegration association, the Pedroni (1999) cointegration test is utilized as well. The Pedroni (2004) cointegration test analyzes the results based on seven statistics, including four panel-based statistics (including panel-v, rho, PP, and ADF statistics which are known as within-dimension tests) and three group-based statistics (including group-rho, ADF, and PP which are named as between-dimension tests). These panel- and group-based statistics are obtained according to residuals of the following equation (Eq. 5).

$$Y_{it} = \beta_i + \varphi_i t + \sum_{j=1}^{m} r_{ji} Z_{jit} + \mu_{it} \tag{5}$$

In this equation, the dependent variable is shown by Y and the independent variables are denoted by Z. β_i and φ_i denote individual intercept and trend. Moreover, the number of predictors, cross-sections, and the period are disclosed by m, i, and t, respectively. In the Westerlund (2007) test, the null hypothesis' rejection demonstrates cointegration. Westerlund (2007) has suggested four distinct statistics to examine panel cointegration. The panel statistics p_t and p_a check the hypothesis of lack of cointegration against the hypothesis of coexistence, and the statistics of the mean group of G_t and G_a compare the hypothesis of lack of cointegration against the presence of at least a vector of cointegration. Unlike Pedroni, Kao, and Fisher tests, the Westerlund test handles heterogeneity and cross-sectional dependence; thus, this study preferred this widely used test and used it as the main test for analyzing cointegration. Westerlund (2007) has used the Bootstrap method for removing the effects of cross-sectional dependence (CSD) on the variables. These panel statistics can be presented as follows:

$$\mathrm{G_t} = \frac{1}{\mathrm{N}} \sum_{\mathrm{i=1}}^{\mathrm{N}} \frac{\lambda_{\mathrm{i}}}{\mathrm{SE}\left(\widehat{\lambda}_{\mathrm{i}}\right)} \mathrm{and} \mathrm{G_a} = \frac{1}{\mathrm{N}} \sum_{\mathrm{i=1}}^{\mathrm{N}} \frac{\mathrm{T}\lambda_{\mathrm{i}}}{1 - \sum_{\mathrm{j=1}}^{\mathrm{k}} \widehat{\lambda}_{\mathrm{ij}}} \tag{6}$$

$$\mathrm{P_t} = \frac{\widehat{\lambda}_{\mathrm{i}}}{\mathrm{SE}\left(\widehat{\lambda}_{\mathrm{i}}\right)} \text{ and } \mathrm{P_a} = \mathrm{T}\widehat{\lambda} \tag{7}$$

In previous studies, the first-generation approaches are applied to calculate elasticities in the long run, but those approaches fail to provide reliable estimates of the existence of cross-sectional dependence (Ahmed et al. 2020a). Similar to the studies of Ahmed et al. (2020a) and Zafar et al. (2019), this study applied the famous econometrics methods, namely CUP-FM and CUP-BC tests of Bai et al. (2009). These techniques can provide reliable calculations in the existence of endogeneity, serial correlation, and CSD.

In the last stage, to investigate the causal connections among variables, the heterogeneous Dumitrescu–Hurlin (D-H) causality approach of Dumitrescu and Hurlin (2012) is applied. The D-H causality test can be specified based on the following equation:

$$X_{it} = \beta_i + \sum_{j=1}^{p} \alpha_i^j \varphi_{it-j} + \sum_{j=1}^{p} \psi_i^j T_{it-1} + \mu_{it} \tag{8}$$

In Eq. (8), β_i is the constant term, X_{it} connotes a vector of response variables, j stands for the lag length, α_i^j indicates autoregressive parameters, and T_{it-1} represents a vector of lagged explanatory variables. In the case of $T < N$, the Wald statistics are recommended that can be stated as follows:

$$Wbar_{NT}^{HNC} = \frac{1}{N} \sum_{i=1}^{N} W_{it} \tag{9}$$

While in the case of $T > N$, the Z-bar statistics are recommended (Habib et al. 2022) that can be presented as follows:

$$Zbar_{NT}^{HNC} = \sqrt{\frac{N}{2k}} \left(W_{NT^{HNC}} - K \right) \tag{10}$$

As a matter of fact, considering the heterogeneity and cross-sectional dependence (CD) concerns, this causality approach can be profitable to find out the nature of the cause-effect relationship among variables. Moreover, the research methodology of this paper is depicted in Fig. 2.

Fig. 2 A schematic overview of the research methodology

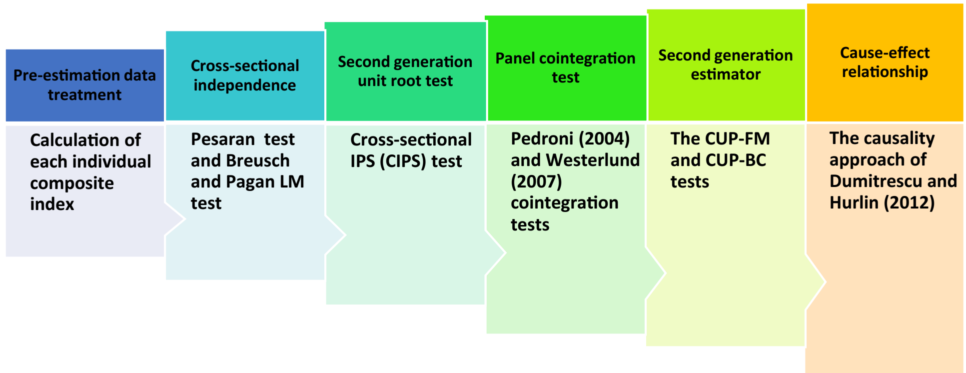

Table 1 Results of CSD tests

Variable	*lnGDP*	*lnCEQI*	*lnFDI*	*lnCTS*	*lnCFDI*	*lnCRE*
Low-income countries						
CD test	16.740* (0.000)	16.423* (0.000)	20.799* (0.000)	6.183* (0.000)	34.727* (0.000)	3.777* (0.000)
Breusch and Pagan LM	887.100* (0.000)	864.957* (0.000)	821.233* (0.000)	488.968* (0.000)	757.445* (0.000)	450.465* (0.000)
High-income countries						
CD test	89.505* (0.000)	99.531* (0.000)	26.623* (0.000)	12.219* (0.000)	36.821* (0.000)	51.382* (0.000)
Breusch and Pagan LM	624.806* (0.000)	721.233* (0.000)	852.622* (0.000)	723.038* (0.000)	418.295* (0.000)	432.428* (0.000)

*It depicts 1% significance

CEQI, composite environmental quality index; *CTS*, composite trade share; *CFDI*, composite financial development index

Model specification

Similar to the works of Ahmed et al. (2020b) and others, the following initial form is employed to estimate the modeled variables:

$$\mathrm{GDP}_{i,t} = f\left(\mathrm{CEQI}_{i,t}, \mathrm{FDI}_{i,t}, \mathrm{CTS}_{i,t}, \mathrm{CFDI}_{i,t}, \mathrm{CRE}_{i,t}\right) \quad (11)$$

In this model, the natural logarithmic forms of variables are used. For log-transformed variables, the calculated coefficients are expressed as elasticities. Additionally, Kahia et al. (2017) and Ahmed et al. (2020, a, b) state that the findings are expected to be more efficient and consistent if log-linear transformation is used. The modified model of the paper is as follows.

$$\begin{aligned}\mathrm{lnGDP}_{it} = \alpha_0 + \alpha_1 \mathrm{lnCEQI}_{it} + \alpha_2 \mathrm{lnFDI}_{it} + \alpha_3 \mathrm{lnCTS}_{it} \\ + \alpha_4 \mathrm{lnCFDI}_{it} + \alpha_5 \mathrm{lnCRE}_{it} + \varepsilon_{it}\end{aligned} \quad (12)$$

In Eq. (12), t, i, and ε_{it} indicate the period, cross-sections, and error term, respectively. Moreover,lnGDP_{it} refers to economic growth, lnCEQI_{it} indicates environmental quality, lnFDI_{it} is foreign direct investment, lnCTS_{it} refers to trade openness, lnCFDI_{it} shows financial development, and lnCRE_{it} is the consumption of renewable energy.

Results and discussion

In the first step for estimating the panel data set of this research, the CD test of Pesaran (2004) for the analyzed model has been applied, and the statistics are presented in Table 1. The null hypothesis related to the lack of CSD is rejected at the 1% level, and thus, the CSD in the model is found.

Therefore, the CIPS method of Pesaran (2007) has been used to examine the existence or lack of the unit root. The results of this test for all of the variables are expressed once with intercept (C), once with intercept and trend (C + T) at the level, and with the difference in the upper part of Table 2. According to these results and the critical values presented by Pesaran (2007), we conclude that all of the variables are nonstationary at level I(0); however, at the first difference, they became stationary.

Considering the existence of CSD in the analyzed model and the fact that each variable used in this study is stationary

Table 2 Unit root test (CIPS)

Variable	Level		First differences	
	C	C+T	C	C+T
Low-income countries				
lnGDP	−1.114	−2.162	−3.178***	−3.342***
lnCEQI	−1.732	−2.534	−3.789***	−4.112***
lnFDI	−1.381	−2.135	−4.113***	−3.512***
lnCTS	−1.013	−1.854	−3.335**	−3.114**
lnCFDI	−0.126	−1.139	−2.791*	−2.834*
Critical values for Pesaran's (2007) unit root test at various confidence levels				
Status	**1%**		**5%**	**10%**
C	−2.59		−2.38	−2.21
C+T	−3.14		−2.87	−2.78
High-income countries				
lnGDP	−2.132	−2.112	−3.852***	−3.924***
lnCEQI	−2.914	−2.368	−2.778***	−3.221***
lnFDI	−2.953	−2.241	−2.991***	−3.091***
lnCTS	−2.221	−1.960	−3.329***	−3.769***
lnCFDI	−1.822	−2.185	−4.224***	−4.181***
lnCRE	−2.236	−1.768	−4.121***	−4.213***
Critical values for Pesaran's (2007) unit root test at various confidence levels				
Status	**1%**		**5%**	**10%**
C	−3.18		−2.90	−2.75
C+T	−2.12		−2.32	−2.94

*It depicts 10% significance

**It depicts a 5% significance

***It depicts a 1% significance

CEQI, composite environmental quality index; *CTS*, composite trade share; *CFDI*, composite financial development index

Table 3 Westerlund panel cointegration tests

H_0: No existence of cointegration

Statistic	*t*-statistic	*P*-value	Robust *p*-value
Low-income countries			
G_t	−5.894*	0.035	0.000
G_a	−4.088***	1.000	0.075
P_t	−5.876*	0.023	0.001
P_a	−5.322***	1.000	0.082
High-income countries			
G_t	−3.372**	0.045	0.015
G_a	−6.731	1.000	0.620
P_t	−12.810**	0.028	0.012
P_a	−5.988	1.000	0.576

*It depicts 10% significance

**It depicts a 5% significance

***It depicts a 1% significance

in the first order, the cointegration in the intended model is analyzed using Westerlund's (2007) approach. This test's findings are presented in Table 3. As it can be seen in Table 3, the null hypothesis is rejected based on all of the panel statistics, and thus, cointegration in low- and high-income groups exists. Additionally, based on the results from the Pedroni cointegration test in Table 4, the obtained *p*-values of five statistics (out of seven) are less than 0.05. Therefore, this test also confirms the presence of cointegration.

After finding the panel cointegration association between modeled variables, without worrying about the problem of false regression, we can estimate the modeled variables' long-run coefficients. As mentioned, the CUP-BC and CUP-FM method were employed to calculate long-term relations between the model variables. The consequences of these two estimates are shown for low- and high-income countries in Tables 5 and 6, respectively.

As it can be seen in Table 5 and Table 6, the outcomes of estimating long-run relationships using CUP-FM and CUP-BC methods are almost similar to each other. Based on the consequences, the estimated coefficients for long-term relationships are statistically significant for all the variables except for the CEQI and the CRE in low-income countries. The CRE in both low- and high-income countries has a positive impact on economic growth. Whereas the influence of this variable on economic growth is not significant for low-income nations. In high-income nations, a 1% rise in CRE escalates economic growth by 1.19% (CUP-FM) and 1.08% (CUP-BC). This empirical outcome is reinforced by the findings of Papieża et al. (2019).

The empirical long-term evidence shows that the FDI variable in two groups of low- and high-income countries has the most influence on the variables of economic growth. The coefficient of FDI is 1.12 in low-income countries and indicates that a 1% rise in FDI upsurges growth by 1.12% (CUP-FM) and 1.08% (CUP-BC), while the coefficient of FDI in high-income countries suggests that 1.86% (CUP-FM) and 1.98% (CUP-BC) increase in GDP is acquired by a 1% increase in FDI. These consequences are similar to the researches of Bolívar et al. (2019) and Boateng et al. (2021). The results also demonstrate that the influences of trade openness and financial development on economic growth in high-income countries are positive and statistically significant. Whereas trade openness, in low-income countries, has a negative effect and financial development has a positive influence on growth.

Accordingly, the consequence displays that a 1% rise in financial development leads toward a 0.16% (CUP-FM) and 0.19 (CUP-BC) rise in GDP for low-income nations, whereas in high-income nations, a 1% rise in financial development upsurges economic growth by 0.89% (CUP-FM) and 0.93% (CUP-BC). Also, the results of this research found that a 1% rise in trade openness leads to a

Table 4 Pedroni panel cointegration tests

	Low-income countries		High-income countries	
	Statistics	Weighted statistics	Statistics	Weighted statistics
Within-dimension tests				
Panel v-statistic	1.8293** (0.0212)	1.1955* (0.0067)	2.1568** (0.0274)	1.9818** (0.0317)
Panel rho-statistic	1.8120 (0.2384)	0.0581 (0.6158)	0.1851 (0.5788)	−0.8631 (0.8050)
Panel PP statistic	−3.2461** (0.0123)	−2.3583* (0.0088)	−3.3902* (0.0004)	−2.8970* (0.0014)
Panel ADF statistic	−1.5462** (0.0238)	−2.9825* (0.0089)	−1.5518** (0.0348)	−2.8363** (0.0185)
Between-dimension tests				
Group rho-statistic	0.5833 (0.8385)		0.3421 (0.3895)	
Group PP statistic	−2.3708* (0.0056)		−3.5116* (0.0003)	
Group ADF statistic	−2.5608* (0.0018)		−3.1824* (0.0006)	

*It shows a significance level at 1%

**It shows a significance level at 5%

Table 5 Long-run estimation for low-income group

Dependent variable: logarithm of GDP					
Variable	CUP-FM		CUP-BC		Explanation
	Coef	T-stat	Coef	T-stat	
lnCRE	0.38	1.0421	0.28	1.1023	Consumption of renewable energy
lnFDI	1.12***	13.5086	1.08***	13.0022	Foreign direct investment
lnCEQI	0.66	0.8721	0.58	0.9529	Composite environmental quality index
lnCTS	−0.18***	−8.1598	−0.16***	−7.7182	Composite trade share
lnCFDI	0.16***	6.9512	0.19***	6.0235	Composite financial development index

***It denotes the significance level of 1%

Table 6 Long-run estimation for high-income group

Dependent variable: logarithm of GDP					
Variable	CUP-FM		CUP-BC		Explanation
	Coef	T-stat	Coef	T-stat	
lnCRE	1.19***	8.4412	1.08***	6.0231	Consumption of renewable energy
lnFDI	1.86***	4.2612	1.98***	3.2963	Foreign direct investment
lnCEQI	1.06***	3.8502	1.02***	4.7649	Composite environmental quality index
lnCTS	0.98***	6.5368	1.12**	2.5548	Composite trade share
lnCFDI	0.89***	11.1741	0.93***	7.2781	Composite financial development index

**It denotes a significance level at 5%

***It denotes a significance level at 1%

corresponding decrease of 0.18% (CUP-FM) and 0.16% (CUP-BC) in GDP in low-income countries. However, a 1 percent rise in trade openness enhances economic growth by 0.98% (CUP-FM) and 1.12% (CUP-BC) in high-income countries. The positive influence of financial development on economic growth is consistent with the study of Combes et al. (2019), and the positive influence of trade openness on economic growth in the context of high-income samples aligns with the findings of Majumder et al. (2020) and Bakari and Sofien (2019). The negative impact of trade openness on economic growth in low-income countries aligns with the findings of Nabi et al. (2022) and Raghutla (2020). Finally, the aforementioned empirical findings are portrayed in Figs. 3 and 4.

After calculating the long-term association between the model variables in two groups of selected low- and high-income countries, we proceed toward the determination of effect and cause relation between individual variables.

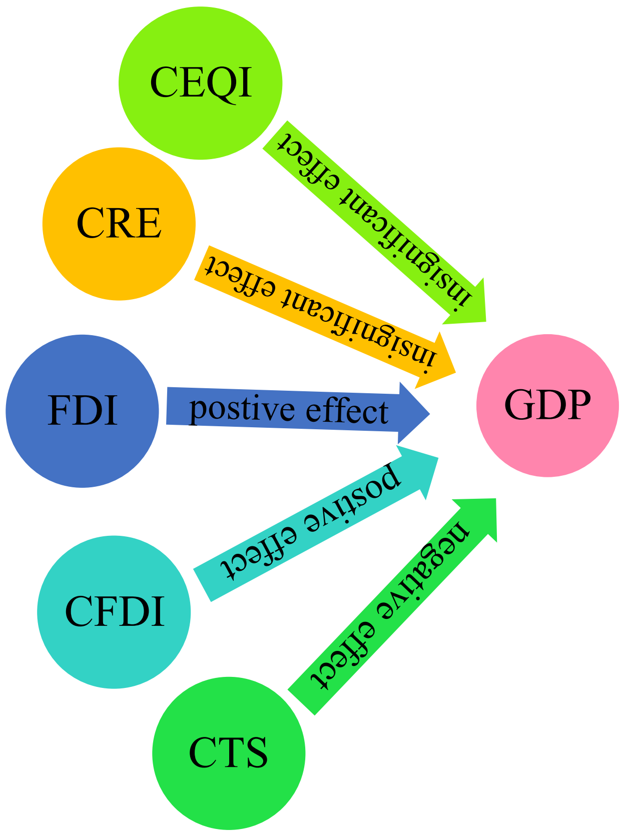

Fig. 3 Long-run output for low-income countries

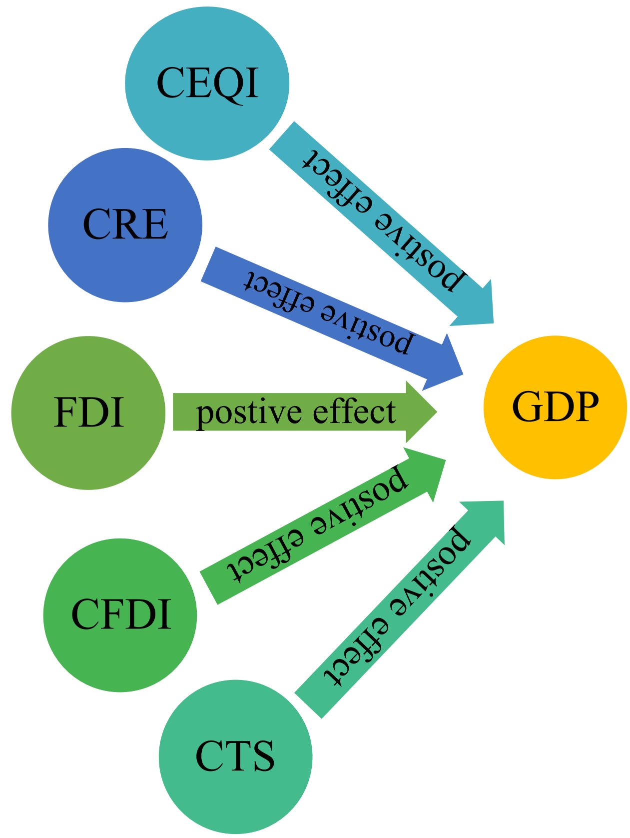

Fig. 4 Long-run output for high-income countries

Thereby, the nature of the causal relationship among the modeled variables is reported in Tables 7 and 8.

Accordingly, from Table 7, the consequences obtained provide evidence of a bidirectional causality relationship between FDI and economic growth and between trade openness and economic growth. In the case of FDI-economic growth, the outcome is in line with Abdouli and Hammami (2020), and in the case of trade openness, the finding is in line with Amna Intisar et al. (2020). The unidirectional causality from economic growth to CRE describes the conservation hypothesis. This consequence is compatible with the studies of Armeanu et al. (2019) and Rasoulinezhad and Saboori (2018) who claimed the presence of a conservation hypothesis between economic growth and renewable energy. However, this finding opposes the findings of Papieża et al. (2019), Tuna and Tuna (2019), Ozcan and Ozturk (2019), and Fan and Hao (2020) who indicated the neutrality hypothesis. Also, Alvarado et al. (2019) and Valadkhani and Nguyen (2019), who claimed the growth hypothesis, oppose this result.

On the flip side, the unidirectional causality from financial development to economic growth supports the supply-leading hypothesis. This result aligns with the consequences documented by Combes et al. (2019) and contradicts the empirical results of Cheng et al. (2021) and Nyasha and Odhiambo (2018) who indicate the demand-following hypothesis as well as Opoku et al. (2019) who illustrate neutrality hypothesis. Moreover, there is a one-way causality flow from growth to environmental quality. This empirical evidence is compatible with the results reported by Fakher (2019) who noted that economic growth leads to environmental quality. Additionally, a one-way causality was revealed from FDI to environmental quality which aligns with the studies of Khan and Ozturk (2020), Fakher (2019), and Shahbaz et al. (2019). However, the opposite results are reported by Abdouli and Omri (2021) and Dou and Han (2019). It is considerable to mention that there is also no causality relationship between CTS and CEQI, CTS and FDI, CFDI and CRE, and FDI and CRE. Finally, unidirectional causality linkages were observed running from CRE to CEQI, from CTS to CFDI, from CTS to CRE, from CFDI to CEQI, and from FDI to CFDI.

As can be observed from Table 8, the estimates reveal that there are bidirectional causalities between growth and CFDI, economic growth and CRE, economic growth and CEQI, FDI and CEQI, CRE and CEQI, economic growth and FDI, and between CRE and CFDI. The two-way causal linkage between CRE and economic growth opposes the

Table 7 Consequences of the D-H test for low-income countries

Null hypothesis	Zbar-stat	Prob
lnGDP ⇏ lnCEQI	7.7820*	0.0000
lnCEQI ⇏ lnGDP	0.1457	0.6816
lnCTS ⇏ lnCEQI	7.0073	0.1270
lnCEQI ⇏ lnCTS	0.9388	0.7470
lnCFDI ⇏ lnCEQI	7.9183*	0.0000
lnCEQI ⇏ lnCFDI	1.8022	0.1154
lnFDI ⇏ lnCEQI	3.8232*	0.0000
lnCEQI ⇏ lnFDI	1.2562	0.2152
lnCRE ⇏ lnCEQI	5.0922***	0.0930
lnCEQI ⇏ lnCRE	2.7275	0.2970
lnGDP ⇏ lnCTS	2.9179	0.5230
lnCTS ⇏ lnGDP	13.397	0.0330
lnGDP ⇏ lnCFDI	0.1487	0.7815
lnCFDI ⇏ lnGDP	5.1158*	0.0000
lnGDP ⇏ lnFDI	4.2681*	0.0000
lnFDI ⇏ lnGDP	1.4488***	0.0689
lnGDP ⇏ lnCRE	2.4551**	0.0102
lnCRE ⇏ lnGDP	−0.2873	0.8335
lnCTS ⇏ lnCFDI	8.9009*	0.0040
lnCFDI ⇏ lnCTS	2.0291	0.3840
lnCTS ⇏ lnFDI	2.3814	0.1810
lnFDI ⇏ lnCTS	1.8456	0.2570
lnCTS ⇏ lnCRE	6.7223*	0.0070
lnCRE ⇏ lnCTS	2.1499	0.2900
lnCFDI ⇏ lnFDI	1.1749	0.4550
lnFDI ⇏ lnCFDI	61.6597*	0.0000
lnCFDI ⇏ lnCRE	3.1430	0.1890
lnCRE ⇏ lnCFDI	0.9133	0.6180
lnFDI ⇏ lnCRE	1.8645	0.2480
lnCRE ⇏ lnFDI	2.5057	0.1840

*It describes the significance of 1%

**It describes the significance of 5%

***It describes the significance of 10%

CEQI, composite environmental quality index; *CTS*, composite trade share; *CFDI*, composite financial development index

Table 8 Consequences of D-H test for high-income countries

Null hypothesis	Zbar-stat	Prob
lnGDP ⇏ lnCEQI	8.9079***	0.0650
lnCEQI ⇏ lnGDP	6.5369***	0.0740
lnCTS ⇏ lnCEQI	12.345**	0.0120
lnCEQI ⇏ lnCTS	2.0273	0.4610
lnCFDI ⇏ lnCEQI	8.0161**	0.0130
lnCEQI ⇏ lnCFDI	12.498	0.1700
lnFDI ⇏ lnCEQI	2.5612**	0.0104
lnCEQI ⇏ lnFDI	1.9428***	0.0520
lnCRE ⇏ lnCEQI	7.6028*	0.0000
lnCEQI ⇏ lnCRE	1.6981***	0.0918
lnGDP ⇏ lnCTS	1.7844***	0.0569
lnCTS ⇏ lnGDP	2.8869*	0.0055
lnGDP ⇏ lnCFDI	15.312*	0.0030
lnCFDI ⇏ lnGDP	6.3149**	0.0420
lnGDP ⇏ lnFDI	5.5845**	0.0230
lnFDI ⇏ lnGDP	3.3785***	0.0570
lnGDP ⇏ lnCRE	4.6881*	0.0000
lnCRE ⇏ lnGDP	1.8939***	0.0582
lnCTS ⇏ lnCFDI	7.5648*	0.0220
lnCFDI ⇏ lnCTS	0.5449	0.7901
lnCTS ⇏ lnFDI	5.4546**	0.0330
lnFDI ⇏ lnCTS	0.5680	0.6280
lnCTS ⇏ lnCRE	5.2407*	0.0000
lnCRE ⇏ lnCTS	0.1504	0.8805
lnCFDI ⇏ lnFDI	1.7534***	0.0785
lnFDI ⇏ lnCFDI	1.5871	0.1156
lnCFDI ⇏ lnCRE	10.6510*	0.0010
lnCRE ⇏ lnCFDI	6.1452***	0.0500
lnFDI ⇏ lnCRE	19.7869*	0.0110
lnCRE ⇏ lnFDI	−0.3197	0.8300

*It describes the significance of 1%

**It describes the significance of 5%

***It describes the significance of 10%

This Causality Test was developed by Dumitrescu and Hurlin (2012). W-stat and Z-bar stat are related to Dumitrescu and Hurlin's test statistics. H0: one variable does not granger cause the other one

CEQI, composite environmental quality index; *CTS*, composite trade share; *CFDI*, composite financial development index

outcomes of Papieża et al. (2019), Tuna and Tuna (2019), Ozcan and Ozturk (2019), and Fan and Hao (2020) who report no causality. However, this feedback hypothesis is similar to Alola et al. (2019), Saint Akadiri et al. (2019), Aydin (2019), and Zafar et al. (2019). In relation to financial development and economic growth, the feedback effect is noticed which aligns with the results of Ponce et al. (2021) and Kassi et al. (2020). However, this finding contradicts the outcomes of Opoku et al. (2019) who establish a neutrality hypothesis between both these variables. The results also display a feedback effect, i.e., a two-way causality link between FDI and environmental quality. This finding aligns with Abdouli and Omri (2021) and Xie et al. (2020) who claimed a feedback effect between FDI and environmental quality, while Akadiri and Ajmi (2020) reported no association between these variables.

The influence of FDI on growth is in line with Bolívar et al (2019), Bakari and Sofien (2019), and Sokhanvar (2019), but contrary to Goh et al. (2017) and Curwin and Mahutga (2014) who documented no significant connection between economic growth and FDI. The impacts of growth on environmental quality confirm the consequences of

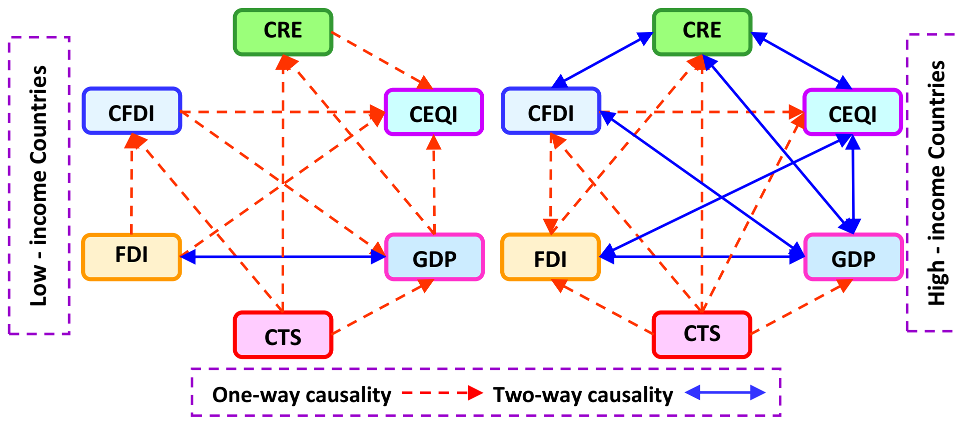

Fig. 5 Representation of causality results among model variables

Ahmed et al. (2020 a, b). The finding of unidirectional causality from trade openness to economic growth is compatible with the results of Amna Intisar et al. (2020) and Bakari and Sofien (2019). Lastly, this paper found evidence of unidirectional causality running from trade openness to environmental quality, financial development, FDI, and CRE, and from FDI to CRE, and from CFDI to FDI and environmental quality. The above-mentioned causality results are depicted in Fig. 5.

Proceeding to the discussion of the results, CRE in both low- and high-income countries has a positive impact on economic growth. However, the influence of this variable on economic growth is insignificant in low-income countries. It is worth mentioning that high-income countries pay more attention to renewable energy than low-income countries. Thus, CRE boosts economic growth in the only high-income group. On the other hand, the low-income group has a less share of CRE in their energy mix; hence, CRE does not make a meaningful contribution to the growth of these nations.

The influence of environmental quality on economic growth is found to be positively significant for high-income countries, but this effect is insignificant for low-income countries. This finding reveals that improvement in environmental quality enhances labor productivity in high-income nations that are extremely sensitive to improving their environmental quality. This result is sensible because high-income group takes numerous measures including imposing environmental regulations, improving technology, and increasing the prices of fossil fuels to boost the quality of the environment. Alternatively, the low-income group is well known for giving precedence to development over environmental quality; hence, environmental quality does not contribute to their economic growth. According to the results, FDI has a positive and significant influence on economic growth in both low- and high-income countries. This is because foreign investments enhance economic activities leading to more development. Financial development's positive influence on economic growth can be associated with financial system strength, the formation of a coherent financial market, and regulations that have led to increased investment efficiency through optimal resource allocation. Evidently, businesses in both groups of nations are dependent on the financial sector for the supply of financial resources, so the positive impact of FD on growth is reasonable.

The positive impact of trade openness on economic growth in high-income countries is also confirmed. In justification for this positive effect, it can be stated that technical progress is available through innovations, imitation, and technology transfer. In this context, trade openness provides the opportunity for technology transfer and innovation, leading to economic growth in a country. However, according to the obtained results, the increase in economic growth through further trade with the outside world is also a kind of explanation for the relative advantage theory. However, the influence of trade on economic growth is significantly negative in low-income countries. In justification for the negative influence of this variable on growth, it can be stated that the differences between institutions and different levels of technology between countries lead to the inefficient performance of trade openness in the low-income group. Moreover, the export of goods in the low-income group mainly consists of traditional goods rather than industrial goods. Hence, their financial capacity to do effective marketing and the knowledge needed to participate effectively in global competitions are very limited.

Based on the D-H causality findings, the conservation hypothesis for low-income countries and the feedback hypothesis for high-income countries are supported. It implies that energy conservation policies will not hurt the economic progress of the low-income group; however, such policies can retard the economic growth of the high-income group. On the other hand, in terms of the relationship between financial development and economic growth, the supply-leading hypothesis for low-income countries and the feedback hypothesis for high-income countries are confirmed. In low-income nations, FD boosts economic growth by providing useful resources to businesses, which enable them to expand their business activities. In the high-income group, FD boosts economic growth, but also an increase in growth improves the effectiveness of the financial system which results in a feedback effect.

Conclusion and policy recommendations

The focus of this research is on the causal dynamics and long-run linkage between variables including CRE, environmental quality, financial development, FDI, trade openness, and economic growth in selected low- and high-income countries from 1996 to 2020. In the first step, two composite indices of environmental quality and financial development were constructed using six environmental indicators and six variables of financial development, respectively. After preliminary unit root and cointegration analysis, the CUP-FM and CUP-BC estimators were used to investigate the association between selected variables. In the last step, the D-H causality test was utilized to explore the nature of the causal relationship among the modeled variables.

Overall, the empirical findings of this paper lead to the following conclusions. The empirical results established that all the variables are significant except for CRE and environmental quality in low-income countries. More precisely, CRE has a positive impact on the economic growth of high-income nations. However, the influence of CRE on economic growth is insignificant in low-income countries. Likewise, the influence of environmental quality on economic growth is positive in only high-income countries. Notably, environmental quality does not influence the economic growth of low-income countries. The positive impact of trade openness on economic growth is found in the high-income group, while in the low-income group, trade reduces economic growth. According to the results, FDI and financial development enhance economic growth in both groups of countries. The causal connections revealed the conservation hypothesis for low-income countries and the feedback hypothesis in high-income countries. On the other hand, the supply-leading hypothesis for low-income countries and the feedback hypothesis for high-income countries are confirmed in terms of the financial development and economic growth nexus. Moreover, a unidirectional causality from economic growth to environmental quality is found in the low-income group, while a bidirectional causality connection between growth and environmental quality is validated in the high-income group.

The estimates of this study can be used for establishing various policies. Regarding the positive influences of trade openness on economic expansion in the high-income countries, these countries are recommended to modify the composition of their trade from semi-manufactured goods to high value-added goods and shift from raw materials exports to sophisticated goods export. Besides, by assigning some trade policies, they should encourage investments in developing human capital- and capital-intensive sectors for developing better technologies. In this regard, enhancing the exports' extensive margin by introducing novel products to the bundle of export and careful innovation design or the promotion of export initiatives will boost the economic development of these countries. To build productive capacity, it is suggested to have a stronger focus on these issues. Moreover, paying more attention to the variety and quality of exports seems to be inevitable.

Additionally, it is necessary to meliorate and expand the financial sector to augment the economic growth process and optimally allocate the necessary financial resources. Therefore, it is recommended that the governments strengthen the banking system to help optimize the allocation of financial resources, and financial resources should be directed more toward productive investment projects.

We found that an increase in FDI boosts economic growth in both groups of nations. Hence, these nations should pay more consideration to foreign investments in more productive projects to speed up their economic growth. Relaxed and supportive tax regulations on foreign investments can speed up economic growth by attracting FDI. In addition, policymakers should devise policies to maintain stable and secure FDI inflows that could boost clean energy projects. Thereby, the government could encourage FDI by creating an efficient macroeconomic environment, giving incentives to investors, and careful use of a loose monetary policy for boosting their economy. Finally, the empirical results of this study advise policymakers to provide exhaustive environmental and economic policies by paying more attention to renewable energies not only to protect the sustainability of the economy but also to accomplish environmental sustainability. In this context, the use of energy sources like wind, solar, and biomass can be enhanced to assure sustainable growth with less environmental pollution. Low-income nations should immediately reformulate energy policies to discourage pollutant energy sources using pricing strategies and enhance clean energy by offering tax benefits and subsidies. More investments in the clean energy sector could enhance the supply of clean energy, which will be necessary to eventually phase out fossil fuels. In addition, energy conservation policies by increasing energy efficiency will also be a useful strategy for the low-income group with the conservation hypothesis.

Despite the interesting aspects of the current study, it has some limitations that can encourage future studies. This study used the aggregated indicator for environmental quality instead of using separate indices for environmental quality. Accordingly, future studies can expand this empirical work by incorporating the individual environmental indicators for useful findings. Furthermore, the current study divulged the causality linkage between economic variables and the composite environmental index. In this context, future studies can scrutinize the nature of the linkage between the modeled variables by considering each environmental indicator separately.

Appendix A

High-income countries: Australia, Austria, Canada, Denmark, France, Germany, China, Italy, the Netherlands, Norway, Spain, Sweden, Switzerland, United Kingdom, and the USA.

Low-income countries: Algeria, Burkina Faso, Chad, Kenya, Madagascar, Mali, Niger, Philippines, Rwanda, Senegal, Sudan, Togo, and Uganda.

Table 9 Weights of environmental indicators

Low-income countries		High-income countries	
Indices	Weights	Indices	Weights
EFI	0.148	**EFI**	0.361
EPI	0.212	**EPI**	0.219
ESI	0.178	**ESI**	0.108
EVI	0.238	**EVI**	0.034
ANS	0.109	**ANS**	0.126
PN	0.115	**PN**	0.152

EFI, ecological footprint index; *EPI*, environmental performances index; *ANS*, adjusted net savings; *ESI*, environmental sustainability index; *EVI*, environmental vulnerabilities index; *PN*, pressures on nature

Appendix B

Composite index for environmental quality (CEQI)

In this study, six indices of the environment such as EPI, ANS, EFI, EVI, ESI, and PN are considered for constructing the composite index. Following the method of Fakher et al. (2021b), the ANN method was employed to construct a CEQI for the two groups of selected low- and high-income countries. The weights of all environmental indices are presented in Table 9.

Based on Table 9, the mathematical equations for the CEQI are shown in Table 10.

Table 10 Calculation of the composite environmental quality index

Low-income countries
$CEQI = 0.148\ \mathrm{EFI} + 0.212\ \mathrm{EPI} + 0.178\ \mathrm{ESI} + 0.238\ \mathrm{EVI} + 0.109\mathrm{ANS} + 0.115\ \mathrm{PN}$
High-income countries
$CEQI = 0.361\ \mathrm{EFI} + 0.219\ \mathrm{EPI} + 0.108\ \mathrm{ESI} + 0.034\ \mathrm{EVI} + 0.126\ \mathrm{ANS} + 0.152\ \mathrm{PN}$

CEQI, composite index for environmental quality

Composite financial development index (CFDI)

This study uses two types of financial development indexes (the indices of financial development with market-based and financial development with bank-based). The bank-based financial development comprises three indexes including PCY, LLY, and DBAY. The market-based financial development comprises three indexes including SMV (obtained from market capitalization to GDP ratio), STR (which is the value of national shares exchanged divided by their market capitalization that actually represents the trading volumes of the securities market corresponding to the size of the securities market), and ML (the ratio of the transactions value in the stock market to the value-traded to GDP ratio, which in fact shows the liquidity in the stock market). Similar to Kassi et al. (2020), Imamoglu (2019), and Shujah-ur-Rahman et al. (2019) studies, PCA was conducted to calculate the CFDI. Therefore, the weights of all financial development indices are reported in Table 11.

Based on Table 11, the mathematical equations for the CFDI are shown in Table 12.

Therefore, using the above equations (the red dotted-line boxes in Table 10 and Table 12), the CEQI and CFDI can be calculated and used in estimating regression models for each of the two groups of selected countries.

Table 11 Weights of financial development indicators

Low-income countries		High-income countries	
Indices	Weights	Indices	Weights
DBAY	0.285	**DBAY**	0.379
LLY	0.098	**LLY**	0.119
ML	0.208	**ML**	0.085
PCY	0.069	**PCY**	0.108
SMV	0.166	**SMV**	0.095
STR	0.174	**STR**	0.214

DBAY, LLY, ML, PCY, SMV, and STR indicate the ratio of deposit money bank assets to GDP, liquid liabilities ratio to GDP, value-traded to the ratio of GDP, private credit by deposit money banks to GDP, market capitalization to GDP ratio, and stock traded turnover ratio, respectively

Table 12 Calculation of composite financial development index

Low-income countries
$CFDI = 0.285\ DBAY + 0.098\ \mathrm{LLY} + 0.208\ \mathrm{ML} + 0.069\ \mathrm{PCY} + 0.166\ \mathrm{SMV} + 0.174\ \mathrm{STR}$
High-income countries
$CFDI = 0.379\ \mathrm{DBAY} + 0.119\ \mathrm{LLY} + 0.085\ \mathrm{ML} + 0.108\ \mathrm{PCY} + 0.095\ \mathrm{SMV} + 0.214\ \mathrm{STR}$

CFDI, composite financial development index

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Declarations

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