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RESEARCH ARTICLE

Revealing empirical association among ecological footprints, renewable energy consumption, real income, and financial development: a global perspective

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Abstract
This study quantifies the effect of real income, financial development, trade openness, and renewable energy consumption on the ecological footprint (EFP) of consumption for a panel data of 152 economies during the period 1990–2017. Several panel unit root tests validate that datasets are stationary. The findings from the Westerlund co-integration test depict that variables are co-integrated. The augmented mean group panel algorithm method is then applied to measure the long-run linkage between variables. The analysis outcomes show a negative and significant association between the EFP and real income per capita in the case of the higher-income group while remaining groups depict the other way round relationship. Further, openness and renewable energy consumption are also observed to reduce EFP in the groups of higher-income and upper-middle-income economies. Finally, financial development is observed to lessen environmental degradation in the case of the higher-income group. Similarly, the results of the Granger causality test based on the Dumitrescu-Hurlin panel provided evidence of varied causality relationship among the variables in different income groups. In addition, we also surpassed an impulse response and variance decomposition analysis that permitted to forecast the impact of concerned variables on environmental degradation during the selected period. Finally, the findings from the empirical analysis suggest that per capita economic growth will have an increasing effect on the EFP for the concerned income group except for higher-income countries in the future.

Keywords Environment · Economic development · Augmented mean group · Ecological footprint · Renewable energy

Introduction

In recent decades, abrupt extreme meteorological events and global warming have raised the policymakers and researchers' focus toward the alarming situation of environment degradation (Sarkodie et al. 2020). In the same way, the impact of economic activities by human beings on environmental degradation has also become a serious problem for the world (Ahmed et al. 2020). Ecological assets' consumption by human beings is more than its growth, and if this demand will continue soon, these resources will be exhausted. Resources generated in 1.5 year are being consumed in 1 year, and this is creating an imbalance between demand and supply of these natural goods (Ahmed and Wang 2019). The rising gap between ecological footprint (EFP) and biocapacity reduces the planet's resource yield that results in climate variations, food insecurity, and damage of biodiversity (Rashid et al. 2018). Despite the growing literature on environmental degradation triggered by human activities, environmental problems are increasing over time. A bunch of available studies estimated

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the linkage between pollution and economic growth by employing carbon emission as the proxy of environmental degradation for their analysis (Wang et al. 2016). To apprehend the important nexus of economic development, openness, financial development (FD), and renewable energy consumption, this article will use EFP rather than CO_2 emission to represent environmental degradation.

The EFPs show the productive land and ocean area under use by human beings to aid human demands and to confiscate the wastes produced as results of these activities (Wackernagel et al. 2002). Since the last three decades, the EFP has been acknowledged as the key variable to study the environmental degradation as it assumes crop and grazing lands, carbon footprints, and land under urban use (Wackernagel and Rees 1998). Based on the above context, this article tries to quantify the association between driving forces of economic development on the EFP in all over the globe. Recently, renewable energy use, FD, and openness are under the limelight due to their imperative role in the current economic development and being emphasized by academia and researchers. Interlinkage of environmental quality and economic development has been quantified largely with the aid of the environmental Kuznets curve in the previous literature, and the findings concluded an inverse U-shaped association (Dogan et al. 2020; Dogan and Inglesi-Lotz 2020; Ike et al. 2020a, b). Relevant studies can be categorized into three branches based on their area of focus, i.e., gross domestic product (GDP), energy consumption, and environment pollution (Bölük and Mert 2014).

The first branch of the literature emphases on the association between economic growth and environmental pollution, and the concerned hypotheses are interpreted as the relative strength of scale versus method impact (Tsurumi and Managi 2010). However, the shape of the curve shows the mixture of scale, technical, and composition effects. In the development process, economies indulge in the establishment of industrialization in the starting phases to establish essential industries and, consequently, greenhouse gas emission rises ultimately. At the same time, per capita income raises both the production techniques and output mix changes. The second strand of the literature concentrates on the energy consumption and economic development association. These studies are focused on measuring the GDP and production association. Economic growth, production, and consumption-related activities are heavily reliant upon non-renewable energy, and these studies validated the connection between energy and economic development (Aboagye 2017; Furuoka 2016; Mattei 2018; Katircioğlu et al. 2019; Li et al. 2020).

Due to omitting variables in the earlier studies, the last cluster of studies emerged. This strand of studies of the concerned hypothesis integrates the two methodologies used in the existing research. Within these studies, the association between pollution, GDP, energy consumption, and some other variables have been explored (Bakirtas and Akpolat 2018; Saidi and Mbarek 2017; Sun et al. 2019; Ahmad et al. 2019; Zafar et al. 2019; Gulistan et al. 2020). In addition, some typical studies also quantified composite associations between these variables. For illustration Caraiani et al. (2015) find out the Granger causal links between energy usage and growth over time. Shahbaz et al. (2016) and Kais and Sami (2016) also estimated the association between energy consumption, emission, and economic growth and provided relatively comprehensive literature. Similarly, Zaman and Abd-el Moemen (2017) have revealed the linkage between energy consumption, emission, and economic development. Kahia et al. (2017) contributed a meticulous understanding of renewable and non-renewable energy use and GDP nexus. Wang et al. (2018a, b) have elaborated about the association between carbon emission and energy use within the different income groups. Likewise, Rasoulinezhad and Saboori (2018) also discussed the association between openness, emission, and economic growth, and these indicators have also been elaborated by Afridi et al. (2019) and in a case study of emerging countries by Zeren and Akkuş (2020). Above-stated case studies built the foundation for our research.

Most cross-country literature, thus, has unnoticed differences in the pattern and variations in the income levels of the economies studied. By considering this gap, the current study has considered four different income groups of economies around the globe that hold the imperative potential for scientific discovery, and this subgrouping permits for the examination of a wider association within characteristics by income inconsistency. Further, it is essential to explore the causal linkage between the proposed variables, and this research explores the causal relationship among the selected variables. These causal links assist researchers in finding whether these are in fact trade openness, FD, economic development or renewable energy consumption that constitute the key driving force of environmental damages, while vice versa in the case of EFP. Development can add to mitigate in EFP for higher-income countries, pursuing FD, trade openness, and renewable energy consumption. Development can increase environmental degradation in a low-income group of nations and governments of these nations should exert pressure for the reduction of environmental damages, and environment-friendly approaches should be adopted. If specific development has an insignificant impact on environmental damages, a reduction of environment-related damages will be successful only if it encourages a sustainable environment. Based on abovementioned context, the objectives of this article are (1) to measure the long-run linkage among concerned variables with the help of augmented mean group (AMG) method and (2) to quantify the link between EFP, trade openness, real income per capita (GDP/C), renewable energy consumption, and FD, while assuming the difference in the income levels among different economies. Using a balance dataset of 152 economies from 1990 to 2017, we explored the linkage among concerned indicators across different income groups from the globe.

Literature review

The purpose of this study is to estimate the long-run linkage among the proposed indicators with EFP. This study has used the different income groups such as higher-, upper-middle-, lower-middle-, and low-income countries, and these all are determined to attain economic development, which, in turn, raise the environmental degradation. Thus, it becomes a substantial challenge to attain economic development without harming the EFP. To achieve the sustainable development, income groups are explaining different co-friendly options that could enhance economic development. In this regard, the different situations across the different income groups, which have mostly been unnoticed in the existing studies as given in the following lines, can provide a new look to stimulate economic development and to lessen the environmental problems. The same as in the second objective, this study quantifies the causality relationship between concerned indicators as proposed by this study. The following lines regarding past studies are classified into two groups: (1) long-run association among variables and (2) causality direction among different variables.

Long-run relationship between environmental degradation and other determinants

Dogan and Seker (2016), using the panel data during the period 1985 to 2011, estimated the dynamic linkage among renewable energy consumption, trade, FD, and emission for top renewable energy–consuming countries. Concluding remarks explained the negative association between explanatory and explained variables. Later on, there was a case study of 27 high carbon–emitting countries related to EFP and real income per capita. The results of GM-FMOLS showed a negative liaison between EFP and FD (Uddin et al. 2017), while this study ignored the causality test. Likewise, Antonakakis et al. (2017) quantified the effect of energy use and GDP on environment performance in the UK and results endorse the incidence of a long-run association between the selected variables. Sulaiman and Abdul-Rahim (2017) studied the effect of energy use and economic development on emission in the case of Malaysia covering the 1975–2015 periods. The results of autoregressive distributed lag (ARDL), as well as DOLS, showed the non-significant influence of growth on energy consumption and emission. Moreover, a case study related to selected African economies measured the impact of renewable energy and growth on environment degradation. Long-run results showed a negative influence of explanatory variables on the dependent variable (Khoshnevis Yazdi and Ghorchi Beygi 2018). Similarly, Pata (2018) measured the effect of renewable energy usage, urbanization, FD, and income on pollution and showed that concerned explanatory variables increase environment pollution except renewable energy consumption. Liu and Hao (2018) measured the association among emission, energy being consumed, and development in the Belt and Road Initiative (BRI) economies during 1970 to 2013, and the findings showed that economic development of these nations is mainly dependent on the energy consumption. Using the Bangladesh data, Rahman et al. (2018) measured the interlinkage of per capita GDP, energy consumption, EFP, and emission. Study results revealed a significantly direct and monotonically increasing association between growth and environment pollution. Later on, Charfeddine and Kahia (2019) measured the association between renewable energy, FD, growth, and emission. Findings disclosed the insignificant effect of renewable energy and FD on the environment pollution and GDP. Furthermore, Nathaniel et al. (2019) applied different econometric techniques to estimate the nexus of EFP, urbanization, and energy usage. The outcomes confirmed the association among the concerning indicators of environmental pollution. Khan et al. (2019) validated the pollution haven and finance push emission hypotheses for BRI economies.

Later on, Destek and Sinha (2020) also confirmed the inverted U-shaped association for these countries. Similarly, using the augmented mean group panel test, Nathaniel et al. (2020) estimated the association between renewable energy and EFP. The findings showed that FD, GDP, and urbanization add to environmental degradation. Later on, there was a case study of emerging economies that explained the significant influence of trade and FD on GDP (Sethi et al. 2020). In the case of Indonesia, Nathaniel (2020) measured the dynamic linkage between urbanization, trade, energy use, and emission. Long-run results showed urbanization, economic growth, and energy consumption have a significantly positive impact on carbon dioxide discharge. In another case study, Ike et al. (2020a, b) estimated the influence of income, energy prices, and trade on the environment quality. The results explained the inverse relationship of renewable energy and its prices with environmental pollution and found a positive effect of trade on the level of the environment.

Causal linkages between environmental proxies and other determinants

Dogan and Turkekul (2016) quantified the impact of energy being used, trade, and FD on CO_2 for a time series dataset of the USA. The causality findings depicted the links between emission and growth, between energy consumption and urbanization, and between GDP and urbanization. For the time series of Qatar, Charfeddine (2017) has quantified the dynamic causality between energy consumption, economic development, and EFP from 1970 to 2015. The causality findings showed two-way Granger links between EFP and income, between EFP and trade openness, between real GDP (RGDP) per capita and FD, and between openness and FD. Sbia et al. (2017) used different econometric techniques, including the ARDL-bound testing procedure, and Granger causality links to quantify the influence of FD and urbanization on electricity consumption in the UAE. Their results showed that the concerned variables have an imperative impact on electricity use. Further, the causality findings depicted the bi-directional links among GDP, FD, and emission for selected African nations (Khoshnevis Yazdi and Ghorchi Beygi 2018). Likewise, a case study related to South African countries used bootstrap panel causality econometric technique and the results of causality showed heterogeneity among selected economies (Olowu et al. 2018). Similarly, Liu and Hao (2018) tried to estimate the causal linkages between selected variables in the case of BRI countries. Results showed two-sided causal relation among environmental pollution, energy use, and economic development, and a unidirectional causal link from GDP to renewable energy was observed. Furthermore, Nathaniel et al. (2019) estimated the causality, and concluding remarks claimed that rise in energy usage causes an escalation in GDP. Jebli et al. (2019) estimated a causal unidirectional association from renewable energy to emission and from economic growth to renewable energy. Another case study of emerging economies by Appiah et al. (2019) estimated the Granger association between the emission, GDP, and energy consumption over the period of 1971–2013. The result found two-sided Granger links between non-renewable energy and environment pollution. Ike et al. (2020a, b) also quantified the causality and found a monodirectional Granger link originating from energy prices, trade, and GDP to emission.

Empirically, there is no agreement among researchers concerning the sway of development, renewable energy, and trade on environmental degradation. As mentioned in the Appendix section Table 10, we emphasize on presenting and discussing income groups. The majority of the previous studies found evidence for a mixture of long-run association as well as causal relationship direction between the concerned variables. For example in the current year, some studies found the long-run link between renewable energy consumption, FD, GDP, and EFP by Nathaniel et al. (2020) and by Nathaniel (2020) for the case of Indonesia. Evidence for the causal association is found by many studies with different variables, i.e., Ike et al. (2020a, b). After reviewing the earlier literature, it is determined that existing studies highlighted the need of studying the empirical linkages among EFP, trade openness, real income per capita, renewable energy usage, and FD that is missing currently across the income groups. To summarize, while there is theoretical consensus regarding the heterogeneous (positive and negative) effect of concerning variables on environmental degradation, previous studies have had trouble in utilizing the same panel. To add to this literature, we applied the AMG panel econometric technique. With such change, we note it is possible to investigate using impulse response analysis. Further, this study has used the Dumitrescu-Hurlin (D-H) panel causality analysis to investigate the linkages among selected variables. Henceforth, the current study, most importantly, emphasizes on the nexus of said variables by using the latest methods and larger datasets.

Data and methodology

This study uses a balanced panel dataset of 152 countries from 1990 to 2017, yielding 4257 observations. The sample is considerably larger (in both numbers of the economies and the length of the period addressed) than those employed in several prevailing studies as discussed in the previous section. The selected economies are divided into four groups following their per capita income estimated from the World Bank spectacle, and these groups are then divided into four panel groups addressed in the study (World Bank 2020). The higher-income subpanel comprises of 43 economies, while the upper-middle-, lower-middle-, and lower-income subpanels included data for 42, 40, and 27 economies, respectively (see Appendix Table 10).

Further, a list of the variables includes total EFP of consumption as a proxy for environment situation, RGDP as a proxy for economic development, domestic credit to private as a proxy for FD, and renewable energy. Related data of the EFP and renewable energy are taken from Knoema online database while remaining data are taken from World Development Indicators (WDI) online database. The explanation of the selected variables is given in Table 1.

The basic aim of the current paper is to measure the association between the variables of the interest. For this purpose, the panel model is used as it is an appropriate technique to achieve the study objective (Adewuyi and Awodumi 2017; Bento and Moutinho 2016). The models employed can be specified as follows (Eqs. (1) to (5)):

$$\mathrm{LEFP}it = f(\mathrm{LRGDP}it, \mathrm{LTO}it, \mathrm{LFD}it, \mathrm{LRE}it) \quad (1)$$

$$\mathrm{LTO}it = f(\mathrm{LRGDP}it, \mathrm{LEFP}it, \mathrm{LFD}it, \mathrm{LRE}it) \quad (2)$$

$$\mathrm{LFD}it = f(\mathrm{LRGDP}it, \mathrm{LEFP}it, \mathrm{LEFP}it, \mathrm{LRE}it) \quad (3)$$

$$\mathrm{LRE}it = f(\mathrm{LRGDP}it, \mathrm{LTO}it, \mathrm{LFD}it, \mathrm{LEFP}it) \quad (4)$$

$$\mathrm{LRGDP}it = f(\mathrm{LEFP}it, \mathrm{LTO}it, \mathrm{LFD}it, \mathrm{LRE}it) \quad (5)$$

where L shows log for the variables, EFP represents ecological footprints as a proxy of environmental degradation, RGDP denotes real GDP per capita, TO is the trade openness,

Table 1 Description of variables

Indicator	Measurement	Source
Income/capita (RGDP)	GDP in US current $/population	WDI
Financial development (FD)	Domestic credit provided by the financial sector (% of GDP)	WDI
Renewable energy consumption	% of total final energy consumption	Knoema
Total EFP of consumption	GHA per person	Knoema
Trade openness	Exports + imports/GDP (in US current $)	WDI

FD denotes financial development, and RE represents renewable energy. Moreover, t shows the years and i symbolizes the cross section.

Ignoring the cross-sectional dependency (CD) in panel data may cause serious issues (Dong et al. 2018a, b). Therefore, three tests such as CD test by Pesaran (2004), CD test by Friedman (1937), and CD test by Frees (1995) are employed to finalize a suitable panel technique, while the mathematical forms of these CD ratio test can be explained as follows (Eqs. (6) to (8)):

$$\mathrm{CD} = \sqrt{2T/N(N-1)}\left(\sum_{i=1}^{N-1}\sum\nolimits_{j=i+1}^{N}\rho ij\right)N(0,1) \tag{6}$$

$$\mathrm{FRI} = (T-1)\left[\frac{2}{N}\sum_{i=1}^{N-1}\sum\nolimits_{j=i+1}^{N}\gamma ij + 1\right]\chi 2(T-1) \tag{7}$$

$$\mathrm{FRE} = \frac{(T-1)\left[\frac{2}{N}\sum_{i=1}^{N-1}\sum\nolimits_{j=i+1}^{N}\gamma ij + \frac{1}{T}\right]}{\mathrm{SE}(Q)}N(0,1) \tag{8}$$

where ρ is the coefficient of residual association in individual OLS regression. Estimated γij is the rank coefficient of Spearman's matrix, and SE(Q) is the standard error of the Q distribution. Fisher's test is the first-generation unit root test supposing panel CD, and it can be written in the form of Eq. (9)

$$\Delta \mathrm{y_{i,t}} = \mathrm{\alpha_i} + \mathrm{y_i}\ \mathrm{y_{i,t-1}} + \sum\nolimits_{j=1}^{k}\alpha jyi, t-1 + \mathrm{\varepsilon_{i,t}} \tag{9}$$

where $\Delta y_{i,t}$ represents the first difference of y_i at T at the ith observation of the panel, the same as γ, ε_i, and t which are the random disturbance terms. Assuming the CD (Pesaran 2007), cross-sectional augmented Dickey-Fuller (CADF) is used as the second-generation unit root test and can be written in the form of Eq. (10)

$$\Delta \mathrm{y_{i,t}} = \mathrm{\alpha_i} + \mathrm{\beta_i^*}\ \mathrm{y_{i,t-1}} + \mathrm{d_{0\ yt-1}} + \sum\nolimits_{j=0}^{p} d\ j+1\ \Delta \mathrm{y_{i,t-j}} + \sum\nolimits_{k=1}^{p} Ck\ \Delta\ \mathrm{y_{i,t-k}} + \mathrm{\mu_{i,t}} \tag{10}$$

CIPS can be measured by the mean of t statistics of the parameter β^* in the CADF model as given in Eq. (11).

$$\mathrm{CIPS} = \sum_{i=1}^{N}\frac{t}{N} \tag{11}$$

The forward step is to conduct the co-integration test. When both of the series are integrated of the same order, there is a long-run liaison between concerned variables. Long-run equilibrium process can be identified with the help of co-integration. For this process, we have applied the Durbin-Hausman group men co-integration test suggested by Westerlund and Edgerton (2008). This test permits the CD ratio and does not rely on previous knowledge regarding the integration order of variables. Thus, it can be applied under the following conditions.

Augmented mean group and long-term relationship

As purposed by Phillips and Sul (2007), when models suffer from the CD, heteroskedasticity, and serial correlation, panel estimators can consequence in unreliable inferior and even inconsistent outcomes. To eliminate these difficulties, Pesaran (Pesaran 2004, 2007) has suggested the common correlated effects, which are further proposed by Kapetanios et al. (2011) and Chudik et al. (2011). This methodology has several benefits as compared with the first-generation econometric techniques. It does not include the estimation of unobserved common factors and factor loading (Pesaran 2007). In this step, the current study uses the AMG algorithm proposed by Bond and Eberhardt (2013) and Dong et al. (2018b). The AMG algorithm is flexible and without limitation of nonstationary variables in the approximation of the parameters (Destek and Sarkodie 2019). The main panel model is given as Eq. (12)

$$\mathrm{lnEFP}it = \beta 0 + \beta 1\mathrm{lnRGDP}it + \beta 2\mathrm{lnTO}it + \beta 3\mathrm{lnFD}it + \beta 4\mathrm{lnRE}it + \varepsilon it \tag{12}$$

Equation (12) is measured with the first-difference form and $T-1$ period dummy

$$\Delta\mathrm{EFP}it = \beta 0 + \beta 1\mathrm{lnRGDP}it + \beta 2\mathrm{lnTO}it + \beta 3\mathrm{lnFD}it + \beta 4\mathrm{lnRE}it + \sum_{t=2}^{T} p_t(\mathrm{AD}_t) + \mu it \tag{13}$$

In Eq. (13), AD_t indicates the first-difference $T-1$ period dummies and p_t mentions parameters for period dummies. In the succeeding phase, the assessed parameter p_t is replaced with T variables, which denotes to the dynamic method as follows (Eqs. (14) and (15)):

$$\Delta \text{EFP}it = \beta 0 + \beta 1 \ln \text{RGDP}it + \beta 2 \ln \text{TO}it + \beta 3 \ln \text{FD}it + \beta 4 \ln \text{RE}it + d1(\delta t) + \mu it \quad (14)$$

$$\Delta \text{EFP}it{-}\delta t = \beta 0 + \beta 1 \ln \text{RGDP}it + \beta 2 \ln \text{TO}it + \beta 3 \ln \text{FD}it + \beta 4 \ln \text{RE}it + \mu it \quad (15)$$

D-H panel causality test

This methodology is developed to test the causality in heterogeneous panel data method. There are three advantages of this methodology: (1) it considers CD ratio, (2) it assumes the time dimension and size of cross section relative to each other, and (3) through this method, effective results can be achieved in the case of unbalanced data (Dumitrescu and Hurlin 2012). Panel causality can be written in the form of Eq. (16)

$$\text{Y}_{\text{i,t}} = \alpha it + \sum_{k=1}^{k} \gamma(k) y_{i,t-k} + \sum_{k=1}^{k} \beta i(k) \text{x}_{\text{i,t-k}} + \varepsilon it \quad (16)$$

where β_i shows $\beta_1 + \beta_2 + \beta_3 + \ldots + \beta_k$, α_i is the individual fixed effect, $\gamma^{(k)}$ is the lag parameter, k is the lag length, and $\beta_i^{(k)}$ is the slope of parameters. The hypothesis used for the D-H panel test is as follows:

Null hypothesis (H_0): $\beta_i = 0$ (homogenous results of causality)

Alternative hypothesis (H_1): $\beta_i \neq 0$ (heterogeneous results of causality)

The H_0 of D-H causality states that there is no causal association in the panel data, and rejection and acceptance of the hypothesis depend on the probability values. This methodology can be denoted as Eq. (17)

$$\text{W}_{\text{N,T}}^{\text{Hnc}} = \frac{1}{N} \sum_{i=1}^{N} Wi, t \quad (17)$$

Further, the findings of impulse response functions (IRFs) and variance decomposition analysis are given in the next section.

Results and discussion

Firstly, the summary statistics of the variables of interest are given in Table 2. Findings show that the highest and lowest mean value of ln EFP is 0.735 and 0.0401 for the higher- and lower-income economies, respectively. Based on the mean of ln RGD P values, the higher-income group is the richest (4.279) and the lower-income group is the poorest (2.571). Moreover, the higher-income group has rich trade openness (10.761), while among the remaining groups, the lower-income group has minimum trade openness. Lastly, for the case of the average value of renewable energy, the lower-income group holds the highest ln RE (1.837), while the higher-income group has the lowest (0.809).

The pairwise correlation coefficient between the RGDP and EFP is positive and significant, telling the economic growth worsens the environmental situation in the concerned income groups. Similarly, openness has a positive correlation with the EFP in the case of higher-, upper-middle-, and lower-income economies and the negative association has been witnessed for the case of a lower-middle-income group. Further, FD also has a positive correlation with the explained variable for all groups excluding the lower-income group. Alternatively, renewable energy is negatively correlated with environmental degradation in all concerned income groups as depicted in Table 3.

Several tests are performed to detect CD, and recent studies like Pala (2020) and Aydoğan and Vardar (2020) used three different tests for the examination of CD by Friedman (1937), Frees (1995), and Pesaran (2004), and we have used the same. The outcomes of these diagnostic tests are summarized in Table 4, and the findings show that the H_0 of no CD cannot be rejected for all income groups. This suggests a shock that arises in one of the sample countries may spill over to the world.

After examining the CD, the study moves to unit root tests. To estimate the stochastic behavior of concerned variables, we have applied the first-generation as well as second-generation unit root tests which are augmented Dickey-Fuller (ADF), Im-Pesaran's, CIPS, and CADF unit root test. Findings of relevant variables are elaborated in Table 5, and it is clear from the findings that all variables are integrated at the first difference with intercept.

After checking the unit root test, it is essential to see whether there is a long-term relationship among the selected variables (Westerlund 2007). The test is useful for application in this study for the subsequent motives; firstly, it allows for the incidence of the vast extent of heterogeneity, in both the long-run co-integration and short-run dynamics (Persyn and Westerlund 2008). Secondly, it is suitable for cross-sectional dependency. Thirdly, this test allows the bootstrap options that are favorable for multiple repetitions of co-integration test. Further, Persyn and Westerlund (2008) proposed the Gt and Ga (group mean test) to study H_1 that at least one of the unit is co-integrated. Result of the Westerlund test (Table 6) shows that Gt and Ga, as well as Pt and Pa test statistics, are significant. H_0 of no panel co-integration in the case of concerned income groups is rejected, and it shows study variables are associated in the long-run relationship.

Table 2 Summary statistics of variables of interest

	LEFP	LRGDP	LTO	LFD	LRE
Higher-income countries					
Mean	0.735357	4.279584	10.76018	1.880751	0.809433
Median	0.739760	4.347187	10.82840	1.915541	0.951406
Maximum	1.231009	5.076369	12.79155	2.403570	1.792701
Minimum	− 0.494052	3.111968	8.830525	− 0.730790	− 2.020790
Std. Dev.	0.163481	0.375091	0.814906	0.278179	0.734162
Skewness	− 0.538115	− 0.800668	− 0.149037	− 1.595717	− 1.257377
Kurtosis	7.837291	3.343352	2.389485	11.27766	4.483269
Jarque-Bera	1230.952	134.4437	23.13652	3945.083	427.2694
Probability	0.000000	0.000000	0.000009	0.000000	0.000000
Upper-middle-income countries					
Mean	0.395440	3.523627	9.845091	1.659005	1.035944
Median	0.407325	3.572750	9.985065	1.487148	1.176826
Maximum	1.078955	5.236987	12.39144	10.59482	1.927939
Minimum	− 1.363667	2.126347	4.956232	− 1.202219	− 2.491231
Std. Dev.	0.175490	0.359731	1.078928	1.387383	0.588954
Skewness	− 1.165352	− 0.525185	− 0.917323	5.378070	− 0.991501
Kurtosis	12.67873	3.606371	4.355327	33.38775	4.036273
Jarque-Bera	4815.091	71.46421	252.7713	50,483.43	243.2158
Probability	0.000000	0.000000	0.000000	0.000000	0.000000
Lower-middle-income countries					
Mean	0.170741	3.060401	9.617724	0.457498	1.506964
Median	0.149769	3.020503	9.617570	0.233170	1.701698
Maximum	0.996344	5.486528	11.75687	2.127473	1.981909
Minimum	− 0.368325	1.467535	7.058433	− 0.239971	− 0.221420
Std. Dev.	0.228696	0.455932	0.798138	0.529356	0.506497
Skewness	0.716408	2.061423	− 0.177297	1.074277	− 1.630656
Kurtosis	4.301694	10.94480	3.125171	2.784389	4.714887
Jarque-Bera	174.8773	3738.826	6.598894	217.5962	633.5929
Probability	0.000000	0.000000	0.036904	0.000000	0.000000
Lower-income countries					
Mean	0.040078	2.571644	8.867193	0.987950	1.837989
Median	0.049821	2.574770	8.870422	1.051253	1.932983
Maximum	0.369018	3.456591	10.33788	1.986510	1.992742
Minimum	− 0.455516	1.013483	7.045127	− 0.730153	− 0.283033
Std. Dev.	0.132376	0.267851	0.582967	0.347026	0.332074
Skewness	− 0.387404	− 0.274732	− 0.002935	− 0.888462	− 4.136187
Kurtosis	2.790915	5.225585	2.624028	4.876128	20.01228
Jarque-Bera	20.28742	165.5368	4.453758	210.3355	11,272.27
Probability	0.000039	0.000000	0.007865	0.000000	0.000000

Findings of long-run AMG estimator

The study uses an AMG estimator to find out the impact of RGDP, openness, FD, and renewable energy on EFP, and the findings are given in Table 7. These results are for all four concerned income groups of economies. The coefficient of ln RGDP is negative for the higher-income group and positive for the other three groups. The negative value of RGDP (− 0.077) shows that the rise in RGDP in higher-income economies would cause a decline in the EFP (damages to environment). In other words, income level increases environmental degradation at early phases of economic development but declines after achieving the optimum point of sustainable development. Further, this view exposed that the reduction in

Table 3 Pairwise correlation

	LEFP	LRGDP	LTO	LFD	LRE
Higher-income countries					
LEFP	1	0.521908	0.267837	0.204980	− 0.214865
LRGDP	0.521908	1	0.583383	0.301303	− 0.128527
LTO	0.267837	0.583383	1	0.259505	0.1172608
LFD	0.204980	0.301303	0.259505	1	0.0705628
LRE	− 0.214865	− 0.128527	0.117260	0.070562	1
Upper-middle-income countries					
LEFP	1	0.493089	0.250407	0.209717	− 0.154058
LRGDP	0.4930896	1	0.381308	0.0926560	− 0.086652
LTO	0.250408	0.381308	1	0.0858115	− 0.1228870
LFD	0.209717	0.092656	0.085811	1	0.0087090
LRE	− 0.154058	− 0.0866523	− 0.1228870	0.00870901	1
Lower-middle-income countries					
LEFP	1	0.431248	− 0.110891	0.345852	− 0.5484576
LRGDP	0.431248	1	0.0737892	0.260312	− 0.1049012
LTO	− 0.110891	0.0737892	1	− 0.2404971	− 0.0359152
LFD	0.3458529	0.2603121	− 0.2404971	1	− 0.1829280
LRE	− 0.548457	− 0.1049012	− 0.0359152	− 0.1829280	1
Lower-income countries					
LEFP	1	0.208080	0.1373347	− 0.1591568	− 0.2375861
LRGDP	0.208080	1	0.4412041	0.25891998	− 0.4858745
LTO	0.1373347	0.4412041	1	0.17399374	− 0.3694225
LFD	− 0.159156	0.2589199	0.1739937	1	− 0.11747201
LRE	− 0.2375861	− 0.4858745	− 0.3694225	− 0.11747201	1

environmental damages as opposed to economic development can be recognized as a structural variation in economic growth and technological progress (Sarkodie 2018). Similarly, as income level rises, environment responsiveness rises thus driving the public to demand clean environment ensuing in the implementation of environmental laws, policies, and regulation, which, in turn, lessens the environment pollution (Sarkodie and Strezov 2019).

The results explain that RGDP would decrease the level of EFP. The coefficient of real GDP suggests that 1% growth in this factor would lead to a reduction in EFP equivalent to 0.077%, and similar results have been found by Al-Mulali et al. (2015), Diputra and Baek (2018), and Xie et al. (2019). The results of AMG show a positive relation of RGDP with environmental damages for upper-middle-, lower-middle-, and lower-income groups. The economic development is the main factor behind the upsurge in the environmental damages for these economies. These groups are primarily focusing on quick economic growth and requiring awareness of energy-saving and environmental damage reduction measures, and in response, energy use in production generated through traditional methods increases, as do environmental damages. Further, developed economies with severe environment policies and regulation transfer their dirty technologies to developing economies with lax environmental laws, hence adding their environmental damages. Indeed, for the case of

Table 4 Findings of cross-sectional dependency ratio tests

Test	LEFP = *f*(LRGDP, LGDP2, LGDP3, LFDEV, biomass)			
	Higher-income	Upper-middle-income	Lower-middle-income	Lower-income
Pearson (CD)	38.219*** (0.000)	5.070*** (0.000)	21.504*** (0.000)	27.574*** (0.000)
Frees (*Q*)	8.661** (0.059)	5.988*** (0.005)	8.109*** (0.014)	5.023** (0.005)
Friedman (CD)	278.31*** (0.000)	48.429* (0.086)	25.093*** (0.000)	25.718*** (0.000)

Table 5 First- and second-generation unit root tests

Variables	Level				1st difference			
	IPS	ADF	CIPS	CADF	IPS	ADF	CIPS	CADF
Higher-income countries								
LRGDP	2.29276 (0.9891)	2.15390 (0.9844)	− 1.983	− 1.983	− 19.2519*** (0.000)	− 17.1539 (0.000)	− 2.150**	− 2.416***
LTO	0.75600 (0.7752)	0.94053 (0.8265)	− 2.437	− 2.437***	− 15.6079*** (0.000)	− 15.0412*** (0.000)	− 4.398***	− 4.475
LFD	− 0.44088 (0.3297)	0.00144 (0.5006)	− 1.851	− 1.851	− 12.3906*** (0.000)	− 11.8617*** (0.000)	− 3.806***	− 3.245***
LEFP	2.29276 (0.9891)	2.15390 (0.984)	− 2.326	− 2.326***	− 19.2519*** (0.000)	− 17.1539*** (0.000)	− 5.332***	− 5.785
LRE	6.20302 (1.0000)	6.09358 (1.000)	− 1.476	− 1.489	− 16.4490*** (0.000)	− 15.1784*** (0.000)	− 2.557***	− 2.570***
Upper-middle-income countries								
LRGDP	2.09348 (0.9818)	2.31014 (0.9896)	− 2.987	− 2.949	− 11.2642*** (0.000)	− 10.9177*** (0.000)	− 5.902***	− 5.236***
LTO	0.66451 (0.7468)	0.92126 (0.8215)	− 1.532	− 1.538	− 13.8631*** (0.000)	− 12.7632*** (0.000)	− 3.755**	− 3.530***
LFD	− 1.99425*** (0.0231)	− 2.03801*** (0.0208)	− 1.909	− 1.929	− 14.7609 (0.000)	− 13.8551*** (0.000)	− 3.211***	− 2.490***
LEFP	− 1.56468** (0.0588)	− 3.59562** (0.0610)	− 1.839	− 1.839	− 21.2304 (0.000)	− 18.2642 (0.000)	− 3.736***	− 3.569***
LRE	2.21017 (0.9856)	2.24785 (0.1356)	− 2.239***	− 2.255***	− 15.2385*** (0.000)	− 15.2385*** (0.000)	− 4.256	− 4.280
Lower-middle-income countries								
LRGDP	6.04054 (1.0000)	6.15028 (1.0000)	− 2.019	− 2.015	− 9.42641*** (0.000)	− 9.43185*** (0.000)	− 4.243***	− 4.263***
LTO	− 9.43185 (0.8681)	1.42430 (0.9228)	− 2.178**	− 2.156***	− 12.2296*** (0.000)	− 12.0984*** (0.000)	− 2.315	− 2.278
LFD	1.46757 (0.9289)	1.49152 (0.9321)	− 1.443	− 1.491	− 17.4752*** (0.000)	− 15.2982*** (0.000)	− 3.484***	− 3.975**
LEFP	3.84857 (0.9999)	3.80563 (0.9999)	− 2.322	− 2.629	− 19.0495*** (0.000)	− 17.2678*** (0.0000)	− 4.390***	− 4.929***
LRE	3.84857 (0.8899)	3.80563 (0.8956)	− 1.192	− 1.198	− 19.0495*** (0.000)		− 3.236	− 3.258***
Lower-income countries								
LRGDP	3.29514 (0.9995)	3.50893 (0.9988)	− 2.005	− 2.012	− 11.4940*** (0.000)	− 11.0785*** (0.000)	− 2.783***	− 2.691***
LTO	3.06097 (0.9989)	3.16128 (0.9992)	− 1.276	− 1.296	− 11.1204*** (0.000)	− 10.3104*** (0.000)	− 3.145***	− 3.225***
LFD	3.39880 (0.9997)	3.36353 (0.9996)	− 2.049	− 1.053	− 11.4414*** (0.000)	− 10.7724*** (0.0000)	− 4.950**	− 4.085***
LEFP	2.00587 (0.9776)	1.89495 (0.9710)	− 1.778	− 1.796	− 17.2041*** (0.0000)	− 15.2493*** (0.0000)	− 3.444***	− 3.210***
LRE	3.64417 (0.9999)	3.56759 (0.9998)	− 1.773	− 1.779	− 10.7485*** (0.0000)	− 10.4308*** (0.0000)	− 3.773**	− 3.861***

Table 6 Results of Westerlund co-integration

Statistics	LEFP = *f*(LRGDP, LTO, LFD, LRE)			
	Value	*z* value	*P* value	Robust *P* value
High-income countries				
Gt	− 2.440	3.065	0.999	0.000
Ga	− 2.230	11.480	1.000	0.225
Pt	− 8.058	9.178	1.000	0.825
Pa	− 1.509	9.429	1.000	0.006
Upper-middle-income countries				
Gt	− 2.631	1.663	0.952	0.100
Ga	− 2.576	− 2.576	1.000	0.000
Pt	− 9.706	7.328	1.000	0.640
Pa	− 2.496	8.576	1.000	0.000
Lower-middle-income countries				
Gt	− 1.659	8.398	1.000	0.930
Ga	− 1.659	11.490	1.000	1.000
Pt	− 10.809	5.813	1.000	0.050
Pa	− 2.097	8.662	1.000	0.610
Lower-income countries				
Gt	− 2.509	2.032	0.979	0.200
Ga	− 2.764	8.776	1.000	0.920
Pt	− 10.708	2.947	0.998	0.000
Pa	− 3.037	6.549	1.000	0.960

concerned income groups, 1% GDP would increase environmental damages by 0.144%, 0.0160%, and 0.023% for these groups, respectively. These outcomes are consistent with the case study of BRICS by using emission as a dependent variable (Wang et al. 2018a, b), a case study of China (Xie et al. 2019), and a case study of the USA (Usman et al. 2020) which also supported our study results.

The second explanatory variable is trade openness, and for this variable, associated coefficient is negative at 1% level for all income groups excluding the lower-middle-income group. These findings depict the imperative role of earning from export in total national income that can cause higher environmental issues, as more production triggers more fossil fuel combustion. Moreover, the findings show that cross-border trade opens the way for updated and environment-friendly technology transfer and, in turn, declines the burden on the environment. Our findings for higher-income and upper-middle-income groups are consistent with those of the study of twenty-seven high carbon–emitting economies, which support the negative influence of trade openness on the EFP (Uddin et al. 2017), and findings from another case study related to Qatar are also in line with our findings (Charfeddine 2017). A case study related to developing economies by Destek and Sinha (2020) also confirms our study findings, but a case study of EU is in contrast with the results of lower-income countries (Destek et al. 2018).

Besides, the third variable used in this study is FD and empirical finding explains that this variable has different signs for different income groups, but all coefficients are significant at 1%. For the EFP, the results support the idea that FD leads to more environmental pollution in all income groups except the higher-income countries. Further, the findings show that an upsurge of 1% in the domestic credit will raise the environmental damages equivalent to 0.028% in the case of upper-middle-income group, 0.661% for the lower-middle-income group, and 0.025% in lower-income countries, while for the case of a higher-income group, it will decrease the EFP by − 0.029%. Our empirical findings imply that all income groups' policymakers should enhance the development of financial factors to raise the advantages from its negative effect on the environmental damages, as it can be seen from higher-income countries. These findings for higher-income countries validated the results of a relevant study by Destek and Sarkodie (2019), while the findings related with other three income groups are in line with a case study of BRI countries which also support the positive relationship between FD and EFP (Baloch et al. 2019) and also supported by Saud et al. (2020).

Lastly, the coefficient values of renewable energy are significantly negative for higher-income and upper-middle-income economies, implying the clear influence of biomass source of energy for declining the EFP. This also shows that higher-income and upper-middle-income nations are doing right for the attainment of sustainable development goals through the inclusion and expansion of renewable energy. However, the lower-middle-income group shows a positive but insignificant value, and a lower-income group of countries depicted a negative and statistically insignificant relationship with the environmental damages. These outcomes explain the dominant role of non-renewable energy in the form of fossil fuels. The coefficient of renewable energy suggests that a 1% escalation in this factor leads to a decrease in EFP for the case of high-income (0.102%) and upper-middle-income (0.201%) groups. Similar results have been found by a case study related to renewable energy and EFP in the case of Europe (Alola et al. 2019); later on, a case study of BRICS countries also validated our findings (Ulucak and Khan 2020), also supported by a case study of OECD countries by Destek and Sinha (2020), while another case study related to the Middle East and North Africa regions contrasted with these findings (Nathaniel et al. 2020). In the concerned model, the key results of this analysis are given as follows:

- EFP, RGDP, trade openness, FD, urbanization, and renewable energy are co-integrated and move together, in the concerned income groups.
- RGDP increases the environmental degradation level in upper-middle-, lower-middle-, and lower-income groups in the long run.

Table 7 LEFP coefficient for the AMG estimators

Variable	LEFP = *f*(LRGDP, LTO, LFD, LRE)					
	Coefficient	Std. Err.	*z*	$P > \|z\|$	95% confidence interval	
High-income countries (Wald $\chi^2 = 42.37$ (0.000))						
LRGDP	− 0.0776691	0.0655667	− 1.18	0.000	− 0.2061776	0.0508393
LTO	− 0.1564958	0.0483286	− 3.24	0.001	− 0.0617734	0.2512181
LFD	− 0.0297007	0.0612962	− 0.48	0.005	− 0.149839	0.0904376
LRE	− 0.1022151	0.0324587	− 3.15	0.002	− 0.1658329	− 0.0385972
Cons.	− 0.4672011	0.3083885	− 1.51	0.009	− 1.071631	0.1372292
Upper-middle-income countries (Wald $\chi^2 = 108.39$ (0.000))						
LRGDP	0.1444544	0.0311661	4.63	0.000	0.0833701	0.2055387
LTO	− 0.0303655	0.042537	− 0.71	0.008	− 0.1137364	0.0530054
LFD	0.0284853	0.0201691	1.41	0.000	− 0.0110453	0.068016
LRE	− 0.2018168	0.0431832	− 4.67	0.000	− 0.2864543	− 0.1171793
Cons.	0.1782586	0.3584701	0.50	0.002	− 0.5243299	0.8808472
Lower-middle-income countries (Wald $\chi^2 = 36.14$ (0.000))						
LRGDP	0.0160074	0.0335566	0.48	0.000	− 0.0497623	0.0817772
LTO	0.413956	0.1193426	3.46	0.983	− 0.0383247	0.0374969
LFD	0.6602831	0.0715365	9.23	0.000	0.520074	0.8004921
LRE	− 0.1887933	0.1235794	− 1.53	0.399	− 0.4310044	0.0534178
Cons.	0.3077512	0.3935298	0.78	0.002	− 0.4635531	1.079056
Lower-income countries (Wald $\chi^2 = 11.83$ (0.019))						
LRGDP	0.0239356	0.0273224	0.88	0.000	− 0.0296154	0.0774867
LTO	0.0217054	0.0266097	0.82	0.004	− 0.0304486	0.0738595
LFD	0.025716	0.0119634	2.15	0.032	0.0022683	0.0491642
LRE	0.1720376	0.3660651	0.47	0.254	− 0.5454369	0.8895121
Cons.	− 0.5828782	0.7415175	− 0.79	0.002	− 2.036226	0.8704694

- Trade openness declines the EFP level in higher-income and upper-middle-income economies while increases the EFP in lower-income groups and has no effect on the EFP for a case of the lower-middle-income group in the long run.
- FD increases the environmental degradation level in all income groups excluding the higher-income group.
- RE consumption cuts the level of EFP in the higher-income and upper-middle-income groups.

These outcomes are also depicted in the graphical representation in Appendix Figure 5.

Findings of D-H panel causality

The confirmation of a long-run association among the variables of interest suggests a causal link in at least one way. Though, the estimates given in Table 7 do not yield the information on the track of the causal association between environmental degradation and other concerned variables. Since a co-integration linkage exists between the EFP and other variable addressed by this study, we led the D-H panel causality test to recognize the directionality. Detailed outcomes of the analysis are given in Table 8. The outcomes provide proof of varied panel causality among the variables for the different income groups. For the high-income economies, a bidirectional Granger association occurs between FD, EFP, and RGDP and between renewable energy and RGDP. On the other hand, a one-way linkage is found from renewable energy usage to EFP, from RGDP to openness, and from LRE to trade openness. Similarly, bidirectional causality is found to characterize the association between FD and openness in upper-middle countries. While a unidirectional causal link has been identified running from EFP to RGDP and FD, from renewable energy to EFP, from RGDP to FD, and from renewable energy to FD.

For lower-middle-income economies, the bidirectional causal associations exist between the FD and EFP. In addition, the unidirectional causal link has been noticed from trade openness to EFP, from RGDP to FD, and from renewable energy to LFD. In a similar finding to that concerning the

Table 8 Findings of D-H panel causality

Null hypothesis	Higher-income countries		Upper-middle-income countries		Lower-middle-income countries		Lower-income countries	
	W-Stat.	Zbar-Stat.	W-Stat.	Zbar-Stat.	W-Stat.	Zbar-Stat.	W-Stat.	Zbar-Stat.
LRGDP ≫ LEFP	1.9057	4.1996 [0.1760]	4.49735	6.02057 [0.2965]	5.2882	19.1774 [0.2232]	4.09291	3.98115 [0.7589]
LEFP ≫ LRGDP	2.3308	6.1706 [0.7589]	3.26848	2.78340 [0.0054]	3.0327	9.0903 [0.6811]	3.84643	3.45986 [0.0005]
LTO ≫ LEFP	1.9057	4.1996 [0.3003]	5.16624	7.76371 [0.8156]	2.6708	7.4719 [0.0934]	4.37025	4.56771 [0.5689]
LEFP ≫ LTO	3.9917	13.8720 [0.5330]	4.37693	5.68825 [0.1856]	5.0627	18.1689 [0.1588]	1.75068	−0.97255 [0.3308]
LFD ≫ LEFP	3.9064	13.4762 [0.0432]	3.95634	4.60514 [0.4658]	3.6589	8.3258 [0.0013]	3.30304	2.31062 [0.0209]
LEFP ≫ LFD	3.3945	11.1027 [0.0165]	5.64121	9.04950 [0.0000]	2.5696	12.4560 [0.0008]	4.19212	4.19099 [0.3569]
LRE ≫ LEFP	2.6327	7.5707 [0.0221]	3.08411	2.30300 [0.0213]	2.3500	6.0375 [0.1558]	4.78017	5.43467 [0.5869]
LEFP ≫ LRE	3.7307	12.6619 [0.3151]	3.77606	4.12773 [0.4568]	2.5563	6.9600 [0.3333]	2.79607	1.23840 [0.2156]
LTO ≫ LRGDP	1.8100	3.7559 [0.9110]	4.47656	5.95023 [0.3965]	2.3689	6.1217 [0.1475]	6.72784	9.55392 [0.0000]
LRGDP ≫ LTO	1.8360	3.8764 [0.0101]	4.86633	6.97513 [0.3214]	6.5325	24.7421 [0.2529]	3.12822	1.94088 [0.0523]
LFD ≫ LRGDP	3.7375	12.6932 [0.0000]	3.82610	4.25233 [0.2535]	5.8063	21.4944 [0.6924]	2.03317	−0.37510 [0.7076]
LRGDP ≫ LFD	4.4777	16.1253 [0.0000]	13.5698	29.9198 [0.0000]	2.6568	7.4095 [0.0072]	9.34451	15.0880 [0.0000]
LRE ≫ LRGDP	5.1708	19.3394 [0.0129]	4.15796	5.12443 [0.5698]	3.4529	10.9696 [0.4719]	3.66589	3.07804 [0.0021]
LRGDP ≫ LRE	1.7067	3.2767 [0.0061]	4.41419	5.79922 [0.7986]	2.8296	8.1822 [0.2235]	4.86299	5.60983 [0.2856]
LFD ≫ LTO	2.8583	8.6164 [0.0414]	3.40912	3.14343 [0.0017]	5.3618	19.5067 [0.0238]	2.30567	0.20122 [0.8405]
LTO ≫ LFD	2.0872	5.0412 [0.2356]	8.36120	16.1647 [0.0000]	2.1781	5.2685 [0.1482]	4.95784	5.81044 [0.6985]
LRE ≫ LTO	5.3107	19.9881 [0.0017]	3.05114	2.20083 [0.0236]	3.0727	9.2693 [0.3094]	3.47461	2.67347 [0.0075]
LTO ≫ LRE	1.5196	2.4095 [0.9971]	4.60005	6.27253 [0.4102]	2.4181	6.3418 [0.8625]	3.30830	2.32175 [0.0202]
LRE ≫ LFD	2.7683	8.1991 [0.7157]	4.56402	6.20566 [0.5104]	2.4178	6.3407 [0.0294]	6.01724	8.05103 [0.9165]
LFD ≫ LRE	3.0613	9.5580 [0.3566]	5.01442	7.39343 [0.1135]	2.6973	7.5904 [0.2296]	2.78394	1.21275 [0.2252]

lower-income group, we observe the two-way Granger links between openness and RGDP. Considering the association among variables, a unidirectional Granger link has also been seen from EFP to RGDP, from FD to EFP, from income per capita to LFD, and from renewable energy to RGDP. Further, the graphical representation is given in Appendix Figure 6.

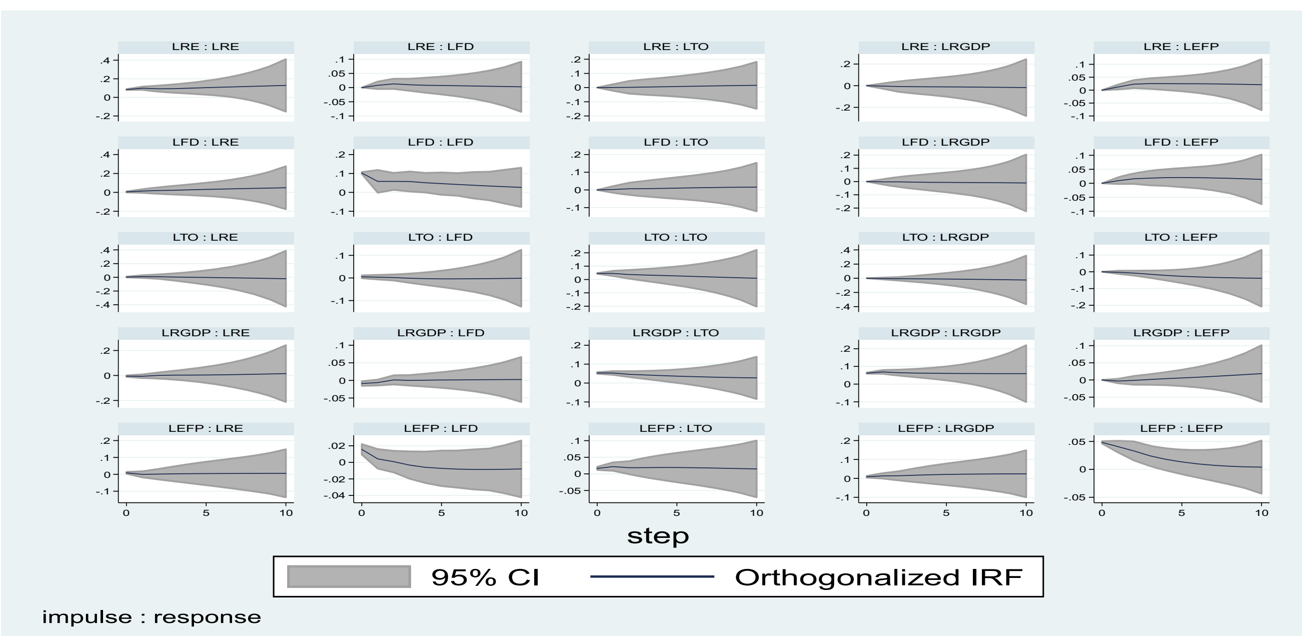

Fig. 1 Findings of IRF estimates for high-income countries

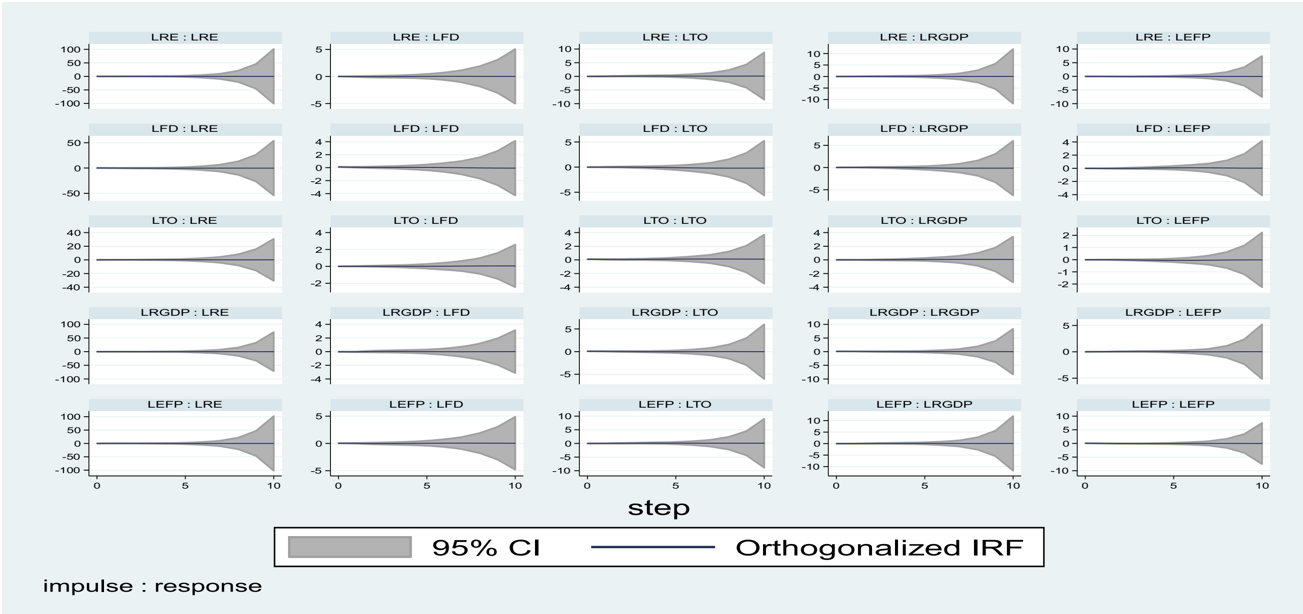

Fig. 2 Findings of IRF estimates for upper-middle-income countries

Results of IRF and variance decomposition analyses

To detect how the volatility of each variable extends to other variables, the IRF is undertaken. With these function styles, it is possible to trace the impact of a variable to one shock on current and future values and the results are shown in Figs. 1, 2, 3, and 4. As it is clear from the figures, if the positive standard deviation shock is given to the residual of RGDP, the rest of the variables react to this innovation. The response of trade openness can be seen to decrease first then it starts to increase and subsequently becomes stagnate due to shock steaming from FD, whereas the response of EFP to RGDP first increases, then it became stagnate over the horizon. These findings show that innovation in income per capita initially exerts a considerably positive effect about environmental degradation. The response of RGDP and FD to trade openness

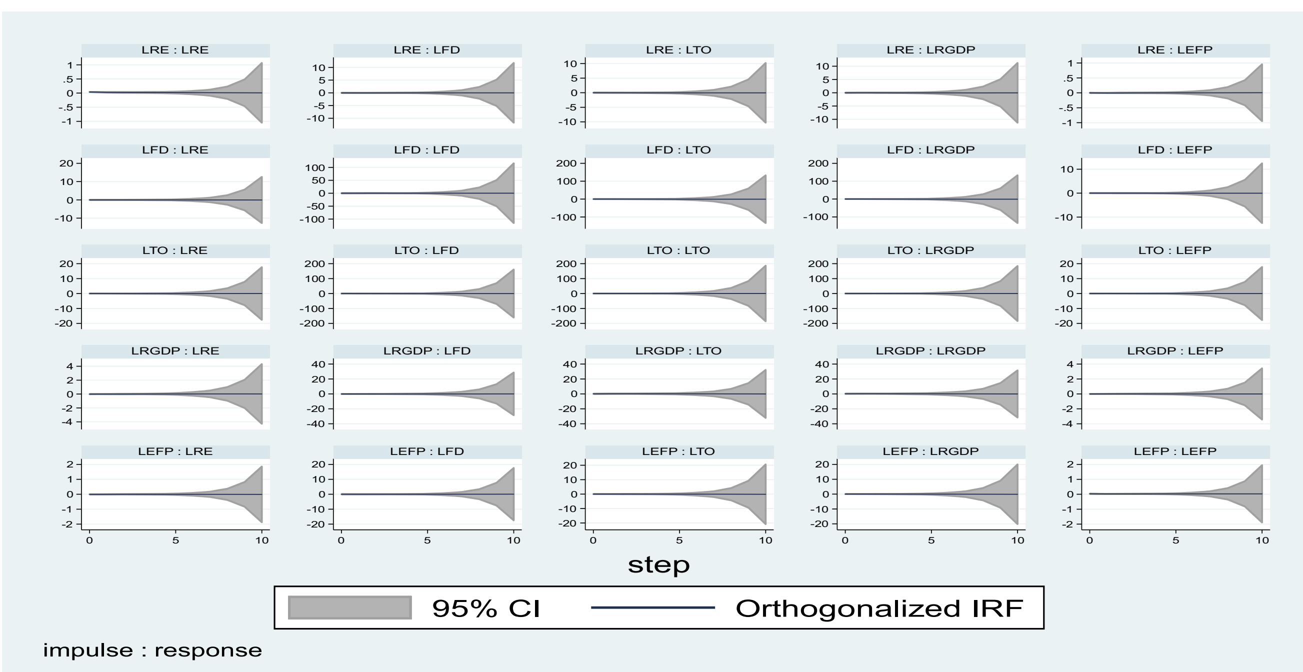

Fig. 3 Findings of IRF estimates for lower-middle-income countries

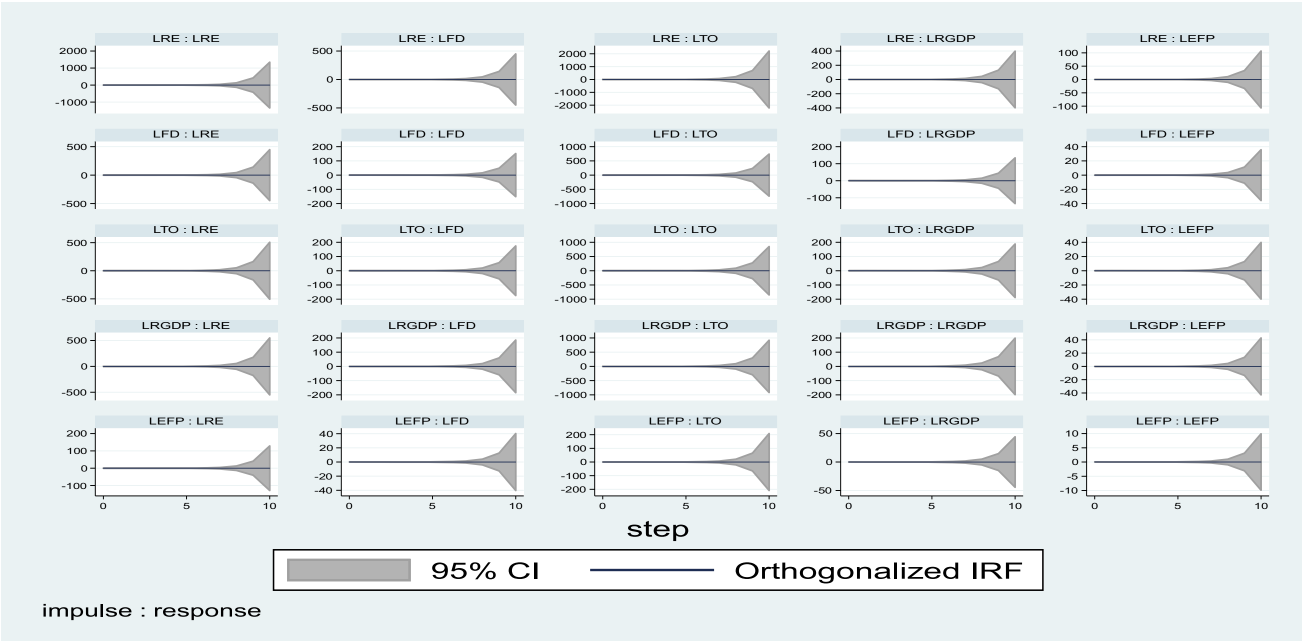

Fig. 4 Findings of IRF estimates for lower-income countries

Table 9 Findings of variance decomposition analyses

Response variable	Period	Impulse variables				
		LEFP	LRGDP	LTO	LFD	LRE
Higher-income countries						
LEFP	10	0.89951	0.04870	0.00527	0.10660	0.00989
LRGDP	10	0.56006	0.39837	0.11763	0.92031	0.003621
LTO	10	0.96728	0.49405	0.75355	0.78299	0.002169
LFD	10	0.10960	0.00860	0.01719	0.81169	0.05291
LRE	10	0.07069	0.14465	0.90525	0.27761	0.60177
Upper-middle-income countries						
LEFP	10	0.87228	0.094487	0.214643	0.042403	0.006186
LRGDP	10	0.684201	0.71451	0.40661	0.736424	0.458248
LTO	10	0.086357	0.15764	0.22189	0.432674	0.101442
LFD	10	0.015747	0.534433	0.07603	0.35891	0.014877
LRE	10	0.428113	0.611505	0.327175	0.156582	0.476623
Lower-middle-income countries						
LEFP	10	0.45666	0.017816	0.404521	0.012821	0.10817
LRGDP	10	0.012821	0.245019	0.881164	0.009401	0.365284
LTO	10	0.027332	0.845761	0.754059	0.167130	0.205722
LFD	10	0.12736	0.189339	0.679453	0.473928	0.529875
LRE	10	0.888402	0.216079	0.587411	0.500249	0.807867
Lower-income countries						
LEFP	10	0.77935	0.916906	0.532411	0.116232	0.655100
LRGDP	10	0.601542	0.182565	0.935861	0.382181	0.897857
LTO	10	0.036214	0.881708	0.717258	0.303568	0.061262
LFD	10	0.813953	0.978961	0.379402	0.695552	0.132134
LRE	10	0.916614	0.089622	0.191102	0.045671	0.75886

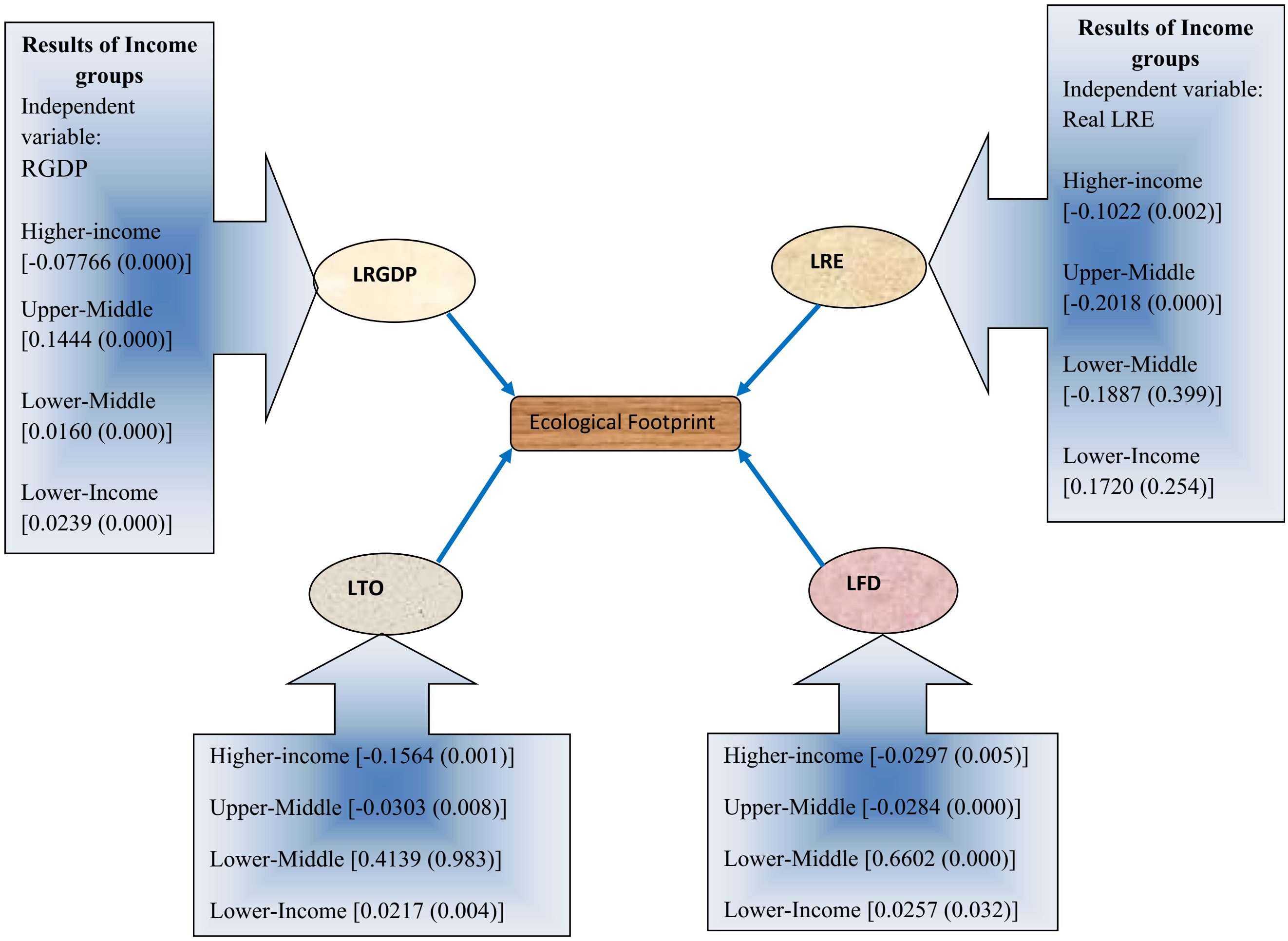

Fig. 5 Graphical representation of AMG-Long Run Estimation

seems to be rather in marginal comparison. Innovation in trade openness produces a significantly positive influence on FD and real economic development.

Alternatively, the response of LEFP to trade openness constitutes a rise firstly and then stagnation occurs due to shock steaming from FD. The responses of economic development and trade openness to FD are found to be relatively small as compared with those of the case of EFP. Result of the response of EFP to FD shows that it decreases first and then it fluctuates to become stationary, indicating the continued FD. Future environmental damages will decrease due to high-level advancement in the FD sector. The response of economic development and renewable energy consumption to EFP both confirmed the same evolution path. Findings reveal that innovations in EFP have a substantial effect on trade openness. The outcomes of IRF for the other three subpanels are presented in Figs. 2, 3, and 4.

For making a comparison of the degree of the contribution made by concerned variables to EFP, we also employed an additional test known as variance decomposition approach. The results of this analysis are given in Table 9. This study allows for the 10-year horizon. For the higher-income economies, the findings revealed that 89.95% of the variation in the EFP can be explained by innovation shocks within the variable itself, whereas the respective contribution made by economic development is 4.87%; similarly, the contribution made by trade openness and FD is 0.52% and 10.66%, respectively, and the contribution made by renewable energy to EFP is 0.989%. The results also show that 56.00% of the variation in RGDP, 96.72% of the variation in trade openness, 10.96% of the variation in FD, and 0.706% of the variation in renewable energy can be elucidated by innovation shocks by considering these variables.

On the other hand, in the case of upper-middle-income economies, 87.22% of the change in the EFP can be described by their innovative shocks for 10 years. The contributions of RGDP, openness, FD, and renewable energy to environmental degradation are found to be equal to 0.944%, 21.46%, 0.424%, and 0.618%, respectively, for upper-middle-income countries. For the lower-middle-income economies, the results indicate that 45.66% of the variation in LEFP can be described by innovative shocks within the variable itself, whereas the contribution made to EFP by economic development is 0.178%, that by trade openness is 40.45%, that by FD is 0.128%, and that by renewable energy consumption is

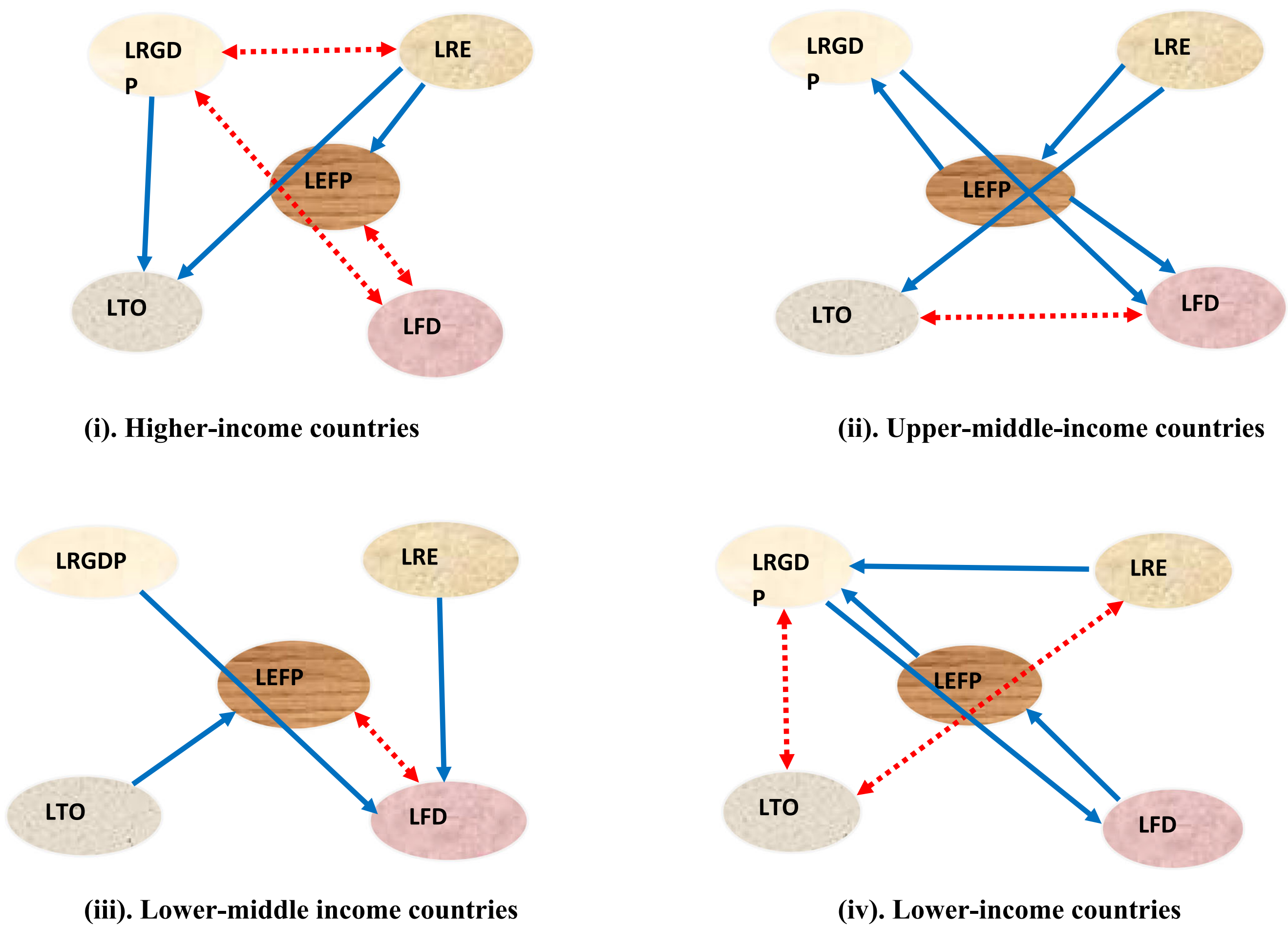

Fig. 6 Graphical representation of D-H panel causality

0.81%. The outcomes for the lower-income group show that 77.93% of the variation in environmental degradation can be described by innovative shocks. Moreover, we found RGDP (91.69%) is the largest contributor to LEFP as compared with trade openness (53.24%), FD (11.62%), and renewable energy consumption (65.11%). These outcomes also recommend that economic development has a much robust impact on environmental degradation in lower-income economies than in other groups under study.

Conclusions

This study measures the effect of economic development, trade openness, FD, and renewable energy consumption on environmental degradation by employing the data spanning from 1990 to 2017 for different income groups. For the efficient and consistent estimates coupled with heterogeneity and CD, we applied the AMG panel estimation technique. The empirical results reveal that real GDP per capita has a significantly negative effect on the EFP in the case of higher-income economies and significantly positive impact for the other three income groups. In other words, EFP diminishes by the rise in the RGDP in case of higher-income economies, whereas economic development in the case of the other three income groups leads to its upsurge.

Secondly, our findings show that openness enhances the EFP in lower-income groups while reduces EFP in the high-income as well as upper-middle-income groups. Furthermore, openness does not affect the EFP in the case of lower-middle-income economies due to insignificant P value. Thirdly, FD is considered as another determinant for EFP. The results found co-integration for the long-run association between FD and environmental pollution in different income groups. Results show FD raises the EFP in all concerned income groups except for higher-income economies. The positive linkage between FD and environmental degradation shows that environmental issues have taken a back seat while encompassing finance to invest those projects that spurred the economic growth course. This entails the endowment of incentives and subsidies to firms undertaking technological innovations and meets the terms with the environmental standard. Policy actions should also emphasis on developing carbon trading markets that offer incentives to mitigate greenhouse gasses.

Table 10 List of countries (income groups)

Income Groups	Countries (152)
High-income	Australia(AUS), Austria(AUT), Bahamas, Barbados, Belgium(BEL), Brunie(BRN), Canada(CAN), Chile(CHL), Croatia(HRV), Cyprus(CYP), Czech(CZE), Denmark(DNK), Estonia(EST), Finland(FIN), France(FRA), Germany(DEU), Greece(GRC), Hungary(HUN), Ireland(IRL), Israel(ISR), Italy(ITA), Korea(KOR), Kuwait(KWT)Latvia(LVA), Lithuania(LTU), Luxembourg(LUX), Malta(MLT), Netherland(NLD), NEWZeland(NZL), Norway(NOR), Panama(PAN), Portugal(PRT), Singapore(SGP), Slovak(SVK), Slovenia(SVN), Spain(ESP), Sweden(SWE), Switzerland(CHE), U-Arab(UAE), United Kingdom(UK), United State(US), Uruguay(URY)
Upper-middle	Albania(ALB), Algeria(DZA), Armenia(ARM), Argentina(ARG), Armenia(ARM), Azerbaijan(AZE), Belarus(BLR), Bosnia and Herzegovina(BIH), Botswana(BWA), Brazil(BRA), Bulgaria(BGR), China(CHN), Colombia(COL), Costa Rica, Dominica(DMA), Dominican Republic(DOM), Equatorial Guinea(GNQ), Ecuador(ECU), Guatemala(GTM), Guyana(GUY), Iran(IRN), Iraq(IRQ), Jamaica(JAM), Jordan(JOR), Kazakhstan(KAZ), Lebanon(LBN), Libya(LBY), Malaysia(MYS), Mauritius(MUS), Mexico(MEX), Montenegro(MNE), Peru(PER), Romania(ROU), Samoa(WSM), Serbia(SRB), Sri Lanka(LKA), South Africa(ZAF), St. Lucia(LCA), Suriname(SUR), Thailand(THA), Tonga(TON), Turkey(TUR), Venezuela(VEN)
Lower-middle	Angola(AGO), Bangladesh(BGD), Bhutan(BTN), Bolivia(BOL), Cabo- Verde, Cambodia(KHM), Cameroon(CMR), Comoros(COM), Congo(COG), Côte d'Ivoire(CIV), Djibouti(DJI), Egypt(EGY), El Salvador(SLV), Ghana(GHA), Honduras(HND), India(IND), Indonesia(IDN), Kenya(KEN), Kyrgyzstan(KGZ), Lesotho(LSO), Mauritania(MRT), Micronesia(FSM), Moldova(MDA), Mongolia(MNG), Morocco(MAR), Myanmar(MMR), Nicaragua(NIC), Nigeria(NGA)(, Pakistan(PAK), Papua New Guinea(PNG), Philippines(PHL), Senegal(SEN), Sudan(SDN), Timor-Leste(TLS), Tunisia(TUN), Ukraine(UKR), Uzbekistan(UZB), Vietnam(VNM), Zambia(ZMB), Zimbabwe(ZWE)
Lower-income countries	Afghanistan(AFG), Benin(BEN), Burkina Faso(BFA), Burundi(BDI), Central African Republic(CAF), Chad(TCD), Congo, Dem. Rep(COD), Eritrea(ERI), Ethiopia(ETH), Gambia(GMB), Guinea(GIN), Guinea-Bissau(GNB), Nepal(NPL), Niger(NER), Rwanda(RWA), Sierra Leone(SLE), Syria(SYR), Tajikistan(TJK), Tanzania(TZA), Togo(TGO), Uganda(UGA)

The results of renewable energy consumption expose that there is the negative impact of environmental degradation on renewable energy for the case of higher-income and upper-middle-income countries, while in the lower-middle- and lower-income groups, renewable energy variable does not affect the regressand. Concerning renewable energy consumption, it has been seen that its penetration is highly cost elastic. Thus, the extensive application of renewable energy sources will not be possible until there is a noteworthy decline in cost, especially for lower-income nations. Further, the absence of proper technology development and high import taxation on renewable energy equipment is also a barrier for its adaptability.

In the second scenario, from the findings of D-H panel Granger causality, we identify the bidirectional association between FD, EFP, and real GDP per capita while unidirectional causality running from renewable energy to EFP, from RGDP to trade openness, and from renewable energy consumption to trade openness. Additionally, two-way causality is found to characterize the association between FD and trade openness in the upper-middle countries. Further, unidirectional Granger link is found from EFP to RGDP and FD, from renewable energy to EFP, from RGDP to FD, and from renewable energy to LFD. Besides this, bidirectional causality has also been observed between FD and EFP in the lower-middle-income countries, and a one-way link running from trade openness to EFP, from RGDP to FD, and from renewable energy to FD.

According to the given results in the variance decomposition analysis, economic development is the most imperative factor which influences the environmental degradation in the case of lower-income countries, as compared with the other three groups. The rise in income per capita often means increasing energy consumption, but it is not guaranteed to save environmental degradation, so it is a time to focus on environment-friendly policies. Further, renewable energy is increasing EFP in the lower-middle- and lower-income nations, so there is a need to promote awareness and opportunities for renewable energy consumption. Our findings recommend that for most of the economies, environmental degradation is energy-led and nations should establish effective energy policies to decrease EFP as their income level increases. From this point of view, reducing the non-renewable energy use is a joint responsibility of higher-income countries by promoting advanced technologies as well as methods to reduce the environmental damages in the lower-income economies.

In addition, the results of this paper have some other imperative policy suggestions. Firstly, economic development harms the EFP in all economies except the higher-income group, and it appears urgent to call for an increase in energy efficiency in production methods if sustainable development is required. In this scenario, the decision-makers should manage the environmental outcomes of investment projects by authorizing the most socially and environmentally conscious investment that use cleaner production technologies. Further, environment policymakers should be aware that enhancing financial development causes environmental damages. Therefore, there is a need to promote green financial development, which is friendly with EFP. This implies that augmentation of green financial development could be attained by the support of domestic credit to the private sector in these groups of nations, which will have the benefit of stepping up capitalization, technology, and income support.

Similarly, another policy suggestion concerning financial development is that the central banks should confine their financial institutions, not to issues funds for those projects which are not co-friendly, and should develop a check and balance mechanism to ensure that allocated financial resources are not invested at the cost of environmental health. The annexation of renewable energy at a higher rate in the energy mix is highly recommended. Especially, developed countries should transfer their ideas and technical innovation to lower countries to minimize environmental damages. With a rise in income, more budgets should be allotted to innovation in renewable energy projects. Finally, the trade policies might be redesigned to accommodate the change in energy policies and trade policies should be directed toward the betterment of environment quality.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflicts of interest.

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