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RESEARCH ARTICLE

The role of economic policy uncertainty and social welfare in the view of ecological footprint: evidence from the traditional and novel platform in panel ARDL approaches

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Abstract
In the contemporary world, environmental degradation has become a concern for human beings. Accordingly, the impact of social welfare, economic policy uncertainty, natural resource rents, life expectancy, and trade openness are examined on ecological footprint (the most comprehensive proxy of environmental degradation) in 19 energy-intensive countries from 1997 to 2018. With this in mind, this study used the traditional panel ARDL and CS-ARDL approaches to evaluate how the study's variables influence ecological footprint. Notably, the results of the CS-ARDL approach are more robust due to cross-sectional dependence and slope heterogeneity problems. The outcomes revealed that economic policy uncertainty and trade openness affect the ecological footprint negatively in the short run and positively in the long run. Moreover, social welfare degrades the environment in the long run, and natural resource rents improve environmental quality by mitigating the ecological footprint in the short run and harming the environment in the long run. Besides, life expectancy does not significantly affect ecological footprint in the long or short run. Meanwhile, the results confirmed the bi-directional causal relationship between the study's variable and ecological footprint. Based on the outcomes, the way to adopt effective policies to improve the quality of the environment has been paved. Furthermore, a comprehensive policy framework for stricter environmental regulation is expected to be developed using the outcomes derived from this study.

Keywords Ecological footprint · Economic policy uncertainty · Social welfare · Life expectancy · Sustainable development · ARDL and CS-ARDL

Introduction

Several significant factors are environmental degradation and income inequality, threatening the smoother running of human existence in life. According to Zafar et al. (2019), environmental experts, energy scientists, and researchers have all agreed, over the years, that climate change is the root cause of global warming and environmental degradation, which threaten the human-health and their quality of life. As for income inequality, it hinders the increase in social welfare and poverty alleviation objectives. Consequently, for several decades, income inequality and environmental quality have been among human beings' main concerns and the most challenging obstacles to sustainable development in international public opinion. To overcome or reduce these challenges, the United Nations, in 2015, set the Sustainable Development Goals (SDGs) to increase the quality of the environment and

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reduce inequality and poverty to address economic, social, and environmental problems (Kassouri and Altıntaş 2020; Uzar 2020). Since then, there has been a requirement for decisions and implementation of strategic policies to promote or increase the sustainable development of social, economic, ecological life, welfare, and health for future generations (Ali et al. 2021; Uzar 2020).

Furthermore, increasing the income levels, alleviating poverty, and improving social welfare through enhancing energy consumption and utilization of natural resources can diminish the rate of environmental degradation (Baloch et al. 2020; Uddin et al. 2020). However, increasing income levels cause structural changes in countries' economies, but profitable changes can be acquired if more advanced technologies and clean energy, which reduces environmental degradation, can be utilized (Uzar and Eyuboglu 2019). Environmental degradation can be measured by several indicators such as greenhouse gas emission, carbon emission, and ecological footprint, all resulting from the unprecedented and unconscious amplification in the energy consumption and natural resources due to rapid and dramatic increase in countries' production baskets, and attention to economic openness and globalization (Caglar 2020). For instance, the dramatic increase in the amount of CO_2 released into the atmosphere comes from the consumption of energy supplied by fossil fuels. Global CO_2 emissions have enhanced egregiously, reaching from 21331.5 million tonnes in 1990 to 34169 million tonnes with an average 1.1% rate of annual growth (BP 2021). However, CO_2 emission is not a powerful indicator of environmental degradation and does not consider resource stocks such as soil, forests, mining, and oil. In this respect, the ecological footprint (EF) is a more precise indicator. EF describes human pressure on the environment and compares human activity–based consumption and biosphere regeneration capacity (Rafindadi and Usman 2021; Zafar et al. 2019). EF calculation, through water and land, is required in global hectares to waste absorption and goods production. Moreover, it measures the ocean, grazing land, forest products, croplands, carbon footprint, and built-up land (Khan et al. 2021).

Political uncertainty, the importance of which has recently become apparent in environmental debates, is another considerable challenge in the global economy. Uncertainty, known as Economic Policy Uncertainty (EPU), relates to fiscal, monetary, trade, and other related policies (Adedoyin and Zakari 2020). EPU is one of the institutional factors that affect economic institutions' decisions by influencing economic entities' external business environment. A coherent set of studies shows that uncertainty calculated by the EPU index can have devastating impacts on economic activity (Baker et al. 2016). Increasing EPU and disrupting environmental protection policies can reduce environmental governance attention, and EPU can also reduce energy consumption and improve the environment's quality by harming countries' economic situation.

Conversely, the unfavorable economic situation may lead firms and companies to ignore the requirements of environmental governance and enhance the use of cheaper traditional energy, which leads to increased environmental degradation (Jiang et al. 2019). Moreover, the EPU can affect energy consumption through price fluctuations caused by supply and demand shocks, which in turn interferes with the quality of the environment (Hailemariam et al. 2019; Pirgaip and Dinçergök 2020). Thus, EPU, depending on countries' environmental policy, can either alleviate or increase the quality of the environment; however, despite extensive environmental studies and the efforts of policymakers and academia, environmental problems are still a primary global concern.

Recently, new dimensions of studies seek, although not yet reaching a broad consensus, to link indicators of human well-being, poverty alleviation, and the reduction of inequalities with environmental degradation. In this context, whether or not income inequalities and social welfare promotion affect the quality of the environment has become a challenging issue. Some studies believe that environmental problems are rooted in income inequalities and are social problems, while others, in comparison, do not consider the quality of the environment to be affected by income inequalities. It is worth noting that various social welfare and income inequality indicators have been proposed in the relevant literature. However, Amartya Sen's (Sen et al. 1997) social welfare index is one of these indicators that provide social welfare based on GDP per capita and income inequality. Thus, reducing income inequality and enhancing GDP per capita will increase social welfare. Therefore, this index considers the increase in the country's production necessary for welfare promotion and is also sensitive to how it is distributed among citizens. Also, new environmental literature considers the discussion of uncertainties, in recent decades, as a factor influencing environmental degradation. Also, debt crises, financial crises, wars and trade disputes, and other widespread global uncertainties have promoted more attention to EPU. Empirical evidence suggests that considering EPU in energy consumption and environmental quality studies is critical. Moreover, some studies have an exceptional sensitivity because they believe energy conservation policies could hurt countries' economic growth. As such, many scholars are investigating the economic policies, laws, and regulations that can balance the improvement of environmental quality while, at the same time, maintaining the economic growth rate (Charfeddine and Mrabet 2017).

This study investigates the influence of EPU and social welfare on the environmental quality of 19 countries with high energy consumption and natural resource extraction. The need to examine environmental quality has been documented in the literature for several economies, including in Asia, as shown in past studies (Jiao et al. 2021; Sharma et al. 2021g; Sharma et al. 2021a, 2021b; Zhang et al. 2022). According to BP (2021) reports, their economies consume about 63.9% of primary energy, of which fossil fuels are the main sources of energy consumption. Interestingly, less than half of the total energy consumption of these countries is provided by clean energy and traditional energy. Hence, about 62.6% of the CO_2 emitted into the atmosphere stems from these countries, the most significant environmental polluters (BP 2021), although, as aforementioned, the EF is a more accurate environment degradation indicator. The geographical distribution of EF and biocapacity is shown in Figs. 1 and 2, respectively. A higher EF indicates the consumption of more natural resources, which is not suitable and useful for environmental sustainability. China, the USA, and Russia are among the world's most important EFs (see Fig. 1).

In contrast, biocapacity provides the capacity to absorb waste and regenerate the ecosystem that exploits natural resources. Thus, higher biocapacity is the key to achieving environmental sustainability, unlike EF. Brazil, Russia, the USA, and China are also among the critical points regarding biological capacity among the selected countries (see Fig. 2). Indeed, the EF is obtained from the difference between the regenerative capacity of the environment and the consumption and exploitation of natural resources. Ecological status can be discussed in two general forms: environmental reserve and ecological deficiency. If the exploitation of natural resources exceeds the country's regenerative capacity, it will suffer from an ecological deficit, whereas ecological reserves occur when the natural resource exploitation is less than its regenerative capacity (DiMaria 2019; Sarkodie 2021).

Based review so far, we intend to assess the impact of EPU, social welfare, total natural resource rents, the openness of trade, and life expectancy on the EF in 19 energy-intensive economies from 1997 to 2018. For this purpose, we first use the traditional ARDL panel estimators. Then, to consider the common factors between these countries, we use the newly introduced cross-sectional augmented autoregressive distributed lag (CS-ARDL) approach. This process examines whether or not considering cross-sectional dependency (CSD) can significantly affect the result. Hence, the structure of this study is as follows: A review of past literature is provided in "Literature review"; "Data, model, and econometrics methods" analyzes the data and methodology; the empirical results are discussed in "Empirical results and discussion". Finally, the study presents in "Conclusion and policy implication" with a conclusion and policy recommendations.

Literature review

The daunting concerns created by economic and social development-oriented human activities for humans on earth have become a severe threat to the world ecosystem in recent years; thus, in this regard, human activities have been accompanied by unprecedented exploitation and

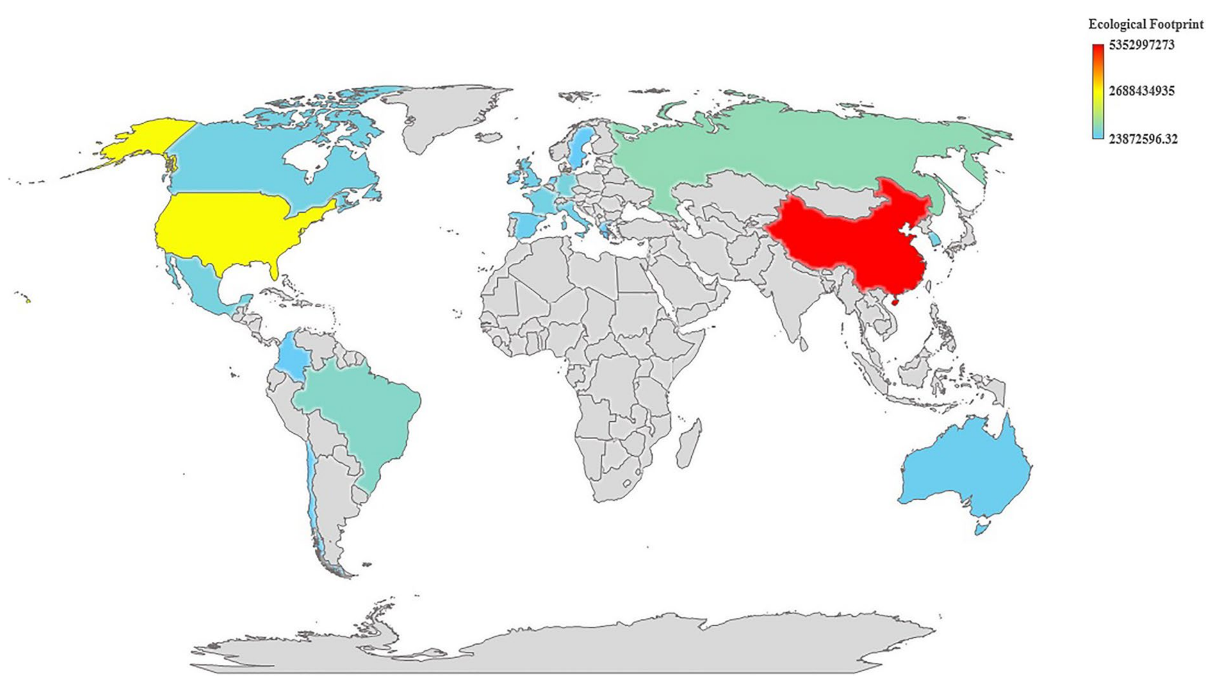

Fig. 1. Geographical mapping of ecological footprint (global hectare). Source: GFN (2017)

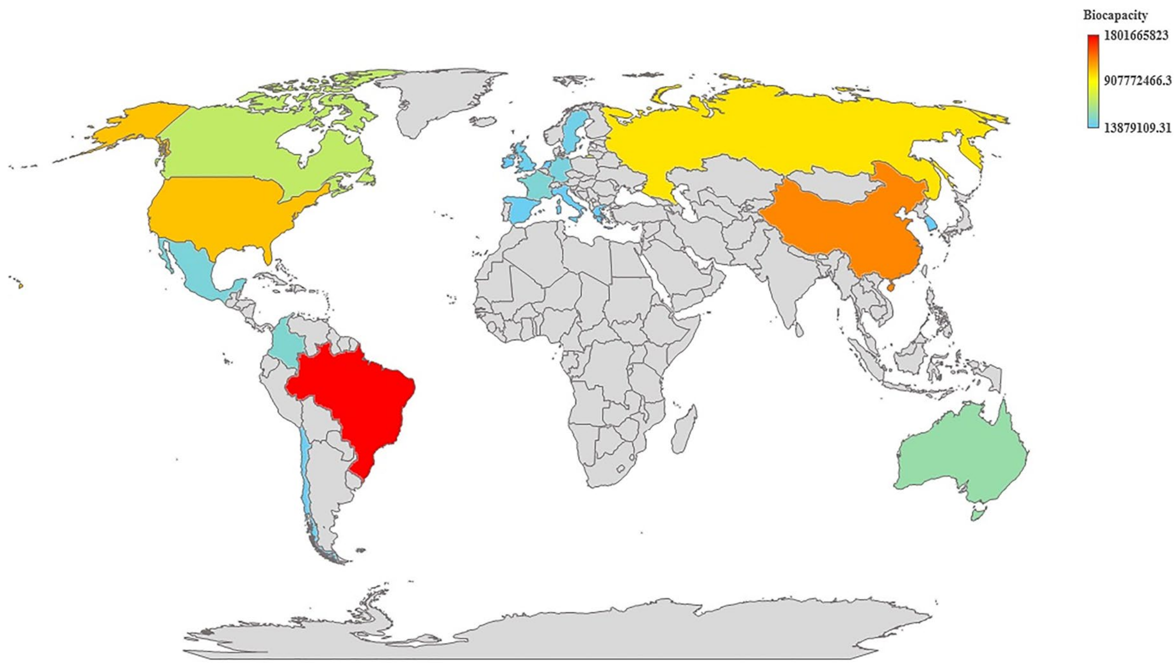

Fig. 2. Geographical mapping of biocapacity (global hectare). Source: GFN (2017)

consumption of natural resources and energy as well as environmental neglect. Despite the efforts of environmental protagonists and policymakers to battle the environmental problems, it has yet not been resolved. Besides, ecosystems' distortion created in previous periods is strengthened through many related channels such as natural resource exploitation, poverty alleviation, income equality, improving welfare, expanding global trade, and paying attention to health status. Hence, studying and examining environmental issues are essential for achieving sustainable social, economic, and ecological life development. Therefore, according to the aims of the present study, we review five nexuses of environmental literature: the health status-environment nexus, natural resource-environment nexus, trade openness-environment nexus, income inequality-environment nexus, and EPU-environment nexus.

All countries seek to enhance health status and reduce mortality. Life expectancy is widely used to describe people's health associated with longevity. Life expectancy is an appropriate indicator of mortality. Hence, life expectancy at birth is a valid indicator of the health status of a country's population and is recognized as a representative of the level of population health. Although health is a multidimensional concept, life expectancy is one of the most widely used health indicators. Life expectancy as an indicator of health status has recently been considered in the environmental literature. A group of studies, such as Saleem et al. (2022), Sharma et al. (2021f), and Li et al. (2020), have argued that improving life expectancy leads to economic growth and environmental degradation. On the other hand, studies such as Charfeddine and Mrabet (2017) have stated that due to the intertwined relationship between health status and environmental quality, improving life expectancy also improves the quality of the environment.

Developed and developing countries have realized the importance of free trade in enhancing income level and trade volume, which strongly impacts the growth of the global economy. However, the environmental consequences should not be neglected in line with the growing trade trend. Overall, the environmental consequences of trade openness divide into two general strands. Khan et al. (2022), Adebayo et al. (2022), Shahbaz et al. (2019), Zhang et al. (2017), and Al-Mulali et al. (2015) believe that free trade has positive effects on the quality of the environment by improving technology and increasing environmental standards. In contrast, other researchers, such as Pata and Caglar (2021), Lv and Xu (2019), and Zamil et al. (2019), have shown that the growing trend of a trade by boosting economic growth and increasing energy consumption has devastating consequences for the environment. In this regard, Shahzad et al. (2017) concluded that a 1% amplification in trade openness equals a 0.247% increase in CO_2 emissions and is harmful to the environment in Pakistan. Also, in a comprehensive study based on evidence from 182 countries, Wang and Zhang (2021) found that in countries of high and high-middle-income, the openness of trade improves the quality of the environment. Moreover, in lower-middle-income countries, trade openness does not affect environmental quality. Worsely, in low-income countries, free trade has devastating effects on the environment.

The study of natural resources impacts the quality of the environment attracting the attention of many researchers who have different views in this regard. For instance, a wide range of researchers believes that nations rich in natural resources can experience high production and export rates and, as a result, achieve significant economic growth in the long run. Naturally, these researchers noted that energy consumption and the exploitation of natural resources, which stimulate economic growth, are increasing dramatically in these countries with devastating environmental consequences (Ahmed et al. 2020; Hassan et al. 2019), while Khan et al. (2021), Zafar et al. (2019), and Ulucak and Khan (2020) have argued the impact of natural resources on the quality of the environment differently and deem that, ultimately, natural resources have positive effects on the quality of the environment.

Another batch of studies has dealt with the synergy of two-day problems: income distribution and environmental quality. These studies have mentioned the Gini coefficient as the most straightforward indicator for expressing income distribution. Meanwhile, some studies have focused on analyzing the effects of income inequality on a regional basis, and some studies have focused on specific countries. Similar to the study of the effect of other factors affecting environmental quality, there is no consensus on the relevance between environmental quality and income distribution. These studies can be evaluated in three general categories based on the results. The first category concluded that enhancing the income gap and unfair income distribution increases neglect of the environment and therefore has devastating effects (Baloch et al. 2020; Khan et al. 2022; Uzar 2020). The second category's results are the opposite of the first category, and these studies conclude that income inequality improves the quality of the environment (Demir et al. 2019). The third category of the studies also pointed out that income distribution does not significantly affect the quality of the environment (Barra and Zotti 2018; Hundie 2021).

So far, we have found that the indicators of health, social, economic well-being, and the environment are highly intertwined. However, it is worth noting that many political, health issues, social, war, conflict, and trade uncertainties have gripped the world today, changing the quality of human life in many ways. For example, the second Gulf War, which took place in 2003, and the global epidemic of COVID-19 in 2020 caused much economic uncertainty that affected businesses and economic activities worldwide. Therefore, it is very valuable to study these uncertainties in the environmental literature, and we review studies that have examined the effect of EPU on environmental quality. Pirgaip and Dinçergök (2020), Adams et al. (2020), and Jiang et al. (2019) concluded that the EPU has detrimental effects on the environment and acts as a stimulant to increase CO_2 emissions and reduce the quality of the environment. In contrast, Liu and Zhang (2022) proved that the EPU could improve the quality of the environment by reducing CO_2 emissions. In another study, Adedoyin and Zakari (2020) found that EPU has the greatest impact on CO_2 emission reduction in the short run.

Consequently, it has positive effects on environmental quality. In the long run, the situation is quite different as CO_2 emissions growth is enhanced by EPU. Therefore, EPU creates an unhealthy environment in the UK. Table 1 provides a summary of reviewed studies.

Furthermore, given sustainable development goals, economic pursuits should not be pursued without considering the effects of the growth on the environmental impacts. A review of the existing literature also reveals that environmental quality changes depend on health, global trade, exploitation of natural resources, income distribution, and uncertainties. With this in mind, unlike the extensive studies that have used CO_2 emissions for environmental degradation, this study considers ecological footprint as a more comprehensive measure of environmental degradation. This is because indicators that consider only air contamination cannot describe the state of environmental degradation adequately. Moreover, income inequalities play a vital role in environmental quality, and many studies declare that environmental problems are rooted in income inequalities. Different indicators of social welfare and income inequality have been used in previous studies. However, Amartya Sen's (Sen et al. 1997) social welfare index has stronger theoretical foundations and introduces more welfare axioms. This index considers social welfare dependent on GDP per capita and income inequalities. According to the authors, Amartya Sen's social welfare index has not been considered in the environmental literature.

Political uncertainty is another considerable challenge in the global economy. EPU is one of the institutional factors that affect economic institutions' decisions by influencing economic entities' external business environment. Therefore, considering its impact on environmental quality has particular importance. Furthermore, many studies have shown that environmental quality affects people's health status; meanwhile, measures taken to improve health status can also have reciprocal effects on the environment. Therefore, the present study examines the impact of social welfare, EPU, and life expectancy and helps to fill the research gap and enrich the environmental literature. Eventually, the present study uses the panel ARDL model to evaluate the impact of considered variables on EF in both the short and long run. Since there is a cross-sectional dependency between countries, this study uses the CS-ARDL model to examine whether

Table 1 Summarize reviewed studies in environmental literature

Authors	Period	Case study	Methodology	Effect on environmental quality
Saleem et al. (2022)	2008–2018	OECD region	PVAR	Life expectancy (−), energy consumption (−)
Adebayo et al. (2022)	1965–2019	Sweden	Novel quantile-on-quantile regression (QQ) approach	Trade openess (+), renewable energy consumption (+), economic growth (+)
Khan et al. (2022)	2002–2019	180 countries	OLS, fixed effect, and system generalized method of moments (SGMM)	Income inequality (−), Institutional quality (−), financial development (−), economic growth (−), trade openness (+), renewable energy (+)
Liu and Zhang et al. (2022)	2003–2017	China	STIRPAT model	EPU (+)
Sharma et al. (2021d)	1990–2015	8 developing countries of South and Southeast Asia	CS-ARDL	Per capita (−), life expectancy (−), renewable energy consumption (+)
Pata and Caglar (2021)	1980–2016	China	AARDL	Globalization (−), trade openness (−), income (−), human capital (+), renewable energy consumption (no)
Wang and Zhang (2021)	1990–2015	High-income countries	PFMOLS	Trade openness (+)
		Upper-middle-income countries		Trade openness (+)
		Lower-middle-income countries		Trade openness (no)
		Low-income countries		Trade openness (−)
Khan et al. (2021)	1971–2016	USA	GMM, GLM	Natural resources (−), renewable energy (−), non-renewable energy (+), biocapacity (+), population growth (+)
Hundie (2021)	1979–2014	Ethiopia	ARDL bounds test, DOLS approach	Economic growth (−), income inequality (no), urbanization (−), population size (−), energy intensity (−), industrialization (−)
Li et al. (2020)	1996–2018	Eastern European countries	GLS	Energy efficiency (+), GDP per capita (+), life expectancy (−)
Ahmed et al. (2020)	1970–2016	China	ARDL	Urbanization (+), natural resources (+), economic growth (+), human capital (−)
Baloch et al. (2020)	2010–2016	40 Sub-Saharan	Driscoll Kray regression estimator	GDP per capita (−), Income inequality (−), poverty (−), total population (+), economic freedom (no), access to electricity (no), inflation (no)
Pirgaip and Dinçergök (2020)	1998–2018	G7 countries	Bootstrap panel	EPU (−)
Adams et al. (2020)	1996–2017	Countries with high geopolitical risk	Panel ARDL	Energy consumption (−), economic growth (−), EPU (−)
Adedoyin and Zakari (2020)	1985–2017	UK	ARDL	EPU (+), real GDP (−), energy use (−)
Shahbaz et al. (2019)	1965–2016	USA	ARDL	Energy consumption (−), trade openness (+), FDI (−)
Lv and Xu (2019)	1992–2012	55 middle-income countries	Panel ARDL	Trade openness (−), urbanization (+)
Zamil et al. (2019)	1972–2014	Oman	ARDL	GDP per capita (−), trade openness (−)
Hassan et al. (2019)	1970–2014	Pakistan	ARDL	Natural resources (+)
Zafar et al. (2019)	1970–2015	USA	ARDL	Energy consumption (+) , economic growth (+), natural resources (−), human capital (−), FDI (−)

Table 1 (continued)

Authors	Period	Case study	Methodology	Effect on environmental quality
Uzar (2020)	1984–2014	Turkey	ARDL	Income inequality (−)
Demir et al. (2019)	1963–2011	Turkey	ARDL	Income inequality (+)
Jiang et al. (2019)	January 1985 to August 2017	USA	Novel parametric test of Granger causality in quantiles	EPU (−)
Barra and Zotti (2018)	2000–2009	120 countries	GMM method	Income inequality (no)
Charfeddine and Mrabet (2017)	1975–2007	15 MENA countries	DOLS, FMOLS	Energy consumption (−), urbanization (+), life expectancy (+), fertility rate (+)
Zhang et al. (2017)	1971–2013	NICs-10	PFMOLS	trade openness (+), real GDP (−), energy consumption (−)
Shahzad et al. (2017)	1971–2011	Pakistan	ARDL	Trade openness (−), financial development (−)
Al-Mulali et al. (2015)	1990–2013	23 selected European countries	PFMOLS	GDP growth (−), urbanization (−), financial development(−), trade openness (+)

(−): degrade environment; (+): improve environmental quality; (no): no effect on environment quality. Source: Current Research

cross-sectional dependency among countries affects the results or not.

Data, model, and econometrics methods

Panel ARDL

Several studies in the past have examined the environmental implications of various factors and documented evidence across regions of the world (Sharma et al. 2020; Sharma et al. 2021b, 2021c; Sharma et al. 2021b). This study, therefore, extends this by investigating the dynamic impact of EPU, social welfare, trade openness, total natural resource rents, and life expectancy on EF which is examined by the autoregressive distributed lag (ARDL) approach by the estimators of the pooled mean group (PMG), dynamic fixed effect (DFE), and mean group (MG) under the maximum likelihood estimation (MLE) developed by Pesaran et al. (1999).

The regression of heterogeneous panel by the PMG estimator is imbedded in the error correction model as follows:

$$y_{it} = \mu_i + \sum_{j=1}^{p} \lambda_{ij} y_{i,t-j} + \sum_{j=0}^{q} \delta'_{ij} X_{i,t-j} + \varepsilon_{it} \quad (1)$$

In Eq. (1), $i = 1, 2, \ldots, N$ executes units of cross-sectional, $t = 1, 2, \ldots, T$ performs the annual periods, j represents the time lags number, p exhibits dependent variable lag, and q displays independent variables lag. μ_i represents the fixed effect, y represents the dependent variable, and X represents the vector of the independent variables.

$$\Delta y_{it} = \mu_i + \phi_i y_{it} + \beta'_i X_{it} + \sum_{j=1}^{p-1} \lambda^*_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{q-1} \delta^{*\prime}_{ij} \Delta X_{i,t-j} + \varepsilon_{it} \quad (2)$$

where $\phi_i = -\left(1 - \sum_{j=1}^{p-1} \lambda_{ij}\right)$, $\beta'_i = \sum_{j=0}^{q-1} \delta_{ij}$, $\lambda^*_{ij} = -\sum_{m=j+1}^{p} \lambda_{im}$, $j = 1,2,\ldots, p-1$, $\delta^*_{ij} = -\sum_{m=j+1}^{q} \delta_{im}$, j=1,2,…, $q-1$.

Eq. (2) is rewritten as an error correction equation by grouping more variables at the level

$$\Delta y_{it} = \mu_i + \phi_i \left(y_{it} + \theta_i X_{it}\right) + \sum_{j=1}^{p-1} \lambda^*_{ij} \Delta y_{i,t-j} + \sum_{j=0}^{q=1} \delta^{*\prime}_{ij} \Delta X_{i,t-j} + \varepsilon_{it} \quad (3)$$

In Eq. (3), the long-run equilibrium relevance between y_{it} and X_{it} is defined by $\theta_i = -\left(\beta'_i / \phi_i\right)$. δ^*_{ij} and λ^*_{ij} relate growth to other determinants' past values and are short-run coefficients. Finally, ϕ_i, which is the error-correction coefficient, indicates the speed at which y_{it} is adjusted toward the long run following tX_{it} change. Moreover, ϕ_i must be negative and between zero and one. Therefore, the estimate will be as follows:

$$\hat{\theta}_{PMG} = \frac{\sum_{i=1}^{N} \tilde{\theta}_i}{N}, \hat{\beta}_{PMG} = \frac{\sum_{i=1}^{N} \tilde{\beta}_i}{N}; \tilde{\lambda}_{jPMG} = \frac{\sum_{i=1}^{N} \tilde{\lambda}_i}{N}, \text{and } \hat{\gamma}_{jPMG} = \frac{\sum_{i=1}^{N} \hat{\gamma}_i}{N} \quad (4)$$

where $j = 0, \ldots, q\ \hat{\theta}_{PMG} = \tilde{\theta}$.

Since the panel ARDL approach considers adequate lag of independent and dependent variables, the existence of endogeneity bias and serial correlation is eliminated. The PMG estimator imposes heterogeneity in the short run and homogeneity in the long run (Boufateh and Saadaoui 2020). MG is the second estimator of the ARDL approach, which performs country-specific regression. Therefore, heterogeneity based on MG is possible in the short and long run, depending on the data size (Erülgen et al. 2020). The difference between the two techniques lies in the estimation procedure. The MG estimator relies on estimating N time-series regressions and averaging the coefficients, whereas the PMG estimator relies on a combination of pooling and averaging coefficients (Udeaja and Isah 2022). DFE is the latest panel ARDL estimator, which imposes homogeneity restrictions on short- and long-term segments. Eventually, the Hausman test concludes the consistency and efficiency of each estimator.

CS-ARDL

The literature on panel data proposes the existence of dependency among cross-sectional units. Mainly, cross-sectional dependency arises due to common shocks and unobserved components. Economic or financial integration, trade enhancement, globalization, and unification of economic policies (such as oil price shock, Asian financial crises, and global financial crises) are among the main reasons for cross-sectional dependency. The cross-sectional dependency issue should be tackled carefully; otherwise, it may provide invalid and inconsistent outcomes and cause lower estimation efficiency. The cross-sectional dependency test recently developed by Pesaran (2021) is employed in this study to check the existence of cross-sectional dependency between units. The mentioned cross-sectional dependency test is useful and efficient to follow for any var-list length. This test is helpful to use when cross-sections are greater than time ($N > T$) (Shen et al. 2021). The cross-sectional dependency test is as follows:

$$CSD_{TN} = \left[\frac{TN\,(N-1)}{2}\right]^{1/2}\hat{\bar{\rho}}_N \tag{5}$$

In Eq. (5), $\hat{\bar{\rho}}_N$ term represents the pair-wise correlation coefficient; T denotes the time period number; N indicates the number of cross-sectional units.

Another panel data problem is slope heterogeneity, which does not consider; it makes the outcomes invalid. Slope heterogeneity arises due to various economic and demographic structures; it is also critically important in panel data econometrics. Heterogeneity reveals that interest parameters differ across cross-sectional units. The present study performed the Pesaran and Yamagata (2008) slope heterogeneity test to unveil the slope heterogeneity between the cross-sections (Ahmad et al. 2020). The mentioned heterogeneity test is expressed as follows:

$$\tilde{\Delta} = (N)^{1/2}\,(2K)^{-1/2}\left(\frac{1}{N}\tilde{S} - k\right) \tag{6}$$

$$\text{adj}\,\tilde{\Delta} = (N)^{1/2}\left(\frac{2k\left(T-k-1\right)}{T+1}\right)^{-1/2}\left(\frac{1}{N}\tilde{S} - k\right) \tag{7}$$

$\tilde{\Delta}$ and adj $\tilde{\Delta}$ denote delta tilde and adjusted delta tilde, respectively.

As mentioned above, considering an econometric approach that considers slope heterogeneity and cross-sectional dependency is critical. Compared to MG, PMG, and DFE estimators, the approach of CS-ARDL introduced by Chudik and Pesaran (2015) is a more efficient method that provides more accurate results; because it considers the potential problems of different econometric methods. In general, this model has three practical advantages. (1) Like the traditional panel ARDL estimators, CS-ARDL can estimate mixed integration order. (2) Endogeneity and heterogeneity issues can also be solved, and (3) over panel ARDL, it has the advantage of using the cross-sectional averages as efficient and effective estimators of cross-sectional dependence (Wang et al. 2021). The CS-ARDL method's equation is formulated as follows:

$$\begin{aligned}\Delta y_{it} &= \mu_i + \varphi_i\left(y_{it-1} - \beta_i X_{it-1} - \phi_{1i}\bar{y}_{t-1} - \phi_{2i}\bar{X}_{t-1}\right) \\ &\quad + \sum_{j=1}^{p-1}\lambda_{ij}\Delta y_{it-j} + \sum_{j=0}^{q-1}\xi_{ij}\Delta X_{it-j} + \eta_{1i}\Delta\bar{y}_t + \eta_{2i}\Delta\bar{X}_t + \varepsilon_{it}\end{aligned} \tag{8}$$

where Δy_{it} represents the dependent variable, X_{it} is all long-run independent variables, and $\overline{X}_{t-1}$ and $\overline{y}_{t-1}$ provide independent and dependent variables mean for the long run, respectively. Moreover, ΔX_{it-j} and Δy_{it-j} perform the independent and dependent variables during the short run, respectively. $\Delta\overline{y}_t$ and $\Delta\overline{X}_t$ display the dependent and independent variables' mean during the short run. The error terms are shown by ε_{it}. β_j indicates the independent variables' coefficients, λ_{it} and ξ_{ij} represent the dependent and independent variables' coefficients for the short run, respectively. Finally, η_{1i} and η_{2i} demonstrate the short-run dependent and independent variables' mean, respectively (Samargandi 2019).

To confirm the existence of the long-run relationship between variables and check the robustness of the CS-ARDL model, the augmented mean group (AMG) model estimation, which Eberhardt (2012) introduces, is proceeded. The two main reasons motivate the adoption of this estimator, among several others. (1) AMG method has been adjusted to be efficient and relevant even in a nonstationary situation. (2) AMG method accounts for the issues of cross-sectional dependency, endogeneity, and slope heterogeneity in the panel regression model (Ibrahim and Ajide 2021). Hence, the AMG equation form is as follows:

$$\Delta y_{it} = \varphi_{1t} + \varphi_{2t}X_{it} + \varphi_{3t}V_i + \sigma_{it} \quad (9)$$

In Eq. (9), y_{it} indicates the explained variable, X_{it} represents an explanatory variables vector, and φ_{1t} is the constant term, and it considers the heterogeneous time-invariant impacts. Further, V denotes the unobservable common factor in the model, while φ_{3t} is factors loading, which is particularly inherent in the heterogeneous terms. Considering φ_{2t} the general form of the AMG model can be obtained as follows:

$$AMG_{\text{estimator}} = \frac{1}{N}\sum_{i=1}^{N}\tilde{\varphi}_{2i} \quad (10)$$

Data

This study considers trade openness, total natural resource rents, life expectancy, social welfare, and EPU as determinants of EF. To this end, the impact of the mentioned variables on EF is examined using the annual data from 1997 to 2018 in 19 countries that play a prominent role in environmental degradation. These countries include Italy, Spain, Canada, France, Brazil, the USA, Russia, Mexico, South Korea, Netherlands, Ireland, Germany, China, Greece, Australia, UK, Sweden, Chile, and Colombia. The periods and countries' selection were based on the availability of the data. EF data are extracted from GFN (2022) and based on global hectare per person. Trade openness means the total share of exports and imports in GDP. Besides, the total natural resource rents, trade openness, and life expectancy data were acquired from WDI (2022). We gained the Gini coefficient from one and divided it by GDP per capita to obtain social welfare. The Gini coefficient is between zero and 100. A higher Gini coefficient means a more unfair income distribution and vice versa. Gini coefficient and GDP per capita were obtained from SWID (2022) and WDI (2022), respectively. Finally, the EPU index is monthly data and was provided by Baker et al. (2013). Therefore, to obtain the annual data extracted from Economic Policy Uncertainty (2022), following Yao et al. (2020), we considered the same weight for all months and got the data on an annual basis. It is worth noting that all data have been converted to natural logarithms.

Empirical results and discussion

The descriptive statistics of study variables in the natural logarithm are reported in Table 2. The average EF in these countries is 1.38 (global hectare per person) with a standard deviation of 0.93. The highest standard deviation is related to natural resource rents, and the lowest value of it is related to life expectancy. A series has a normal distribution if its skewness value is 0 and its kurtosis value is 3 (Mensah et al. 2019). Specifically, EF, social welfare, natural resource rents, and life expectancy have been negatively skewed. The mentioned series tend to the left, contrasted with a normal distribution. The skewness values of EPU and trade openness are positive and inclined to the right. Moreover, the kurtosis of social welfare and natural resource rents are less than 3, indicating that the distribution of these series is platykurtic.

Moreover, the kurtosis values of EF, EPU, trade openness, and life expectancy are greater than the normal value, and their distribution is leptokurtic. Based on kurtosis and skewness values, none of the variables satisfies the conditions required for the normal distribution, so none have a normal distribution. Evidence from the Jarque Bera test also proves that none of the series is normally distributed because the null hypothesis of normality is rejected.

Table 2 Descriptive statistics

	lnEF	lnEPU	lnW	lnTO	lnNR	lnLE
Mean	1.38	4.67	9.53	4.05	−0.49	4.35
Median	1.65	4.66	9.97	4.03	−0.21	4.37
Maximum	2.34	6.29	10.83	5.42	3.09	4.42
Minimum	-2.79	3.29	7.02	2.79	−4.05	4.17
Standard deviation	0.92	0.43	0.94	0.47	1.98	0.04
Skewness	−2.83	0.32	−0.78	0.35	−0.10	−1.53
Kurtosis	11.36	3.73	2.25	3.56	1.70	5.58
Jarque-Bera	1777.883	16.62	52.50	14.220	30.05	279.25
Probability	0.00	0.00	0.00	0.00	0.00	0.00
Observations	418	418	418	418	418	418

Source: Current Research

Table 3 Slope-heterogeneity and cross-section dependence results

Slope coefficients homogeneity/heterogeneity					
Delta		10.484***			
Adjusted delta		12.696***			
Cross-section dependence test (CSD test)					
lnEF	lnEPU	lnW	lnTO	lnNR	lnLE
9.784***	26.532***	42.600***	20.176***	31.448 ***	57.357***

*, **, and *** denote statistically significant at the 10%, 5%, and 1% levels, respectively. Source: Current Research

In the first step, ensuring that the considered variables fluctuate around a constant mean is critical for using panel data. Thereby, assessing the stationary of variables is essential as if the variables are nonstationary, the regression results will not be reliable. First-generation panel unit root tests involve Hadri, Breitung, Levin-Lin-Chu (LLC), Im-Pesaran-Shin (IPS), and Fisher panel unit root tests which are extensively considered and used to examine the stationary of the studies variables. Meanwhile, the two main problems of most panel data are slope heterogeneity and cross-section dependence (CSD); the main assumption of all first-generation tests is cross-section independence. Hence, the existence of these two problems makes the results of the first-generation panel unit root test misleading and unreliable. Conducting the CSD and slope heterogeneity tests is crucial for all series to apply the more reliable unit root test (Hao et al. 2021; Li et al. 2020). The slope heterogeneity results presented in Table 3 show that the values of delta and adjusted delta are statistically significant, and therefore, there is a slope heterogeneity problem.

Moreover, the Pesaran (2021) CSD test examines the cross-sectional dependency. The lowest part of Table 3 reports the results of this test. The null hypothesis of the absence of CSD is rejected for all variables. Hence, any change occurring in any of the variables in a country, its consequences are observed in other countries under study. Therefore, these countries are interconnected (Hao et al. 2021). In this context, the existence of CSD and slope heterogeneity is allowed to use the second-generation unit root tests of cross-sectional augmented modified Dick-Fuller (CADF) and CIPS. The CADF and CIPS panel unit root tests consider the CSD and slope heterogeneity and provide more robust results.

Table 4 reports the results of the CADF and CIPS panel unit root test. The CADF and CIPS findings show the stationary of the variables in their first difference. In Panel ARDL model estimation, the variables should be I(1) or I(0) or a combination of both but should not be I(2). Therefore, we are allowed to use the panel ARDL model.

Examining the cointegration relationship in econometrics of panel data has particular importance. Notably, evaluating the presence or absence of a cointegration relationship among variables is not necessary to estimate the panel ARDL. It is worth noting that the existence of cointegration makes the model's results more reliable (Uzar 2020). Pedroni (1999) and Kao (1999) cointegration tests have become popular among researchers and are widely used in studies. It should be noted that the null hypothesis of both of these tests is the absence of cointegration in sets

Table 4 Panel unit-root test

Variables	CADF		CIPS	
	Intercept	Intercept and trend	Intercept	Intercept and trend
lnEF	1.028	0.928	−1.64065	−2.41089
lnEPU	−1.520*	−0.499	−2.15064*	−2.69391
lnW	−1.372*	0.097	−1.84572	−1.84572
lnTO	0.023	0.963	−1.39772	−1.99891
lnNR	0.339	1.044	−2.20141*	−1.05729
lnLE	−2.103**	−1.056	−2.26499***	−0.96670
dlnEF	−6.024***	−3.324***	−4.03353***	−4.42097***
dlnEPU	−8.098***	−6.911***	−3.98337***	−3.55142***
dlnW	−4.642***	−2.811***	−2.97080***	−3.23896***
dlnTO	−4.451***	−3.175***	−3.19117***	−3.60167***
dlnNR	−10.782 ***	−8.264 ***	−2.49272***	−3.53532***
dlnLE	−3.809***	−5.532***	−2.87120***	−3.05773***

*, **, and *** denote statistically significant at the 10%, 5%, and 1% levels, respectively. Source: Current Research

Table 5 Pedroni, Kao, and Westerlund cointegration tests

Pedroni cointegration	Panel-PP	Panel-ADF	Group-PP	Group-ADF
	−6.2563	−6.0854	−5.9980	−5.9615
Probability values	0.00	0.00	0.00	0.00
Kao cointegration	ADF	MDF	UDF	UMDF
	1.8468	0.2225	−6.1140	−8.2006
Probability values	0.03	0.41	0.00	0.00
Westerlund cointegration	Gt	Ga	Pt	Pa
	−2.362	3.604	−0.979	1.502
Probability values	0.00	1.00	0.04	0.09

*, **, and *** denote statistically significant at the 10%, 5%, and 1% levels, respectively. Source: Current Research

of panel data. However, these two cointegration tests have been criticized, and it has been stated that these tests consider cointegrated vectors to be homogeneous across units of cross-sectional. Hence, the results obtained from them are not reliable and robust if there is a CSD. In this regard, the Westerlund (2007) cointegration test eliminates these barriers and reports more efficient and accurate results in the presence of CSD. This test offers four cointegration tests, two of which determine the cointegration relationship across the whole panel and the other two at least in one group of the panel (Khan et al. 2020). Thereby, the use of the Westerlund cointegration test due to the existence of CSD is necessary and impressive. Following Khan et al. (2020) and Sharma et al. (2021e), this study simultaneously uses the first-generation cointegration tests (Pedroni and Kao) and second-generation cointegration test (Westerlund) to achieve more realistic results, provide better policy guidance, and use the features of the first and second-generation cointegration tests. The outcomes of the Pedroni, Kao, and Westerlund tests reveal the existence of the cointegration relationship between the study variables (Table 5).

The long-run and short-run relationships between variables can be estimated afterwards in the cointegration analysis. Table 6 demonstrates the panel ARDL results with PMG, MG, and DFE estimators. The Hausman and Taylor (1978) test reveals that PMG is the more efficient estimator than MG and DFE in this study. The error correction term (ECT) coefficient indicates whether, if the equilibrium is left, it will approach to equilibrium level in the long run or not. In this regard, it converges to the equilibrium level in the long run if the ECT coefficient is between 0 and −1 (Uzar 2020). Based on the results of PMG, the value of the ECT coefficient is −0.37, so it satisfies this condition and is also statistically significant. EPU and trade openness negatively and positively impact EF in the long and short run.

Further, social welfare positively affects EF in both the short and long run. The long-run natural resource rents coefficient is positive, and its short-run coefficient is negative. Eventually, unlike social welfare, life expectancy negatively impacts EF in both the short and long run. Notably, the impact of all variables on EF is statistically significant

Table 6 Panel ARDL estimation results (1,1,1,1,1)

Variables	PMG		MG		DFE	
	Coefficients	*z*-statistic	Coefficients	*z*-statistic	Coefficients	*z*-statistic
Long-run results						
lnEPU	−0.0792331	−5.20***	−0.0641288	−2.93***	−0.0754501	−2.13**
lnW	0.4531534	5.96***	0.631202	2.30**	0.5379684	6.18***
lnTO	−0.5215974	−8.04***	−0.4741248	−3.04***	−0.3304449	−3.21***
lnNR	0.0982784	8.88***	0.093378	2.80***	0.0259528	1.05
lnLE	−4.42931	−6.31***	−2.682202	−0.91	−2.785417	−2.86***
Short-run results						
ECT(-1)	−0.3744295	−4.87***	−0.8947111	−9.16***	−0.3941237	−8.84***
Δ(lnEPU)	0.0181691	1.21	0.0616388	2.20**	0.0173634	1.09
Δ(lnW)	0.5103846	3.23***	0.1286102	0.42	0.2648649	2.41**
Δ(lnTO)	0.137651	1.31	0.2283546	1.68*	−0.0579973	−0.84
Δ(lnNR)	−0.0077148	−0.74	−0.0331151	−1.80*	0.016159	1.37
Δ(lnLE)	−6.361601	−1.19	−5.222865	−0.49	−0.2006225	−0.14
C			13.4671	1.38	3.973503	2.66***
Hausman test						
PMG vs. MG		PMG vs. DFE		MG vs. DFE		
p-value	0.8966	*p*-value	1.0000	*p*-value	1.0000	

*, **, and *** denote statistically significant at the 10%, 5%, and 1% levels, respectively. Source: Current Research

Table 7 CS-ARDL results

Dependent variable: lnEF	Coefficients	Standard error	*z*-statistic	*p*-value
Short-run estimation				
Δ(lnEPU)	0.0616388	0.0280475	2.20	0.028
Δ(lnW)	0.1286102	0.3093468	0.42	0.678
Δ(lnTO)	0.2283546	0.1358288	1.68	0.093
Δ(lnNR)	−0.0331151	0.0183501	−1.80	0.071
Δ(lnLE)	−5.222865	10.58172	−0.49	0.622
Constant	9.152548	11.15852	0.82	0.012
Long-run estimation				
Error correction	−0.8947111	0.0976226	-9.16	0.000
lnEPU	−0.0641288	0.021915	−2.93	0.003
lnW	0.631202	0.274867	2.30	0.022
lnTO	−0.4741248	0.1560682	−3.04	0.002
lnNR	0.093378	0.0332952	2.80	0.005
lnLE	−2.682202	2.963176	−0.91	0.365

*, **, and *** denote statistically significant at the 10%, 5%, and 1% levels, respectively. Source: Current Research

in the long run; also, only social welfare has a statistically significant impact on EF in the short run.

As aforementioned, the presence of cross-sectional dependency can confuse the PMG results. Therefore, re-estimating the model by the CS-ARDL approach is crucial to get more accurate results and check the robustness of the traditional panel ARDL model. The long- and short-run results of CS-ARDL are documented in Table 7. If disequilibrium occurs, ECT approves that EF establishes the long-run equilibrium with the speed of −0.89. In other words, if it deviates from the long-run path, the EF can automatically establish the equilibrium with EPU, social welfare, trade openness, natural resource rents, and life expectancy.

The EPU is a positive and significant determinant of EF in the short run, while it is a negative determinant in the long run. In other words, EPU has a deteriorating role toward EF in the short run, and an increase in EPU is responsible for environmental degradation in the short run. On the other hand, EPU reduces EF in the long run and improves environmental quality and sustainability. In the short run, EPU induced low income and revenue. Manufacturers and economic institutions may ignore environmental standards and utilize low-cost energy resources in their production patterns and methods to compensate for the low income and revenue not to lose their profits. While in the long run, economic enterprises and manufacturers adapt to existing uncertainties. Consequently, they move toward using environmentally friendly energy sources when their revenues grow, improving the environmental quality. Zahra and Badeeb (2022), Pirgaip and Dinçergök (2020), Adams et al. (2020), and Jiang et al. (2019) confirm our results, but Liu and Zhang (2022) and Adedoyin and Zakari (2020) have achieved different results.

The social welfare coefficient has a positive and insignificant effect on the EF in the short run. While in the long run, its effect on EF is positive and significant. The possible explanation of the destructive effect of increasing social welfare on the quality of the environment is debatable in several ways. One of the most important proceedings of these countries to reduce income inequalities is to increase the minimum wage for workers and low-income groups; as low-income groups earn higher incomes, their demand for food and natural resources increases, which can harm the environment and cause pollution. Investing in education and improving schools' quality is another effective way to reduce inequalities. These factors can increase economic mobility and have devastating effects on the environment.

Meanwhile, the study countries are industrialized countries that rely heavily on increasing their GDP and achieving high economic growth rates to increase their welfare programs. Increased production can significantly increase the consumption of natural resources and energy and impose species extinction, soil and climate pollution, excessive waste production, deforestation, and other forms of environmental degradation on human society. The results of Demir et al. (2019) are somewhat consistent with our results.

Similar to EPU, trade openness impacts EF positively and significantly in the short run. Moreover, not only does trade openness affect EF positively in the short run, but also it affects EF negatively and significantly in the long run. The expansion of global trade can stimulate the growth of countries' economies and increase the incentive to improve production and energy and natural resource consumption. Hence, global trade leads to environmental degradation in the short run. On the other hand, developing trade between countries requires compliance with environmental standards.

Consequently, trade openness leads countries to more advanced and less carbon-intensive technologies in the long run. The results of the Wang and Zhang (2021) study are similar to our results for the countries of upper-middle-income and high income. Also, the studies of Adebayo et al. (2022), Khan et al. (2022), Shahbaz et al. (2019), Zhang et al. (2017), and Al-Mulali et al. (2015) support our results.

In the case of natural resources, the coefficient of natural resources is negative in the short run and positive in the long run. Notably, the impact of natural resources on EF is statistically significant in both the short and long run. In the short run, the sale of natural resources may enhance the wealth of countries and encourage them to strengthen infrastructure and green technologies. However, since the income from natural resources is directly related to the exploitation of natural resources, increasing the exploitation of natural resources will severely damage the environment in the long run. Eventually, life expectancy negatively affects EF in both the short and long run; the coefficient of life expectancy is not statistically significant neither in the short run nor in the long run. Charfeddine and Mrabet (2017) results for 15 MENA countries are consistent with our results.

Fig. 3 compares the outcomes of the PMG and CS-ARDL. Regardless of the coefficients' magnitude, it is evident that the signs of coefficients in PMG and CS-ARDL approaches are very similar. Thereby, it shows the robustness of the study results.

Following Hao et al. (2021), this study also considers the AMG method to check the sign of variables and robustness of the CS-ARDL approach. The AMG method confirms the signs of coefficients in the long run. Notably, the CS-ARDL approach is re-estimated by adding some other countries; also, the study results are robust by adding new countries (see the Appendix) (Table 8).

Finally, the panel causality test of Dumitrescu Hurlin is used to evaluate the causal relationship among the studied variables. The result of this causality test is presented in Table 9 and Fig. 4. Evidence shows that the EF in these countries is affected by EPU, social welfare, trade openness, natural resource rents, and life expectancy, and also, all these variables are affected by the EF. Videlicet, there is a bi-directional causal relevance among them. Accordingly, it can be concluded that EPU, social welfare, trade openness,

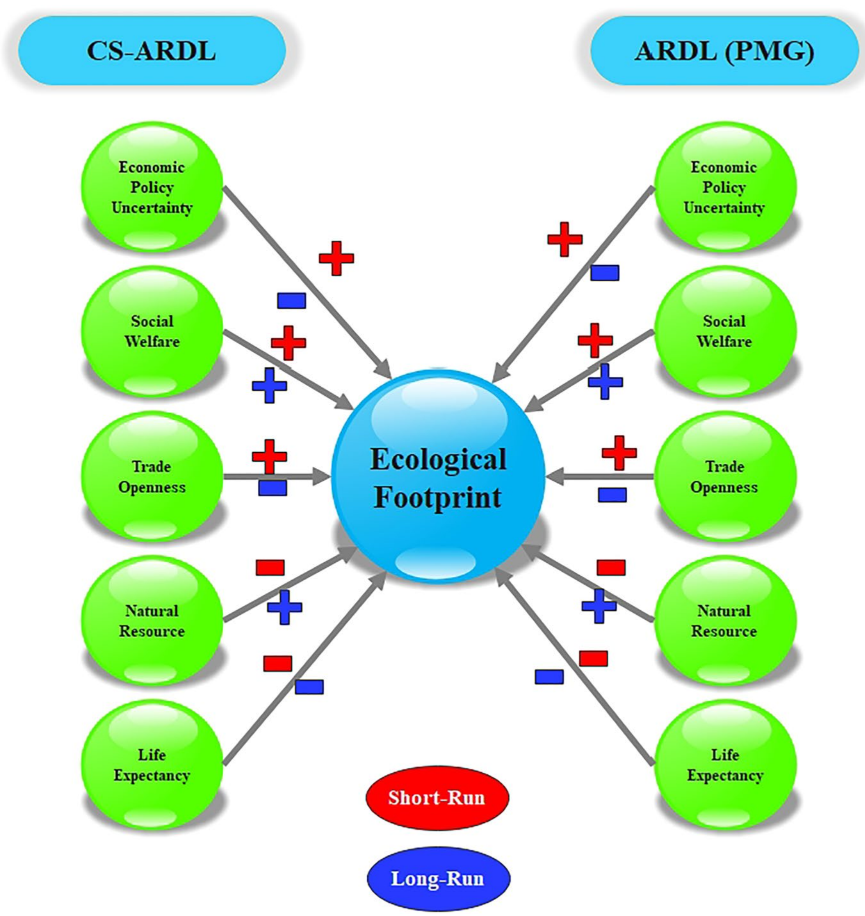

Fig. 3 Graphical abstract empirical results

Table 8 Robustness check (AMG)

Variables	lnEPU	lnW	lnTO	lnNR	lnLE	C
Coefficients	−0.0131849***	0.6137553***	−0.2924488***	−3.85731***	0.0609362***	13.55897***

*, **, and *** denote statistically significant at the 10%, 5%, and 1% levels, respectively. Source: Current Research

natural resource rents, and life expectancy shock will have consequences for EF and vice versa.

Conclusion and policy implication

Environmental degradation has been one of the most challenging human concerns for several decades, where the absence of adequate regulations and policies can cause catastrophic damage to the earth's economy, human life, and survival. To mitigate environmental problems and propose effective policies, this study, using the 19 energy-intensive countries as a case study, examines the impact of two challenging twenty-first-century factors, social welfare, and economic policy uncertainty, on widely used environmental degradation proxies (ecological footprint) in the short-run and long-run. Moreover, the impacts of life expectancy, trade openness, and the natural resource on EF are also considered. The traditional panel ARDL approach was used to examine the impact of study variables on EF. Notably, panel data models face two problems of slope heterogeneity and CSD. Besides, both of these two problems were confirmed in this study. The approach of CS-ARDL is a new generation of panel ARDL approaches that, unlike the traditional panel ARDL, overcomes these problems well and provides robust and more reliable results. Hence, this study performed CS-ARDL to remark on panel data's problems for obtaining more accurate results. The results of the CS-ARDL approach revealed that EPU has destructive impacts on the quality of the environment in the short run. Meanwhile, the impact of other variables on the EF becomes apparent in the long run. Specifically, social welfare also degrades the quality of the environment, while trade openness and life expectancy favor the environmental quality by reducing EF. Eventually, evidence demonstrates the insignificant impact of natural resource rents on the EF in the long and short run.

Table 9 Results of panel causality test

Causality direction	W-statistics	$\overline{Z}$–statistics	Result	Conclusion
lnEF → lnEPU	1.7343***	2.2632***	Yes	lnEF cause lnEPU
lnEPU → lnEF	2.9403***	5.9805***	Yes	lnEPU cause lnEF
lnEF → lnW	2.8307***	5.6426***	Yes	lnEF cause lnW
lnW → lnEF	4.1084***	9.5808***	Yes	lnW cause lnEF
lnEF → lnTO	3.4090***	7.4249***	Yes	lnEF cause lnTO
lnTO → lnEF	5.1506***	12.7931***	Yes	lnTO cause lnEF
lnEF → lnNR	2.3004***	4.0080***	Yes	lnEF cause lnNR
lnNR → lnEF	1.9241***	2.8484***	Yes	lnNR cause lnEF
lnEF → lnLE	2.8538***	5.7137***	Yes	lnEF cause lnLE
lnLE → lnEF	4.6672***	11.3030***	Yes	lnLE cause lnEF

*, **, *** denote statistically significant at the 10%, 5%, and 1% levels, respectively. Source: Current Research

The study's policy implications for governments and policymakers are as follows: The consumption of clean energy sources, often a vital solution to reduce pollution, is recommended. Increasing renewable energy consumption while improving the environment's quality can also provide the energy needed for economic growth in these countries. Since uncertainties can lead to environmental pollution in a short period, special attention should be paid to it. Thus, enterprises and economic institutions must be required to use clean energy and comply with environmental standards in all circumstances. It is possible to reduce the taxes of companies and organizations that comply with environmental standards.

Otherwise, there are specific policy implications that arise from this research study. Firstly, the powers should be delegated and distributed to institutions at a lower level to allow them to design environmental policies to promote environmental sustainability. Moreover, central governments should allocate more powers to local governments to further strengthen the fiscal expenditure decentralization and enhance the projects for green energy to control environmental degradation. Additionally, increasing the fiscal expenditures ratio in current and development spheres to improve environmental sustainability is an effective tool. Thus, this is also suggested for the selected OECD countries.

Similarly, the "Free Riding" behavior of local governments and the industrial sector, fiscal decentralization, should be curtailed by bounding carbon shares in environmental degradation both in the short run and long run. Setting special autonomous bodies at local and provincial levels to monitor the institutional qualities to guard against environmental concerns can play an influential role. It is also suggested to implement the carbon tax at the very root of provincial and local authority levels, which will play an effective role like a two-way sword, which will not only

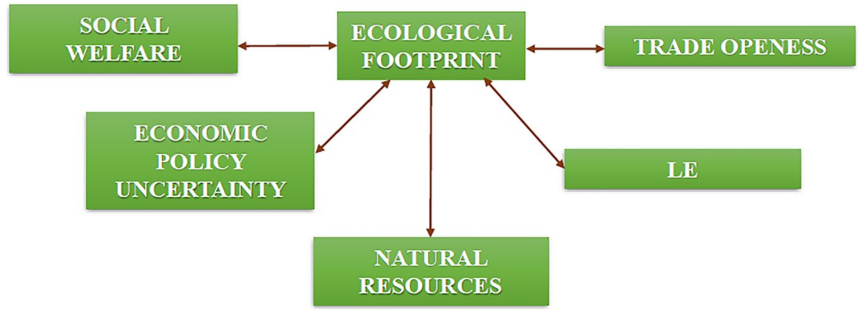

Fig. 4 Causality results

surge government revenue but thus will prompt fiscal revenue decentralization and control environmental degradation, and upgrade climate sustainability. Similarly, delegating more power to the provincial government to manipulate the policies in favor of a paradigm shift from extensive economic growth-oriented models to low environmental degradation developmental models, especially low carbon economic growth models to achieve sustainability concerning environmental perspective, will be favorite. The subsequent policy implication for these countries is to focus on a paradigm shift related to energy portfolio by accumulating the share of green energy in the total sphere of energy consumption.

Similarly, proper planning for technological advancements and enhancements in the power sector to enhance carbon capture and storage is the need of the hour to subdue environmental degradation. Therefore, it is indispensable to increase green investment to promote environmental sustainability. Another suggestion is to devise additional credit or green credit mechanisms or systems to allow varying interest rates for industries depending on their parts in environmental degradation and carbon emission. The more polluting industries may offer credit at higher interest rates and vice versa, which will compel industries to innovate green or renewable energy production at their potential level. Likewise, industries with low carbon emissions should be given an incentive through a low tax rate or tax exemptions. In parallel, importers should be given subsidies to import green energy products. These suggestions exhibit the collaboration of three crucial goals of Sustainable Development Goals (SDGs), which are to enhance economic growth (SDGs-8), consider the problem of environmental degradation, and uplift the ecological quality (SDGs-13) in addition to providing masses of affordable green energy (SDG no 7). The role of renewable energy in environmental sustainability cannot be denied. Therefore, it is suggested to increase green investment to migrate from traditional methods of energy production to enhance and modernize green energy production techniques. More focus should be given to increasing geothermal, nuclear, and wind energy production. The scope and volume of green finances to promote renewable energy production should be enlarged in selected OECD countries.

Additionally, it is highly recommended that income increases be synchronized with appropriate and efficient education for low-income groups. Thus, these groups must understand that this increase in income will continue for them as long as they adhere to environmental regulations and standards. Moreover, the effort to capture the global market is crucial, as it encourages using less carbon-intensive and equipped technologies that will positively affect environmental quality. Another critical recommendation to control economic policy uncertainty is implying very fair and transparent economic policies so that government authorities and officials can analyze the economic policy uncertainty transparently and diagnose economic illness and thus treat it properly and timely. At the global level, economic organizations such as World Trade Organization, United Nations Organizations, International Monetary Funds, and World Bank must campaign to shrink economic policy uncertainty both globally and country-wise. Governments should assess how Economic Policy Uncertainty and other emission-causing factors could affect environmental sustainability, and they should concentrate on controlling Economic Policy Uncertainty while stimulating renewable energy, energy-efficient technology, and knowledge production and transfer deployment.

So, improving environmental quality requires increasing attention to health levels. Health and environmental standards are related to each other like a cycle, the observance of each of which improves the situation of the other. By adopting all these policies, both the quality of the environment and the economic growth rate will improve.

Finally, we consider that future studies may focus on finding the threshold level of fiscal decentralization to optimize economic growth with sustainable environmental goals, which is the soul of SDGs. Secondly, World Uncertainty Index can be a relatively better proxy for monetary policy uncertainty which can be used in future studies for better policy suggestions. Thirdly, this research study assumes the impact of green energy on ecological footprint; however, energy segregation paves the way for future researchers to dissect the energy consumption role in enhancing ecological footprint with particular reference to fiscal decentralization and economic policy uncertainty. Fourthly, this research study assumes fiscal expenditure decentralization as a proxy for fiscal decentralization. However, future studies can develop an index to aggregate the impact of both dimensions of fiscal decentralization, namely, fiscal revenue decentralization and fiscal expenditure decentralization.

Appendix

The CS-ARDL approach is re-estimated by adding India and Japan to check the robustness of the study results (Table 10). Based on Table 10, the results of our study are robust. It is worth noting that adding more countries was impossible due to data availability.

Table 10 CS-ARDL results: adding India and Japan

Dependent variable: lnEF	Coefficients	Standard error	*z*-statistic	*p*-value
Short-run estimation				
Δ(lnEPU)	0.0533634	0.0259715	2.05	0.040
Δ(lnW)	0.082053	0.2814626	0.29	0.771
Δ(lnTO)	0.2091352	0.1238971	1.69	0.091
Δ(lnNR)	−.0256457	.0173509	−1.48	0.039
Δ(lnLE)	−3.799121	9.615194	−0.40	0.693
constant	8.55389	10.08001	0.85	0.396
Long-run estimation				
Error correction	−.8993027	.0881509	−10.20	0.000
lnEPU	−.055116	.0208398	−2.64	0.008
lnW	.6328697	.2480365	2.55	0.011
lnTO	−.4326741	.1437027	−3.01	0.003
lnNR	.081715	.0313798	2.60	0.009
lnLE	−2.594759	2.675127	−0.97	0.332

*, **, *** denote statistically significant at the 10%, 5%, and 1% levels, respectively. Source: Current Research

Abbreviation CSD: cross-sectional dependency; CS-ARDL: cross-sectional augmented autoregressive distributed lag; DFE: dynamic fixed effect; MG: mean group; PMG: pooled mean group; ECT: error correction term; EF: ecological footprint; EPU: economic policy uncertainty; LE: life expectancy; TO: trade openness; W: social welfare; NR: natural resource rent

Data availability Under request

Author contribution Parisa Esmaeili: conceptualization, methodology, software, validation, formal analysis, investigation, data curation, writing — original draft, writing — review and editing. Meysam Rafei: conceptualization, methodology, software, validation, formal analysis, data curation, writing — original draft, writing — review and editing, supervision. Daniel Balsalobre-Lorente: validation, writing — review and editing, supervision. Adedoyin Festus Fatai: validation, writing — review and editing.

Declarations

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