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RESEARCH ARTICLE

The effect of financial development and economic growth on ecological footprint: evidence from top 10 emitter countries

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Abstract

This study investigates the effect of financial development and economic growth on ecological footprint by including non-renewable energy consumption and trade openness as additional determinants. For this purpose, annual data of 10 countries with the highest ecological footprint (China, the USA, India, Japan, Brazil, Indonesia, Mexico, Korea, Turkey, and the UK) for the period 1992–2017 is used. The Westerlund and Edgerton (2007) Panel LM bootstrap test results reveal that there is cointegration between the variables. Additionally, the results obtained from the Common Correlated Effects (CCE) coefficient estimator show that financial development, economic growth, and non-renewable energy consumption negatively affect environmental quality by increasing ecological footprint. On other hand, the effect of trade openness on ecological footprint is found to be statistically insignificant. In addition, according to the panel causality test results, a unidirectional causality from financial development to ecological footprint is found while bidirectional causality between economic growth and ecological footprint exists. Therefore, it would be beneficial for policymakers in such countries to direct financial resources to green energy production and consumption and to encourage projects and practices.

Keywords Ecological footprint · Economic growth · Financial development · Non-renewable energy

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Introduction

Water scarcity, increasing population, energy demand, and waste generation cause environmental degradation. The rising trend of greenhouse gases not only poses a threat to the ecosystem but also has an impact on society. Therefore, dealing with environmental degradation worldwide in recent years is of great importance for both developed and developing countries. The fact that the subject has global as well as local effects forces countries to cooperate in increasing environmental quality in this field. Researchers examine the numerous determinants of environmental quality that can help reduce the growing ecological footprint and achieve sustainable development and make recommendations on how environmental quality can be improved worldwide. Financial and economic variables can affect environmental dynamics in various ways, ultimately causing environmental degradation or contributing to environmental improvement. Panayotou (1993) states that the state of natural resources and environment in a country depends on five main factors. These are the level of economic activity or the size of the economy, the sectoral structure of the economy, the old state of technology, the demand for environmental opportunities, protection, and environmental expenditures, and their effectiveness. The study of Grossman and Krueger (1991), one of the pioneering studies investigating the relationship between environmental pollution and economic growth, explains the interaction between changes in trade and foreign investment policy, pollution level, and depletion rate of scarce environmental resources, with three different mechanisms. These are scale effect, composition effect, and technique effect. According to the scale effect, if the liberalization of trade and investment leads to the expansion of economic activities and the nature of these activities remains unchanged, then the total amount of pollution produced must increase. According to the composition effect, once trade is liberalized, countries specialize more in sectors in which they have a competitive advantage. If the competitive advantage is largely due to differences in environmental regulations, the compositional effect of trade liberalization will harm environment. Each country will then tend to specialize more in activities not strictly regulated by government and withdraw from production in industries where the local costs of reducing pollution are relatively large. Technique effect asserts that following the liberalization of trade and foreign investment, there is no need for production to be carried out by exactly the same methods. Especially in less-developed countries, firstly, as a result of the relaxation of restrictions on foreign investments, foreign producers can transfer modern technologies to the local economy, and secondly, if trade liberalization provides an increase in income levels, the political structure can demand a cleaner environment as an expression of increasing national wealth by decreasing pollution per unit.

The relationship between per capita income and environmental pollution is expressed by the Environmental Kuznets Curve (EKC). Kuznets (1955) found that the relationship between per capita income and income inequality is similar to an inverted U-shaped curve, that is, a bell curve. Following that, studies conducted since the 1990s have also determined that the relationship between per capita income and environmental degradation is inverted U-shaped. Because of this similarity, the relationship between environmental degradation and economic development was first put forward by Panayotou (1993) as EKC (Dinda, 2004). According to the EKC hypothesis, the relationship between economic growth and environmental pollution is likened to a bell curve or inverted U-shaped. So, it is assumed that environmental pollution will increase until economic growth reaches a certain income level (threshold value), but after this income level is reached, environmental pollution will decrease. The scale effect explains the positively sloped part of the EKC, while the composition effect and the technique effect explain the negatively sloped part of the EKC.

Another factor affecting environmental dynamics is financial development. Financial development, which expresses a country's decision to allow and encourage an increase in foreign direct investment (FDI), banking, and stock market activities, can increase economic growth and an increase in economic growth can also affect energy demand (Sadorsky, 2010). Financial development is a vital and potentially important factor in rapidly increasing economic growth and reducing environmental CO_2 emissions. Financial sectors affect energy consumption and CO_2 emissions by accelerating technological progress in the energy field (Yang et al. 2015). However, there is also an approach in which a robust and developed financial sector will play an important role in economic growth of the country and increase economic efficiency of the financial system (Chien et al. 2021). On other hand, it is also stated that financial institutions support the financial needs of individuals and cause an increase in the purchasing power of people, intensifying resource consumption, and leading to higher ecological footprint. On other hand, financial institutions can encourage technological progress that can reduce the consumption of energy and other resources and therefore ecological footprint (Kihombo et al. 2021). Although it provides economic benefits, another result is that financial development may have many shortcomings as it can bring negative problems to environment and consume natural resources in various ways (Baloch et al. 2019). Wider access to financial capital increases the demand for energy consumption and exacerbates environmental degradation with increasing pollution levels (Usman et al. 2021).

It is thought that this study can contribute to the literature in four aspects: (i) most of the environmental studies in the literature take consider carbon emissions. Number of the limited studies investigating the impact of financial development and economic growth on EFP. In this context, in the past studies, no research was found using the data of the 10 countries with the highest ecological footprint in terms of the variables of this study. Therefore, this study is important in terms of filling this gap in the current literature. (ii) The fact that the countries selected as the sample (China, the USA, India, Japan, Brazil, Indonesia, Mexico, Korea, Turkey, and the UK) have different development levels will also allow the results to be evaluated in terms of developed and developing countries. By using the second-generation CCE estimator, the impact of economic growth and financial development will allow country-specific results and policy recommendations to be developed. (iii) There is no consensus in the literature on the environmental impact of non-renewable energy consumption and trade openness. This study presents new empirical findings on the environmental damage caused by non-renewable energy consumption and trade openness for the 10 countries with the highest ecological footprints. It contributes to the expansion of the academic literature on the environment. (iv) The finding of the study in which direction, how financial development and economic growth affect the EFP or not, will guide the policies to be implemented towards the environment. It will help researchers and policymakers better understand the environmental consequences of financial development and economic growth in countries. In other words, it will be able to contribute to the countries' development of policies to reduce the CO_2 emission volume, which is one of the Sustainable Development Goals, and to increase environmental protection. It will also help to identify other factors that affect the increase of the ecological footprint. Ultimately, it will help policymakers to organize their environmental quality strategies more realistically and accurately.

Following introduction part, literature review is presented in the "Literature review" section. In the "Data, model, and methodology" section, empirical model and methodology together with data is presented. The empirical findings are given in the "Empirical findings" section. Conclusion, suggestions for potential policymakers, and also, explanations are made about the direction of future studies are in the "Conclusion, implication, and future directions" section.

Literature review

There are many studies on energy economy in existing literature. In many studies, energy consumption and economic growth-financial development relations are discussed. In this context, Masih and Masih (1996), Dhakal (2009), Sadorsky (2010), Apergis and Payne (2012), and Destek and Okumus (2017) investigated the relationship between energy consumption and economic growth. Similarly, the relationship between energy consumption and financial development is discussed in the studies of Sadorsky (2011) and Lin and Moubarak (2014). Shahbaz and Lean (2012) and Islam et al. (2013) examined energy consumption, economic growth, and financial development variables together. On other hand, a significant number of studies in existing literature investigated the relationship between environmental pollution or environmental degradation variables, which are directly related to energy consumption, and financial-economic variables, instead of energy consumption. Thus, financial-economic determinants of air quality or environmental degradation were tried to be estimated, and the validity of the EKC hypothesis was tested for the countries within the scope of the research. Grossman and Krueger (1991), Shafik and Bandyopadhyay (1992), Panayotou (1993), and Selden and Song (1994) carried out pioneering studies in this field.

For instance, Grossman and Krueger (1991) investigated the relationship between economic growth and three environmental pollution variables (sulfur dioxide, suspended particles, and dark matters) for urban areas in 42 countries. In the study, the effects of various urban/country characteristics were also included in the analysis as dummy variables. According to their results, it is determined that environmental pollution increase at low national income levels and decrease at high income levels for two pollution indicators (sulfur dioxide and dark matters). Shafik and Bandyopadhyay (1992) investigated the relationship between 10 different environmental quality indicators (EQIs) and various macroeconomic and political variables for 149 countries classified as low, medium, and high according to their income levels. They found that economic growth generally has positive effects on EQIs for the relevant countries. Panayotou (1993) and Selden and Song (1994) examined the relationship between four different environmental pollutants and economic growth and population density with panel regression models for a large number of countries. They noted that economic growth increases environmental degradation, that is, it has a positive effect on environmental pollution. In all the pioneering studies described so far, it is determined that the EKC hypothesis is valid for the relevant countries. Another remarkable point in these studies is that many different variables representing environmental pollution are used in the studies. Tamazian et al. (2009) and Tamazian and Rao (2010) used panel regression models in their studies. Tamazian et al. (2009) conducted research on BRIC countries, the USA and Japan, and as a result of the study, they found positive relationship between CO_2 emissions and economic growth, but generally negative relationship between CO_2 emissions and financial development. Tamazian and Rao (2010) stated that there is a positive relationship between CO_2 emissions and economic growth for 24 transition countries, but a negative relationship between CO_2 emissions and financial development. According to Tamazian and Rao (2010), financial development generally has positive effects on environmental quality, i.e., financial development reduces environmental degradation.

In literature, the relationship between environmental degradation and the explanatory variables of environmental degradation is analyzed with panel regression models for many countries, and there are also a significant number of studies in which countries are discussed one by one. For example, Jalil and Feridun (2011) and Zhang (2011) have reached empirical evidence on China, a far eastern country, for different data periods. Jalil and Feridun (2011) found negative significant relationship between CO_2 emissions and financial development. They further found a positive and significant relationship between CO_2 emissions and real income. However, Zhang (2011) concluded that China's financial development is acting as a major driver for carbon emissions increases. In another study on Far East countries, Shahbaz et al. (2013a) determined that there were positive and significant relationships between economic growth and financial development and CO_2 emissions in Indonesia. Shahbaz et al. (2013b) found a positive and significant relationship between economic growth and CO_2 emissions, but negative and significant relationship between financial development and CO_2 emissions in Malaysia. Ahmed et al. (2021) examined the relationship between EFP, economic globalization, economic growth, financial development, population density, and energy consumption in Japan, the world's third-largest economy after the USA and China. They noted the presence of positive relationship between EFP and financial development. Abbasi and Riaz (2016), Javid and Sharif (2016), and Shahzad et al. (2017) investigated the relationship between environmental degradation and economic growth and other economic variables in Pakistan. In resulting, Abbasi and Riaz (2016) found a positive and significant long-term relationship between CO_2 emissions and economic growth in the full sample (1970–2011) and sub-sample periods (1988–2011), while there was a negative significant long-term relationship between CO_2 emissions and total credit variable only in the sub-sample period. The empirical results by Javid and Sharif (2016) showed a positive and statistically significant long-term relationship between economic growth, financial development, energy consumption, and CO_2 emissions. Shahbaz et al. (2017) concluded that current account deficit, financial development, and energy consumption in Pakistan increase CO_2 emissions. In addition, the maximum energy use threshold for Pakistan was calculated by solving the first derivative of CO_2 emissions according to energy consumption equal to zero in the study. According to the threshold value, energy consumption in Pakistan is determined to be below the threshold level; in other words, it is stated that current energy consumption is still below technology impact point and is largely dominated by scale and composition effects.

In other individual studies, Ozturk and Acaravci (2013) and Pata (2018) investigated the variables affecting environmental degradation in Turkey for different periods. Ozturk and Acaravci (2013) concluded that for the 1960–2007 period, financial development in Turkey did not have a significant effect on per capita CO_2 emissions in the long run, but economic growth had a positive effect on CO_2 emissions. Pata (2018) determined that economic growth and financial development had a positive effect on CO_2 emissions in Turkey. In addition, Pata (2018) also stated that the turning points for per capita GDP level that can reduce environmental pollution in Turkey are around 13,523 to 14,077 USD. Shahbaz et al. (2013c) examined the effects of financial development, economic growth, coal consumption, current account deficit, and urban population ratio on CO_2 emissions in South Africa. They found that economic growth increases CO_2 emissions and financial development decreases CO_2 emissions. Therefore, through financial reforms, financial development factor can be used as a tool for a cleaner environment. Boutabba (2014) investigated the effects of financial development, economic growth, energy consumption, and current account deficit on CO_2 emissions for India. The empirical results reveal that the effects of other variables, except the current account deficit, on CO_2 emissions are positive and statistically significant. Al-Mulali et al. (2015) investigated the relationship between environmental degradation and various socioeconomic variables in 93 countries. They concluded that the EKC hypothesis, which examines the relationship between economic growth and environmental degradation, is valid for high- and upper-middle-income countries, but not valid for low- and lower-middle-income countries. Finally, financial development reduces environmental degradation in lower-middle, upper-middle, and high-income countries, excluding the low-income countries. Salahuddin et al. (2015) investigated the relationship between economic growth, electricity consumption, financial development, and CO_2 emissions for GCC countries. They found that a long-term positive relationship is found between electricity consumption and economic growth and CO_2 emissions, whereas a negative relationship between CO_2 emissions and financial development. Further, electricity consumption and economic growth increase CO_2 emissions in GCC countries; financial development reduces CO_2 emissions.

Baloch et al. (2019) researched the effects of three separate financial development indicators on EFP for 59 BRI countries and included economic growth, energy consumption, FDI, and urbanization variables as explanatory variables. They noted that all explanatory variables pollute environment by increasing EFP. For 131 countries, Majeed and Mazhar (2019) found a negative relationship between financial development and environmental degradation, and a positive relationship between economic growth and environmental deterioration. Khan et al. (2020) examined the effect of financial development and energy consumption on CO_2 emissions for 184 countries using panel regression approaches. Their empirical analysis indicates that energy consumption and economic growth affect CO_2 emissions positively but the effect of financial development on CO_2 emissions varies, i.e., financial development increases CO_2 emissions using SUR method but financial development helps to reduce CO_2 emissions by applying two-step difference GMM and two-step system GMM methods. Shoaib et al. (2020) examined the effect of financial development on CO_2 emissions for developing countries (D8) and developed countries (G8) by using panel ARDL and panel causality methods. They noted that financial development increases CO_2 emissions in the long run; economic growth reduces CO_2 emissions. Kihombo et al. (2021) investigated the effects of technological innovation, economic growth, financial development, and urbanization on EFP for West Asia/Middle East (WAME) countries, as well as the validity of the EKC hypothesis. Their empirical analysis shows that economic growth, financial development, and urbanization increase EFP, while technological development decreases EFP. Further, the EKC hypothesis is also valid.

Apart from these studies, the effects of economic growth and financial development on the environment have continued to be investigated recently. For example, Destek and Sarkodie (2019) found a bidirectional causality relationship between economic growth and ecological footprint in their research on 11 newly industrialized countries. In addition, the EKC hypothesis was confirmed for Mexico, Philippines, Singapore, and South Africa. On the other hand, no significant effect of financial development on EFP was found. Khan et al. (2021) found that FD positively affected EFP for Malaysia and confirmed the EKC hypothesis. Similarly, Zia et al. (2021) determined that both financial development and economic growth increase the ecological footprint. Similarly, Zeraibi et al. (2021) found a positive relationship between EG and EFP in terms of ASEAN-5 countries, and a statistically insignificant relationship between FD and EFP. In addition, a bidirectional causality was determined between EG, FD, and EFP. AL-Barakani et al. (2022) found that financial development has a positive and spillover effect on ecological footprint and carbon emissions for BRI (Belt and Road Initiative) countries. The authors found that economic growth increases the ecological footprint and carbon emissions. Jahanger et al. (2022) conducted a study in terms of Asian, African, Latin American, and Caribbean regions countries. The Kuznets curve hypothesis was confirmed in all countries except Asian countries. It was found that financial development reduces ecological footprints for Asian countries but increases it for African and Latin American and Caribbean countries. Saqib (2022) investigated the factors affecting environmental degradation using panel data from 63 developing and developed economies. As a result of the study, negative between CO2 and FD, a positive relationship was found between EG and CO2. In addition, a statistically significant bidirectional causality was found between non-renewable energy, financial development, economic growth, and carbon footprint.

Recently, there have been important studies on the subject in existing literature. For example, Akinsola et al. (2022) investigated the relations of EFP, public-private partnership investment in energy, financial development, and renewable energy in Brazil. Their empirical results indicate the presence of a long-term positive relationship is found between EFP with economic growth and public-private partnership investment in energy. The long-term negative relationship also exists between EFP with renewable energy consumption and financial development. Their empirical results indicate the presence of bidirectional causality between EFP and economic growth and, EFP and financial development in the short run; one-way causality exists running from renewable energy to EFP and, from EFP to public-private partnership investment in energy. Ansari et al. (2022) investigated the main determinants of EFP for G-20 countries and reported the presence of an inverted N-shaped augmented EKC relationship between economic growth and EFP. Dogan and Shah (2022) investigated long-term relationship between EFP, economic growth, energy intensity, renewable energy, and urbanization population ratio for the UAE. They found positive relationship between EFP and economic growth and negative relationships between EFP and other variables. Ngoc and Awan (2022) investigated the impact of financial development, economic growth, and human capital on EFP for Singapore. Their results showed that financial development and economic growth have a positive effect on EFT, while human capital has a negative effect. In existing literature, the relationship between environmental degradation and FDI is tested with a different hypothesis. Accordingly, the positive relationship between FDI and environmental degradation is also known as "Pollution haven hypothesis (PHH)," which states that FDI increases investment in high-polluting industries and deteriorates environmental quality (Majeed and Mazhar, 2019). Further, Zhang (2011), Shahbaz et al. (2013b), Baloch et al. (2019), and Majeed and Mazhar (2019) found positive relationships between FDI and environmental degradation. Thus, it is concluded that PHH is valid in all of the literature surveys, except for Abbasi and Riaz (2016). A summary of the literature is presented in Table 1.

Considering the literature review, many different types of variables are used as indicators of environmental degradation in pioneering studies, as mentioned earlier. However, in later studies, CO_2 emissions are frequently used to represent environmental degradation, and it has been observed that EFP has been used extensively in recent studies. In addition, many quantitative and qualitative variables are used as explanatory variables of environmental degradation. On other hand, as can be seen from the literature, no study was found for the countries with the highest EFP.

Data, model, and methodology

In this study, which focuses on the effect of economic growth and financial development on EFP, non-renewable energy consumption and trade openness explanatory variables are also included in the model. The variables, sources, and explanations of the variables are shown in Table 2.

In all studies examining the impact of economic growth and financial development on EFP, data were used annually. In this context, the annual 1992–2017 data of 10 countries with the highest EFP hectares is used. These countries are China, the USA, India, Japan, Brazil, Indonesia, Mexico, Korea, Turkey, and the UK. The development of the model in Eq. (1) was referenced from Destek and Sarkodie (2019), Khan et al. (2021), Zia et al. (2021),

Table 1 Literature summary

References	Variables		Country/territory	Data period	Econometric method	Findings		
	Dependent	Independent				EKC	Long-run relationship	Short-run causality
Grossman and Krueger (1991)	SO_2, SP, and DM	EG, TO, D	42 countries	1950–1988	Panel regression (RE and FE)	√	SO_2 (+) EG DM (+) EG SP (-) EG	n/a
Shafik and Bandyopadhyay (1992)	10 EQIs	EG, macroeconomic and political variables	149 countries	1960–1990	Panel regression	√	EQIs (+) EG (generally)	n/a
Panayotou (1993)	DEF, SO_2, NO, and SPM	EG, POP	68 countries 55 countries	1980s	Panel regression	√	DEF (+) EG SO_2 (+) EG NO (+) EG SPM (+) EG	n/a
Selden and Song (1994)	SO_2, SP, NO, and CO	EG, POP	30 countries	1973–1984	Panel regression (RE and FE)	√	SO_2 (+) EG SP (+) EG NO (+) EG CO (+) EG	n/a
Tamazian et al. (2009)	CO_2	EG, FD, EC, EI, OC	BRIC countries ABD and Japan	1992–2004	Panel regression (RE)	√	CO_2 (+) EG CO_2 (-) FD	n/a
Tamazian and Rao (2010)	CO_2	EG, FD, IQI, INF, EC, EI	24 transition economies	1993–2004	Panel regression (RE and GMM)	√	CO_2 (+) EG CO_2 (-) FD	n/a
Jalil and Feridun (2011)	CO_2	FD, EG, TO, EC	China	1953–2006 1978–2006	ARDL, ECM, Granger causality	√	CO_2 (+) EG CO_2 (-) FD	EG→CO_2
Zhang (2011)	CO_2	FD, EG, FDI	China	1980–2009 1984–2009 1992–2009 1994–2009	Johansen cointegration, Granger causality, VD	n/a	CO_2 (+) FD	EG→CO_2 (for financial inter.) CO_2→EG (for stock market efficiency)
Ozturk and Acaravci (2013)	CO_2	EC, EG, TO, FD	Turkey	1960–2007	ARDL, VEC-Granger causality	√	CO_2 (+) EG	No
Shahbaz et al. (2013a)	CO_2	EG, EC, FD, TO	Indonesia	1975:Q1–2011:Q4	ARDL, Granger causality, IRF, VD	√	CO_2 (+) EG CO_2 (+) FD	CO_2↔EG
Shahbaz et al. (2013b)	CO_2	FD, EC, EG, FDI, TR	Malaysia	1971–2011	ARDL, VEC-Granger causality	n/a	CO_2 (+) EG CO_2 (-) FD	CO_2↔EG CO_2→FD
Shahbaz et al. (2013c)	CO_2	FD, EG, EC, TO, POP	South Africa	1965–2008	ARDL, ECM, Pair-wise Granger causality	√	CO_2 (+) EG CO_2 (-) FD	EG→CO_2
Boutabba (2014)	CO_2	FD, EG, EC, TO	India	1971–2018	ARDL, ECM, VEC-Granger causality	√	CO_2 (+) EG CO_2 (+) FD	No
Al-Mulali et al. (2015)	EFP	EG, EC, URB, TO, FD	93 countries	1980–2008	Panel regression (FE and GMM)	√[1]	EFP (+) EG EFP (-) FD^2	n/a

Table 1 (continued)

References	Variables		Country/territory	Data period	Econometric method	Findings		
	Dependent	Independent				EKC	Long-run relationship	Short-run causality
Salahuddin et al. (2015)	CO_2	EG, EC, FD	GCC countries	1980–2012	Pedroni panel cointegration, panel regression (DOLS, FMOLS, DFE and MG), panel VEC-Granger causality, IRF, VD	n/a	CO_2 (+) EG CO_2 (-) FD	No
Abbasi and Riaz (2016)	CO_2	EG, FD, FDI	Pakistan	1970–2011 1988–2011	ARDL, ECM, Toda-Yamamoto causality, VD	n/a	CO_2 (+) EG CO_2 (-) FD	FD→CO_2 (for reduced sample)
Javid and Sharif (2016)	CO_2	FD, EG, EC, TO	Pakistan	1972–2013	ECM, ARDL, VEC-Granger causality	√	CO_2 (+) EG CO_2 (+) FD	CO_2→EG CO_2→FD
Shahzad et al. (2017)	CO_2	EC, TO, FD	Pakistan	1971–2011	ARDL, Granger causality	n/a	CO_2 (+) FD	FD→CO_2
Pata (2018)	CO_2	EG, FD, EC, URB	Turkey	1974–2014	ARDL, Gregory-Hansen, Hatemi-J regime cointegration tests	√	CO_2 (+) EG CO_2 (+) FD	n/a
Baloch et al. (2019)	EFP	FD, EG, FDI, URB, EC	59 BRI countries	1990–2016	Panel regression (Driscoll-Kraay)	n/a	EFP (+) EG EFP (+) FD	n/a
Majeed and Mazhar (2019)	EFP and CO_2	FD, EC, EG, URB, FDI	131 countries	1971–2017	Panel regression (pooled OLS, FE, RE, Driscoll-Kraay and GMM), panel Granger causality, sensitivity analysis	n/a	EFP (+) EG EFP (-) FD CO_2 (+) EG CO_2 (-) FD	EFP↔FD
Khan et al. (2020)	CO_2	FD, EC, LAB, TR, TO, URB, EG, INFR, POP, SAV	184 countries	1990–2017	Panel regression (SUR, FE, two-step difference GMM and two-step system GMM)	√	CO_2 (+) EG CO_2 (-) FD	n/a
Shoaib et al. (2020)	CO_2	FD, EC, EG, TO	D_8 and G_8 countries	1999–2013	ARDL, panel regression (PMG), DH panel causality	√	CO_2 (+) FD CO_2 (-) EG	CO_2↔FD (only for G_8) CO_2→EG
Ahmed et al. (2021)	EFP	EG, EC, GLB, FD, POP	Japan	1971–2016	ARDL, N-ARDL and asymmetric BDM cointegration tests; VEC-Granger causality	√	EFP (+) EG EFP (+) FD	EFP→FD EFP↔EG

Table 1 (continued)

References	Variables		Country/territory	Data period	Econometric method	Findings		
	Dependent	Independent				EKC	Long-run relationship	Short-run causality
Kihombo et al. (2021)	EFP	EG, FD, TIN, URB	WAME economies	1990–2017	Westerlund, Kao and Pedroni cointegration, panel regression (CUP-FM and CUP-BC), Dumitrescu-Hurlin panel causality	√	EFP (+) EG EFP (+) FD	FD→EFP EFP↔EG
Akinsola et al. (2022)	EFP	EG, FD, EC, EIN	Brazil	1984–2017	ARDL and Maki cointegrations, regression (DOLS), gradual shift causality	n/a	EFP (+) EG EFP (-) FD	EFP↔EG EFP↔FD
Ansari et al. (2022)	EFP	EG, URB, GLB, EC	G-20	1991–2016	Pedroni, Kao and Westerlund panel cointegration, panel regression (DOLS, FMOLS and PMG)	No	EFP (-) EG	n/a
Dogan and Shah (2022)	EFP	EC, ENI, RO, URB	BAE	1992–2017	ARDL	n/a	EFP (+) EG	n/a
Ngoc and Awan (2022)	EFP	FD, EG, HC	Singapore	1980–2016	ARDL, ECM, Granger causality, Bayesian analysis	n/a	EFP (+) EG EFP (+) FD	EFP↔EG EFP→FD
Acar et al. (2023)	EFP	EG, FD, TO, POP	Azerbaijan	1996–2017	ARDL	√	EFP (+) EG EFP (-) FD	n/a

[1]For high- and upper-middle-income countries only

[2]Except for low-income countries

Note: abbreviations for dependent variables are *CO*, carbon monoxide emission; CO_2, carbon dioxide emission; *DEF*, deforestation; *EFP*, ecological footprint; *NO*, nitrogen oxide; SO_2, sulfur dioxide; *SP*, suspended particulate matter; *SPM*, solid particulate matter; *DM*, dark matter

Note: abbreviations for arguments: *EC*, energy consumption; *EG*, economic growth; *LAB*, labor force; *FD*, financial development; *FDI*, foreign direct investment; *GLB*, globalization; *URB*, urbanization; *TR*, trade; *TO*, trade openness; *POP*, population; *INFR*, infrastructure; *TIN*, technological innovation; *SAV*, saving; *IQI*, institutional quality index; *INF*, inflation; *EI*, energy import; *D*, dummy variables for country/city attributes; *HC*, human capital per person; *EIN*, energy investment; *ENI*, energy intensity; *RO*, real output; *OC*, oil consumption

Note: some abbreviations of econometric methods are *ECM*, error correction model; *FE*, fixed effect; *IRF*, impulse-response function; *PMG*, pooled mean group; *RE*, random effect; *VD*, variance decomposition; *DH*, Dumitrescu-Hurlin. Note: the "√" sign indicates the validity of the EKC hypothesis, the "(+)" sign indicates the positive, and the "(-)" sign indicates the existence of a negative cointegration relationship between the related variables. In addition, the "→" sign indicates unidirectional causality between the variables, and the "↔" sign indicates bidirectional causality

Table 2 Variables, descriptions, and source of data

Variables	Descriptions	Sources	Samples
EFP	The ecological footprint of consumption (global hectares per capita)	Global Footprint Network	Ngoc and Awan (2022); Acar et al. (2023)
EG	GDP per capita (constant 2015 US$)	World Bank, WDI	Saqib (2022); Ansari et al. (2022)
FD	Domestic credit to private sector by banks (% of GDP)	World Bank, WDI	Kihombo et al. (2021); Zia et al. (2021)
NRE	Non-renewable (fossil fuel) energy consumption (% of total consumption)	World Bank, WDI	Apergis, N. and Payne, J. E. (2012); Usman et al. (2021); Saqib (2022)
TO	Trade openness (% of GDP)	World Bank, WDI	Khan et al. (2020); Shoaib et al. (2020); Acar et al. (2023)

Zeraibi et al. (2021), AL-Barakani et al. (2022), Saqib (2022), and Acar et al. (2023).

$$\mathrm{EFP}_{i,t} = \beta_0 + \beta_1 \mathrm{FD}_{i,t} + \beta_2 \mathrm{EG}_{i,t} + \beta_3 \mathrm{NRE}_{i,t} + \beta_4 \mathrm{TO}_{i,t} + \varepsilon_{i,t} \quad (1)$$

In Eq. (1), $i = 1, \ldots, N$ shows cross-section units, $t = 1, \ldots, T$ time period, and $\varepsilon_{i,\,t}$ error terms. $\beta_1, \ldots\ldots, \beta_4$ shows the parameters that measure the effect of independent variables on the dependent variable. In panel data analysis studies, first of all, cross-section dependence and slope homogeneity should be investigated in order to determine the appropriate panel unit root test, panel cointegration test, panel cointegration estimator, and panel causality tests. Robertson and Symons (2000) and Pesaran (2004) demonstrated that cross-sectional dependence should be taken into account in panel data analysis. On other hand, Phillips and Sul (2003) argue that ignoring the cross-sectional dependence gives ineffective estimates. In this study, the LM test developed by Breusch and Pagan (1980) and the $\mathrm{CD}_{\mathrm{LM}}$ test and CD test developed by Pesaran (2004) are used to determine cross-section dependence.

Breusch-Pagan LM test (1980), which is the first cross-section dependency test used, is a test based on the correlation coefficients of residues in $T \to \infty$ states when N is constant. The LM test statistic is calculated as in Eq. (2):

$$\mathrm{LM} = T \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \hat{\rho}_{ij}^2 \quad (2)$$

In Eq. (2), $\hat{\rho}$represents the sample estimate of the binary correlation of residues. In this test, the null hypothesis shows that there is no relationship between cross-sections and it has a chi-square asymptotic distribution with $\frac{N(N-1)}{2}$ degrees of freedom. It is assumed that this test will be used when the time dimension is greater than the cross-section dimension. The second test used in the study is $\mathrm{CD}_{\mathrm{LM}}$ test developed by Pesaran (2004). This test is an improved version of the Breusch-Pagan LM test (1980). It is expressed as in Eq. (3):

$$\mathrm{CD}_{\mathrm{LM}} = \sqrt{\frac{1}{N(N-1)}} \sum_{i=1}^{N-1} \sum_{j=i+1}^{N} \left(T\hat{\rho}_{ij}^2 - 1 \right) \quad (3)$$

The third test used is the CD test developed by Pesaran (2004). This test is illustrated in Eq. (4):

$$\mathrm{CD} = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=1+1}^{N} \hat{\rho}_{ij} \right) \quad (4)$$

The CD test is based on the sum of the correlation coefficients between the cross-section residues. In the case of the null hypothesis stating that there is no relationship between the cross-sections, the test statistic shows a standard normal distribution. The H_0 hypothesis created for the tests shown in Eqs. (2), (3), and (4) states that there is no cross-section dependency, while H_1 hypothesis states that there is a cross-section dependency. According to the test results, if H_0 hypothesis is accepted, the analysis should be continued with the first-generation panel unit root tests, and if H_1 hypothesis is accepted, the analysis should be continued with the second-generation panel unit root tests (Baltagi and Baltagi 2008).

As mentioned before, in panel data analysis, it is investigated whether there is homogeneity in determining the appropriate unit root and cointegration tests. The presence of heterogeneous slope coefficients is determined by the delta (Δ) tests first developed by Swamy (1970) and later calculated by Pesaran and Yamagata (2008). However, if there is heteroskedasticity and serial correlation in regression errors, Δ tests developed by Blomquist and Westerlund (2013) are used. The HAC version of the homogeneity test, which is based on Blomquist and Westerlund (2013) delta test preferred in the study, is shown in Eq. (5):

$$\Delta_{\mathrm{HAC}} = \sqrt{N} \left(\frac{N^{-1} S_{\mathrm{HAC}} - k}{\sqrt{2k}} \right) \quad (5)$$

The S_{HAC} given in Eq. (5) is shown in Eq. (6):

$$S_{\mathrm{HAC}} = \sum_{i=1}^{N} T\left(\hat{\beta}_i - \hat{\beta}\right)'\left(\hat{O}_{\mathrm{i}T} V_{\mathrm{i}T}^{-1} \hat{O}_{\mathrm{i}T}\right)\left(\hat{\beta}_i - \hat{\beta}\right) \tag{6}$$

$\hat{\beta}$ value is as shown in Eq. (7):

$$\hat{\beta} = \left(\sum_{i=1}^{N} T\hat{O}_{\mathrm{i}T} V_{\mathrm{i}T}^{-1} \hat{O}_{\mathrm{i}T}\right)^{-1} \sum_{i=1}^{N} \hat{O}_{\mathrm{i}T} \hat{V}_{\mathrm{i}T}^{-1} X_i' M_T y_i \tag{7}$$

$\hat{\beta}_i$ represents the OLS estimator for cross-section units. Heteroskedasticity and serial correlation are explained using the HAC estimator in equation-8:

$$\hat{V}_{\mathrm{i}T} = \hat{\Gamma}_i(0) + \sum_{j=1}^{T-1} K\left(\frac{j}{M_{\mathrm{i}T}}\right)\left[\hat{\Gamma}_i(j) + \hat{\Gamma}_i(j)'\right] \tag{8}$$

In homogeneity test, if null hypothesis is rejected and alternative hypothesis is accepted, the slope coefficients become heterogeneous. In this case, it is appropriate to prefer second-generation tests. Since the cross-sectional dependence of the series was determined in the study, second-generation panel unit root tests should be used. Cross-sectionally augmented ADF (CADF) and cross-sectionally augmented IPS (CIPS) panel unit root tests developed by Pesaran (2007) were preferred according to the results of the cross-sectional dependency test. Pesaran (2007) proposes the surrogate variables method to eliminate cross-section dependency. This method uses the extended version of ADF unit root test with delayed cross-sectional means. In addition, the first difference of this regression destroys the correlation between units. This approach is known as CADF. Pesaran (2007) uses equation-9 for the CADF unit root test:

$$\Delta y_{i,t} = \alpha_i + \beta_i y_{i,t-1} + u_{i,t} \tag{9}$$

In order to consider the cross-sectional dependence, the error term is defined as in Eq. (10):

$$u_{i,t} = \gamma f_t + \varepsilon_{i,t} \tag{10}$$

f_t, in Eq. (10) shows the unobservable factors. f_t is assumed to be stationary. In this test, the cross-section dependence in the model is due to unobservable factors, and $\Delta\overline{y}_{i,t}$ and $\overline{y}_{i,t-1}$, which express the cross-sectional averages, are added to the model instead of the unobserved common factor. In the absence of autocorrelation in the error term or factor, the CADF regression is as in Eq. (11):

$$\Delta y_{i,t} = \alpha_i + \rho_i y_{i,t-1} + d_0\overline{y}_{t-1} + d_1\Delta\overline{y}_t + \varepsilon_{i,t} \tag{11}$$

$\overline{y}$ in Eq. (7) is the time average of all observations. In case of autocorrelation in the error term or factor, the equation can be expanded as in Eq. (12) by adding the first-order differences of $y_{i,t}$ and $\overline{y}_{i,t}$:

$$\Delta y_{i,t} = \alpha_i + \rho_i y_{i,t-1} + c_i\overline{y}_{t-1} + \sum\nolimits_{j=0}^{p} d_{i,j}\Delta\overline{y}_{t-j} + \sum\nolimits_{j=0}^{p} \beta_{i,j}\Delta y_{i,t-j} + \mu_{i,t} \tag{12}$$

After estimating the CADF regression, the *t*-statistics of the lagged variables are averaged to calculate the CIPS statistic in Eq. (13):

$$\mathrm{CIPS} = \frac{1}{N}\sum_{i=1}^{N} \mathrm{CADF}_i \tag{13}$$

In studies with panel data analysis, it is necessary to choose the cointegration test to be applied in line with the findings obtained after determining the cross-sectional dependence and stationarity. In this direction, Westerlund and Edgerton (2007) Panel LM bootstrap cointegration test was preferred because of the cross-section dependence for the series examined in the study. Westerlund and Edgerton (2007) cointegration test, which is based on the Lagrange multiplier test developed by McCoskey and Kao (1998), considers cross-section dependency. In addition, it was observed that the test gave good results in small samples. The null hypothesis of the test is "There is a cointegration relationship" and the alternative hypothesis is "There is no cointegration relationship." The equation from which the panel cointegration test is derived can be seen in Eq. (14).

$$\gamma_{i,t} = \alpha_i + x_{i,t}'\,\beta_{i,t} + Z_{i,t} \tag{14}$$

$$Z_{i,t} = \mu_{i,t} + V_{i,t}\; V_{i,t} = \sum\nolimits_{J=1}^{t} \eta_{i,j} \tag{15}$$

The *t* index in Eq. (15) represents the time series, *i* the cross-section unit, and $Z_{i,t}$ the error term. The LM statistics of Westerlund and Edgerton (2007) cointegration test testing cointegration for the overall panel in econometric models with LM test bootstrap critical values under cross-section dependency are as follows:

$$\mathrm{LM}_N^{+} = \frac{1}{\mathrm{NT}^2}\sum\nolimits_{i=1}^{N}\sum\nolimits_{t=1}^{t} \hat{\omega}_i^{-2} S_{i,t}^2 \tag{16}$$

In Eq. (16), the partial sum of the $Z_{i,t}$ error term is shown with $S_{i,t}^2$ and the long-run variance of $\mu_{i,t}$ is $\hat{\omega}_i^{-2}$ (Westerlund and Edgerton 2007). In order to estimate the cointegration coefficients between the series, it is necessary to use estimators that take into account the cross-section dependence. In this context, the Common Correlated Effects (CCE) coefficient estimator proposed by Pesaran (2006), which takes into account the cross-sectional dependence, will be used. The basic model of this method is as follows:

$$\gamma_{i,t} = \alpha_i' d_t + \beta_i' x_{i,t} + e_{i,t} \tag{17}$$

In Eq. (17), *d* represents the observed common effects, and *x* represents the explanatory variables. The error

Table 3 Summary statistics and correlation matrix

	EFP	FD	EG	NRE	TO
Mean	3.335512	69.8298	17489.78	78.40704	43.67529
Std. Dev.	2.580364	47.61287	16942.95	11.86098	18.19554
Min	.0608106	11.61185	546.4409	51.31851	15.63559
Max	10.34308	191.5883	58207.58	94.6333	105.5663
Obs	260	260	260	260	260
EFP	1.0000				
FD	0.1644	1.0000			
EG	0.8005	0.4445	1.0000		
NRE	0.3765	0.3014	0.4708	1.0000	
TO	− 0.4529	0.1197	− 0.1177	0.2839	1.0000

terms obtained within the scope of the model are defined as follows:

$$e_{i,t} = \gamma_i' f_t + \varepsilon_{i,t} \tag{18}$$

The expression f in Eq. (17) is the unobservable joint effects vector, and together with the parameter found, it allows the cross-sectional dependence to be allowed. It is determined that there is a relationship between the variables with the cointegration test. The direction of this relationship is determined by the causality test. In our study, Dumitrescu and Hurlin (2012) panel causality test was used, which gives correct results in case of cross-section dependence due to cross-sectional dependence. Dumitrescu-Hurlin (2012) panel causality test can provide accurate results in heterogeneous panels, where N > T or T > N. The linear model in which the test measures the causality relationship between X and Y, and the variables must be stationary in order to determine the relationship between the variables is as follows:

$$Y_{i,t} = \alpha_i + \sum_{k=1}^{K} Y_i^{(k)} Y_{i,t-k} + \sum_{k=1}^{K} \beta_i^{(k)} X_{i,t-k} + \varepsilon_{i,t} \tag{19}$$

K in the model shows the optimum number of delays. The null hypothesis of the test states that there is no causal relationship between the variables, while the alternative hypothesis states that there is a causal relationship.

Table 5 Slope homogeneity analysis

	Model	p values
$\tilde{\Delta}$	12.748	0.000
$\tilde{\Delta}_{adj}$	14.535	0.000

Blomquist and Westerlund (2013) slope homogeneity HAC version was used

Empirical findings

In this part of the study, empirical findings regarding the effect of economic growth and financial development on EFP are given. In accordance with the literature, slope homogeneity and cross-section dependency tests are performed to determine the long-term estimator and causality approach.

Table 3 consists of descriptive statistics and correlation matrix in terms of the variable used in the study. According to the results, there is a strong and positive relationship between economic growth and ecological footprint. Similarly, there is a positive relationship between renewable energy and financial development.

According to Table 4, the findings obtained from the LM, CD_{LM}, and CD tests show that there is no dependence between cross-sections for all the variables. In Table 5, delta tests are performed to detect the presence of slope homogeneity. The results show that there is no slope homogeneity and the null hypothesis is rejected. In other words, it is understood that there is slope heterogeneity in the model.

Pesaran (2007) CADF and CIPS second-generation panel unit root tests, which were developed under cross-section dependence, are used to analyze the stationarity of the series for 10 countries with the highest ecological footprint. In Table 6, panel unit root tests are calculated for the fixed and constant-trend model. According to the results, the findings for fixed and fixed-trend model show that all the variables included in the analysis are not stationary at level, but stationary at the first difference. This confirms that all the variables are integrated at I (mix).

After getting all the variables found stationary at 1st difference, we move to examine the presence of cointegration between the variables. In doing so, the long-term cointegration relationship, which takes into account the cross-section

Table 4 Cross-sectional dependence analysis

Variables	EFP	FD	EG	NRE	TO
Breush-Pagan LM	734.03 (0.000)	406.777 (0.000)	802.149 (0.000)	702.343 (0.000)	515.853 (0.000)
Pesaran scaled CD_{LM}	71.576 (0.000)	37.080 (0.000)	78.756 (0.000)	68.236 (0.000)	48.578 (0.000)
Pesaran CD	14.400 (0.000)	4.819 (0.000)	27.577 (0.000)	− 2.189 (0.028)	11.450 (0.000)

Table 6 CADF and CIPS unit root analysis

Variables	CADF test statistic for constant		CIPS test statistic for constant	
	Level	First difference	Level	First difference
EFP	− 1.322	− 2.931 (0.000)	− 1.089	− 4.755 (0.000)
FD	− 2.017	− 3.632 (0.000)	− 1.485	− 5.741 (0.000)
EG	− 1.532	− 3.453***	− 1.005	− 4.636 (0.000)
NRE	− 1.483	− 3.274***	− 1.573	− 5.851 (0.000)
TO	− 1.319	− 2.876*** (0.000)	− 1.788	− 5.956 (0.000)

dependence, is investigated with the Westerlund-Edgerton (2007) LM bootstrap cointegration test. The bootstrap *p* value from the results in Table 7 should be taken into account in the cross-section dependence between the series. Since the bootstrap *p* value is greater than 0.10, the basic hypothesis of "there is cointegration" of the Westerlund-Edgerton (2007) LM bootstrap cointegration test is accepted. In line with these results, it is understood that the series move together in the long run. In other words, the cointegration test results indicate the existence of a long-term relationship between independent variables and dependent variable. Financial development, economic growth, and changes in commercial activities can affect energy consumption and, therefore, environmental quality in the long term.

After determining the long-term cointegration relationship of the series, the direction of the cointegration of the series in the model and the coefficient estimation are investigated with the CCE estimator, which takes into account the cross-section dependence. According to the CCE estimator panel results in Table 8, the effect of financial development, economic growth, and non-renewable energy consumption on EFP is positive and statistically significant. A 1% increase in financial development, economic growth, and non-renewable energy consumption causes an increase of 0.0555%, 0.0736%, and 0.4951% in EFP, respectively. On other hand, trade openness coefficient is statistically insignificant. As a result, it can be said that increases in financial development and economic growth have a detrimental effect on environmental quality for various reasons that may differ according to countries.

Table 9 shows the CCE estimator results for the impact of country-specific economic growth and financial development on EFP. When the analysis results are examined in

Table 7 Westerlund-Edgerton LM bootstrap cointegration analysis

Model	LM statistic	Asymptotic *p* value	Bootstrap *p* value
LMN^T	11.501	0.000	0.733

the number of bootstrap iteration is 1000. The test result is obtained with the constant and trend models

Table 8 Long-term CCE coefficient estimator

$EFP_{i,t} = \beta_0 + \beta_1 FD_{i,t} + \beta_2 EG_{i,t} + \beta_3 NRE_{i,t} + \beta_2 TO_{i,t} + \vartheta_{i,t}$

Dependent variable: EFP		CCE	
Panel	Coefficient	Standard error	Probability
FD	0.0555	0.0222	0.012
EG	0.0736	0.0426	0.084
NRE	0.4951	0.0119	0.000
TO	− 0.0130	0.0169	0.440
Wald chi^2	27.04		
Prob. > chi^2		0.000	

terms of countries, it is determined that the effect of financial development on EFP is positive and statistically significant in India, Japan, Brazil, Korea, and Turkey. On other hand, there is no significant relationship between financial development and EFP in China, the USA, the UK, Indonesia, and Mexico. In addition, economic growth has a positive and significant effect on EFP in India, Japan, Korea, and Turkey. Similarly, non-renewable energy consumption has a positive and significant effect on EFP in India, Korea, Indonesia, Brazil, and Turkey. In these developing countries, dependence on fossil fuels is relatively high, and the rate of renewable energy in total energy consumption is low. In addition, another common feature of this developing country is that it is less sensitive to the environment than developed countries. The high-willed efforts of developed countries such as the USA and Japan regarding sustainability and the relatively low dependence on fossil fuels have resulted in less negative impact on the environment. Finally, a positive and significant relationship exists between trade openness and EFP for Korea and Japan countries, but no statistically significant relationship is found on EFP for other countries. Generally, in developing countries, economic growth and financial development increase EFP. In other words, developed countries have taken environmental quality into account in the process of economic and financial development. However, it can be thought that developing countries such as Brazil, Turkey, and India ignore environmental quality for reasons such as lack of capital and providing competitive advantage in their economic growth and financial development processes. It can also be said that in the first stage of development, policy makers in this country are more interested in ensuring growth rather than clean environment. This may cause these countries to import cheap and highly polluting technologies to increase production. From this, it can be interpreted that the developed countries have higher environmental awareness.

The findings regarding the effect of financial development on ecological footprint in the long run show similarities with Javid and Sharif (2016), Pata (2018), Baloch et al. (2019),

Table 9 Long-term CCE coefficient estimator analysis

$EFP_{i,t} = \beta_0 + \beta_1 FD_{i,t} + \beta_2 EG_{i,t} + \beta_3 NRE_{i,t} + \beta_2 TO_{i,t} + \vartheta_{i,t}$

		Coefficient	Standard error	Probability
China	FD	0.0370616	0.0592304	0.531
	EG	− 0.0176857	0.0550233	0.748
	NRE	0.027277	0.0537694	0.612
	TO	− 0.06037	0.0447293	0.177
USA	FD	0.0693699	0.1181318	0.557
	EG	0.2582943	0.1949255	0.185
	NRE	0.0394326	0.0859974	0.647
	TO	− 0.056286	0.1454259	0.699
India	FD	0.2630929	0.121059	0.030
	EG	0.1953113	0.1175855	0.097
	NRE	0.6805533	0.3335192	0.041
	TO	− 0.0260404	0.1673677	0.120
Japan	FD	0.0379569	0.0226896	0.094
	EG	0.133458	0.0522674	0.011
	NRE	0.048536	0.0688112	0.481
	TO	0.0677557	0.0380368	0.075
Brazil	FD	0.70394268	0.0136768	0.004
	EG	0.0122646	0.0145521	0.399
	NRE	0.0633855	0.0366675	0.063
	TO	0.013347	0.0284403	0.639
Indonesia	FD	− 0.0076153	0.0103234	0.461
	EG	0.0308722	0.0204531	0.131
	NRE	0.0764369	0.0399154	0.055
	TO	− 0.0001581	0.0309963	0.996
Mexico	FD	− 0.0179255	0.0345417	0.604
	EG	0.0249436	0.0353381	0.480
	NRE	0.0875399	0.0639653	0.171
	TO	− 0.0190881	0.0325552	0.558
Korea	FD	0.0882834	0.0539226	0.099
	EG	0.0755329	0.0387711	0.051
	NRE	0.073055	0.0744959	0.097
	TO	0.2309592	0.1304368	0.077
Turkey	FD	0.1982263	0.1079165	0.066
	EG	0.1783244	0.0692407	0.010
	NRE	0.2620851	0.1863646	0.023
	TO	− 0.0410414	0.0805038	0.610
UK	FD	0.095788	0.0839808	0.254
	EG	0.1066223	0.1018032	0.295
	NRE	0.0856094	0.0885670	0.334
	TO	0.0048840	0.0982450	0.960

Kihombo et al. (2021), Ahmed et al. (2021), and Ngoc and Awan (2022). On other hand, they contradict with the results of Akinsola et al. (2022) and Majeed and Mazhar (2019). In addition, findings on the effect of economic growth on ecological footprint are consistent with Baloch et al. (2019), Ahmed et al. (2021), Kihombo et al. (2021), Dogan and Shah (2022), Akinsola et al. (2022), and Ngoc and Awan (2022). However, our results contradict with Ansari et al. (2022).

Table 10 Dumitrescu-Hurlin (2012) panel causality analysis

	W-statistic	*Z*-bar statistic	Probability
EFP↛ FD	1.29780	0.37226	0.7097
FD↛ EFP	3.68346	4.86207	0.0000
EG↛ EFP	5.84873	8.93709	0.0000
EFP↛ EG	3.06114	3.69085	0.0002
NRE↛ EFP	4.58903	6.56634	0.0000
EFP↛ NRE	3.15744	3.87209	0.0001
EFP↛ TO	1.86574	1.44112	0.1496
TO↛ EFP	3.86147	5.19709	0.0000

the maximum lag length is taken as 2. *** indicates 1% significance level

After determining the cointegration relationship, the causality relationship of the series which are analyzed with Dumitrescu and Hurlin (2012) panel causality test are shown in Table 10. Dumitrescu-Hurlin (2012) panel causality test can provide accurate results in heterogeneous panels, where N > T or T > N. According to Table 10, a unidirectional causality relationship from financial development to EFP has been determined. These results are consistent with Kihombo et al. (2021) for WAME countries. On other hand, Majeed and Mazhar (2019) found bidirectional causality between financial development and EFP for 131 countries. Similarly, Akinsola et al. (2022) determined a bidirectional causality between financial development and EFP in Brazil. Additionally, Shahbaz et al. (2013b), Abbasi and Riaz (2016), Javid and Sharif (2016), and Shahzad et al. (2017) have provided evidence for unidirectional causality from financial development to carbon emissions, another environmental indicator.

There is a bidirectional causality relationship between economic growth and EFP. These results are akin to Destek and Sarkodie (2019), Ahmed et al. (2021), Zeraibi et al. (2021), Kihombo et al. (2021), Akinsola et al. (2022), Dogan and Shah (2022), and Saqib (2022). In addition, Zhang (2011), Shahbaz et al. (2013a), and Shahbaz et al. (2013b) found bidirectional causality between carbon emissions and economic growth. However, unlike our findings, Jalil and Feridun (2011) and Shahbaz et al. (2013c) have demonstrated a unidirectional causality from economic growth to carbon emissions. Apart from these studies, Javid and Sharif (2016) revealed unidirectional relationship from carbon emissions to economic growth for Pakistan and Shoaib et al. (2020) for D8 and G8 countries. On other hand, there is bidirectional causality between EFP and non-renewable energy consumption. Another important finding obtained in the study is a unidirectional causality relationship from trade openness to EFP.

Conclusion, implication, and future directions

In this study, the effect of economic growth and financial development on ecological footprint has been examined. The data from 10 countries with the largest EFTs for the period of 1992–2017 is used. Non-renewable energy consumption and trade openness are included as additional explanatory variables. In order to test the stationarity properties of the variables, CADF and CIPS unit root tests are applied. The relationship between the variables was investigated by applying Westerlund and Edgerton (2007) Panel LM bootstrap cointegration test. Long-run elasticity coefficients are obtained from the CCE estimator and causality relationship which are obtained from the Dumitrescu and Hurlin (2012) panel causality test.

According to the results, financial development, economic growth, and non-renewable energy use play an important role in environmental quality. In other words, financial development, economic growth, and the use of non-renewable energy increase environmental degradation by increasing EFP. On other hand, for the 10 countries with the highest EFP, the effect of trade openness on environmental quality is statistically insignificant. In the countries examined in the study, financial development, economic growth, and non-renewable energy have a detrimental effect on environmental quality. In order to achieve sustainable development, it is important to allocate funds to well-developed financial institutions and research and development, to encourage green finance and to facilitate the development of financial institutions. For this reason, it would be beneficial for policymakers to direct financial resources to green energy production and consumption and to encourage and support projects and practices. In addition, the finding that non-renewable energy consumption plays an important role in the deterioration of environmental quality can be considered as an important policy proposal in the countries included in the analysis, giving priority to investments in renewable energy sources and minimizing environmental degradation.

Today, the increase in the interest in the use of renewable energy sources has been influential in the fact that fossil-based energy sources are limited in the world, causing environmental problems and increasing the foreign dependency of production in countries. In terms of the sustainability of economic growth and financial development, especially developing countries should focus on more clean energy investments in order to reduce foreign dependency. In these countries, instead of old technologies based on fossil fuel consumption, environmentally friendly technologies should be used, and these activities should be supported by the state, and investments should be made in this field. On the other hand, giving priority to investments in renewable energy sources and minimizing environmental degradation can be considered as an important policy proposal in the countries included in the analysis.

The study has suggestions for similar studies to be conducted in the future. This study focused on the determinants of ecological footprint in terms of countries with the highest EFP. In future studies, since the number of empirical studies on the determinants of EFP according to carbon emissions is quite low, similar studies can be conducted for different country groups, contributing to the expansion of the literature. In addition to the model developed in the research, the mediating role of the effects of variables such as technological innovation, natural resources, globalization, and urbanization on environment may be examined. Designing these proposals into consideration in future studies may allow the development of more detailed policy proposals for the improvement of environmental quality.

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Data availability The data that has been used is confidential.

Declarations

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