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ORIGINAL RESEARCH

Examining the Role of Remittances, Technological Innovation, and Foreign Direct Investment on Environmental Quality in Pakistan: Fresh Evidence from a Novel Dynamic ARDL Simulation Approach

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Abstract

This study investigates the effect of remittances, financial sector development, and technological innovation, while also taking into account the foreign direct investment and economic growth on environmental quality by using its more comprehensive proxy, ecological footprint, and by focusing on yearly data from 1990 to 2021 in the context of Pakistan. To this purpose, we used the autoregressive distributed lag (ARDL) cointegration technique with the dynamic simulated ARDL approach. Further, the study also used the Frequency Domain Causality (FDC) test to investigate the potential causality between research variables at various time frequencies. The results of cointegration test show a long-term cointegration association among the considered variables. Further, the empirical findings demonstrate a negative association between remittances and ecological footprint, thus suggesting that remittances betters the environmental quality. Similarly, technological innovation enhance the environmental quality of Pakistan by lowering the level of ecological footprint. Besides, financial development, economic growth, and foreign direct investment degrade environmental health by rising the ecological footprint. Finally, the outcomes of FDC analysis indicate that the ecological footprint is granger caused by the considered research variables. These findings can help government and policymakers to develop effective policies to reduce environmental degradation and achieve long-term socioeconomic development.

Keywords Ecological footprint · Remittances · Financial development · Technological innovation · Dynamic simulated ARDL model (DARDL)

JEL Classification F24 · G20 · O30 · Q57

1 Introduction

Over the past few decades, the world has seen a rise in environmental degradation that has resulted in many ecological problems, including climate change, deforestation, water wastage and shortage (Ulucak et al., 2019). Carbon dioxide (CO_2) emissions represent the main source of environmental contamination as well as a fundamental objective

Extended author information available on the last page of the article

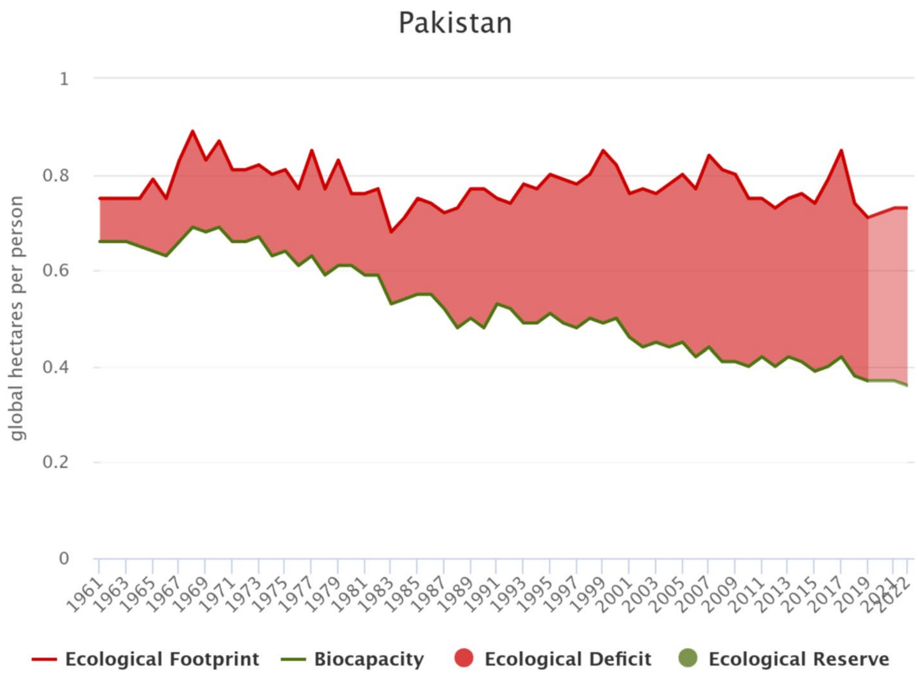


Fig. 1 Pakistan biocapacity (1961–2022). *Source*: Global Footprint Network (2022)

of the Sustainable Development Goals. Pakistan has transformed from an agrarian-based economy to an industrialized economy during the last three decades. Researchers investigated and documented a wide range of environmental quality factors as well as sources to improve the environmental quality around the world. Remittances, technological innovation, and financial development, among others, obtained significant attention as major predictors of environmental sustainability. On the other hand, many researchers have looked at the factors that affect environmental quality by utilizing CO_2 emissions as an indicator of environmental health (Adedoyin et al., 2020; Wang et al., 2017; Adebayo & Odugbesan, 2021; Chen et al., 2023). However, CO_2 emissions, which constitute a large amount of greenhouse gases, might not accurately measure environmental deterioration (Solarin & Bello, 2018). Further, CO_2 emissions also ignore resources including forests, oil, mining, fishing grounds, and soil (Ulucak & Apergis, 2018). On the contrary, ecological footprint (EFP) is considered the most comprehensive indicator to measure ecological sustainability, and researchers have started looking into the factors that influence it (Galli et al., 2012; Ahmed et al., 2020a).

The EFP has six different categories of biocapacity lands that jointly express the general idea of environmental quality, including forest, farming, fishing, grazing, built-up lands and carbon footprint. Furthermore, EFP is also a thorough accounting tool that is used to determine how much natural resources are needed to produce everything that is consumed as well as to manage waste material produced by humans (Javed et al., 2023b; Khalid et al., 2020; Wang & Dong, 2019). The biocapacity of Pakistan is estimated at 0.3 gha per capita, whereas its EFP is 0.7 gha per capita, as reported by the Global Footprint Network (2022). In 2021 Pakistan registered an ecological deficit of 0.3 gha per capita, as shown in Fig. 1; however, for sustainability, the EFP must be lower than biocapacity.

The development of new technologies is widely considered a key factor in the fight against environmental degradation (Chen & Lee, 2020; Javed et al., 2023b; Sohag et al., 2015; Yu & Du, 2019). It plays an essential part in reducing environmental degradation and promoting sustainable growth. Numerous factors, such as social, political, and financial ones, have an impact on technological innovation's ability to improve the environment. Given environmental concerns, the private and public sectors are working harder to create new technologies that can support environmentally friendly and clean production methods. Therefore, such actions may result in higher economic growth with less environmental loss. A high level of technological innovation could also hasten the adoption of clean energy to fulfil the demand for rising energy and alter the energy consumption structure. Furthermore, if given enough attention and importance, technological innovation can aid in achieving sustainable growth by increasing the efficiency of natural resources (Song et al., 2019). Many researchers have highlighted the interlinkage between technological innovation and environmental sustainability (Ali et al., 2016; Mensah et al., 2018; Hao et al., 2020; Demir et al., 2020; Ibrahiem, 2020).

Remittances represent a considerable source of income for developing nations, such as Pakistan, and a recent increase in global migration can further increase remittances in the future. Pakistan is the second-highest recipient of remittances in South Asia. From 2019 to 2020, remittances raised by 17% in Pakistan, which received $26.11 billion in remittances from around the world (World Bank, 2020). whereas remittances increased by 26% in 2021, reaching 33 billion dollars. This rise in remittances affects household income, which influences the economy's consumption and saving rates, which automatically leads to economic growth. Remittances help with the economy's financial growth because they are personal transfers that will stimulate financial activity. Increased output and investment require massive energy consumption, and Pakistan continues to rely extensively on traditional energy sources. Thus, more remittances put pressure on energy demand and ultimately degrade the environment. A significant number of economic outcomes, including financial development (Olayungbo and Quadri, 2019), technological innovations (Tshikala et al., 2019), the inflow of foreign investment (Basnet & Upadhyaya, 2014) and economic development (Chowdhury, 2016), are positively impacted by remittances, which constitute a significant source of foreign capital. Thus, remittances help the financial industry by providing funding and loans to environment-friendly technology investors (Yang et al., 2020).

Furthermore, the connection between financial sector growth and environmental performance has become more crucial in recent years due to the growing interest in green finance. Besides, financial development lowers environmental contamination through funding research and development projects, eco-friendly technologies, and offering firms fiscal and technical support. According to Khan (2008), financial development essentially causes Pakistan's economic growth, which in turn increases environmental deprivation. Contrary to this, the State Bank of Pakistan (SBP) has carried out some steps to reduce economic stress by fostering clean investment initiatives. SBP and the International Finance Corporation (IFC) have signed an agreement to make green financing easier (Mumtaz and Smith, 2019).

The primary objective of the present work is to explore the role of REM, FD, TI, FDI, and GDP on environmental quality (EFP) in Pakistan by focusing on yearly data from 1990 to 2021. To this purpose, we use the ARDL cointegration approach with the novel dynamic simulated ARDL model. The present research contributes to the existing literature in several dimensions. First of all, most of the earlier researchers have broadly utilized CO_2 emissions as an environmental indicator, even many researchers have mainly criticized this choice for its incomplete nature (Brown et al., 2020;

Rahman et al., 2019; Sharma et al., 2019). To the authors' best knowledge, this is the first empirical study to employ the most comprehensive proxy of environmental quality, namely ecological footprint, to investigate the dynamic interconnections among the research variables in the case of Pakistan, in order to provide more practical policy suggestions that could potentially reduce the environmental damage. Secondly, most of the empirical studies have applied time series data tools, such as the ARDL model recommended by Pesaran et al., (2001). Differently from previous studies, this work employs a novel dynamic simulated ARDL (DARDL) methodology pioneered by Jordan and Philips (2018), thus being the first study to use this approach to analyze the positive and negative effects of REM, TI, FD, FDI, and GDP on the EFP in Pakistan. This approach estimates, stimulates and visualizes graphs of fluctuations (both negative and positive) in variables in addition to showing the relationships among them. Though, the traditional ARDL model only approximates short- and long-run connections between the explained and explanatory factors of the study.

The rest of the study is organized as follows. Section 2 evaluates the relevant previous studies. Section 3 illustrates the data used and introduces the econometric model. Further, Sect. 4 describes the methodology applied. Section 5 presents and discusses the results obtained, and Sect. 6 concludes and provides policy implications.

2 Literature Review

2.1 Theoretical Background

Many researchers have extensively analyzed the factors that promote environmental deterioration. Apart from these factors, economic growth (GDP) is one of the main promoters of environmental deterioration. For instance, higher energy consumption for production is required for increased GDP. In the end, increased GDP results in a deteriorated environment. However, for an emerging country like Pakistan, the role of REM, TI, and FD which have gained considerable attention and represent the determining factors of environmental qualityhas not yet been empirically investigated. Figure 2 presents a theoretical framework that shows the impacts of these factors on environmental health.

An increase in production activities within an economy increases economic expansion with the support of ecologically friendly technologies, which lead to enhanced energy efficiency and, as a result, improved environmental conditions. Moreover, remittances boost the income and savings of the household as well as accelerates the demand for goods and services, which in turn speeds up production (De & Ratha, 2012). Further, rise in the industrial production directly correlates to the rise in energy consumption. There may be negative impacts on the environment performance due to the resulting high energy demand (Yang et al., 2020). Several researchers argue that TI can increase energy efficiency leading to a decrease in overall energy usage or for fossil fuels (Wang and Wang, 2020; Jin et al., 2018). The growth of the financial system can also help by providing bank loans to green industries. Further, remittances accelerate the financial sector development. This demonstrates that remittances may reduce environmental hazards if remitted funds are invested in clean and energy-saving technologies that reduce pollution and energy usage.

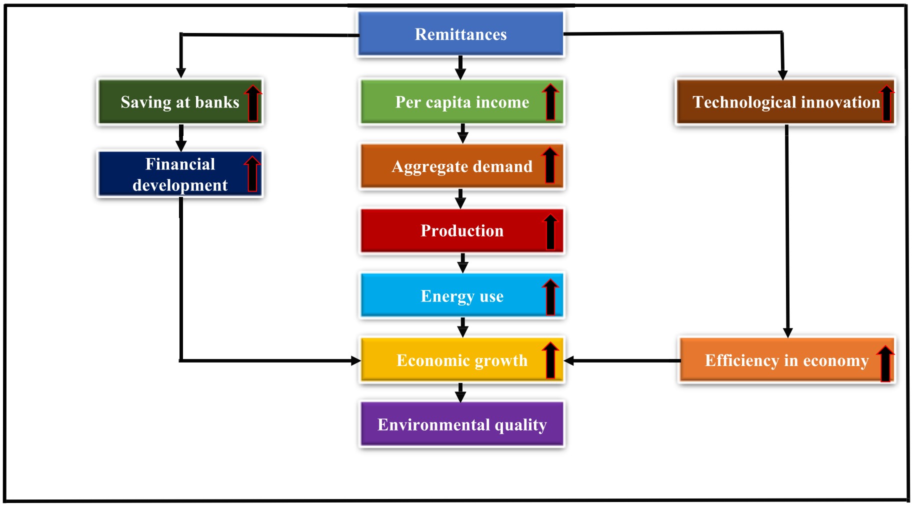


Fig. 2 Theoretical framework. *Source*: Ahmad et al., 2019; Villanthenkodath & Mahalik, 2020

2.2 Empirical-Related Literature

During the last few decades, the association among remittances, financial development, technological innovation, economic development, inflow of foreign direct investment, and quality of the environment has attracted the attention of both academicians and policy makers. Several studies have highlighted the influence of these factors on the environment. Nevertheless, the conclusions of these researchers are inconsistent and unclear. For better understanding, the current study split the literature into five parts. In the first part, we present the studies which have demonstrated the influence of remittances on the environment. The second part concentrates on the correlation between FD and environmental health. In the third and fourth part, we discuss the relationship between TI and FDI with environmental performance, respectively. The last part emphasizes the connection between GDP and environmental performance.

Firstly, by focusing on the earlier studies which demonstrates the effect of remittances on the environmental performance, we noted that REM are regarded as a key aspect in determining the level of income and play a substantial role in intensifying economic development (Glytsos, 2005; Meyer & Shera, 2017). An increase in remittances increases demand for financial institutions, which could lead to further environmental deprivation. Many researchers have studied the relationships between REM and environmental performance (e.g., Sharma et al., 2019; Rahman et al., 2019; Neog & Yadava, 2020; Villanthenkodath & Mahalik, 2020; Brown et al., 2020; Yang et al., 2020; Zafar et al., 2022; Chishti, 2023; Umair et al., 2023). For example, Yang et al., (2020) utilized the GMM estimation technique to analyze the effect of REM on CO_2 emissions by using panel data from 97 global economies ranging from 1990–2014. They claimed that REM deteriorate the environment. Similar to this, Rahman et al., (2019) detected a beneficial impact of REM on the environment in Sri Lanka, Pakistan, and the Philippines, however, noted an insignificant impact in the context of China and India. On the contrary, Jamil et al., (2021) analyzed the G20 countries for the period 1990–2019 and revealed that REM degrade environmental health. Zhang et al., (2022) looked at the correlation between remittances and EFP in the top 10 remittance receiving nations. According to their findings, remittances are good for the environment. Usman and Jahanger (2021) investigated the linkage between REM and environmental quality, concluding that REM harm the environment. Neog and Yadava (2020) examined how remittances and environmental sustainability are related. Their analysis revealed that negative shocks in remittances accelerate environmental destruction. Sharma et al., (2019) explored the correlation between REM and environmental performance in Nepal and found a negative connection. In the case of Ethiopia, Usama et al., (2020) revealed an adverse connection between REM and environmental degradation. Further, Ali et al., (2022) examined the impact of REM on CO_2 emissions in Pakistan and discovered that REM enhances the environmental degradation. Similarly, Ahmad et al., (2022) examined the linear and non-linear impacts of REM on the CO_2 emissions in Pakistan. They discovered that positive shocks in REM degrades the environmental quality, while the negative shocks mitigates the environmental degradation.

Secondly, with respect to the association between FD and the environment, some studies show that FD contributes significantly to enhancing environmental quality since investors are encouraged to install clean technology and energy-efficient techniques in affordable and simple availability of credit facilities. Al-Mulali et al., (2015), discovered that the financial sector growth enhances environmental sustainability. Zafar et al., (2019) considered the association between FD and environmental sustainability in the OECD nations and established that FD promotes environmental sustainability. Paramati et al., (2017) employed G-20 countries data and revealed that financial sector expansion increases environmental damage. However, after dividing the sample into two income groups, the authors proposed that the financial sector growth promotes environmental sustainability in developed nations. However, they observed opposite results in developing nations. Ngoc and Awan (2022) studied the impact of FD on EFP in Singapore. Their outcomes explained that FD enhances ecological deficit. Nguyen et al., (2020) showed that environmental deprivation is an outcome of financial development in G-20 countries. According to the work by Acheampong et al., (2020), environmental factors in industrialized and developing nations respond differently to financial development. They discovered that financial development benefits the environment in industrialized nations while hastening environmental degradation in less developed nations. Cetin et al., (2018) shown that Turkey's financial prosperity has resulted in environmental damage. Similarly, Nasir et al., (2019), revealed that environmental damage in the Philippines, Singapore, Indonesia, Thailand, and Malaysia is a result of financial development. Further, Baloch et al., (2019) documented that the poor environment in Belt and Road counties is also a result of financial sector growth. In a similar way, Sehrawat et al., (2015) explained for the Indian economy that financial development harms the environment. Komal and Abbas (2015) also showed similar findings for Pakistan.

Thirdly, many researchers have inspected the connection between environmental performance and technological innovation. However, they register conflicting results due to different methodologies and sample size. The first set of studies asserts that technological innovation significantly reduces environmental degradation. A few examples include Mensah et al., (2018), Hao et al., (2020), Ali et al., (2016), Demir et al., (2020), and Ibrahiem (2020). Kumail et al., (2020) evaluated the association between TI and the environmental health in the context of Pakistan and discovered that TI boost Pakistan's environmental health. Similar findings were presented by Töbelmann and Wendler (2020), who also demonstrated that TI leads to environmental benefits. Li and Wang (2017) evaluated the linkage between TI and the environmental health for the period 1996–2007 in 95 different nations, and they discovered that TI improves environmental conditions. Ahmad et al., (2020) evaluated the influencing factor of EFP by utilizing data from rising nations from 1984 to 2016.

Their results demonstrated that TI had a detrimental impact on the environment. This conclusion is also endorsed by Shahbaz et al., (2018) in France and Lin and Zhu (2019) for Chinese provinces. Furthermore, Usman and Hammar (2021) analyzed the effect of TI on the environment in APEC nations. They showed that TI substantially degrades the environmental quality. Villanthenkodath and Mahalik (2020) observed the connection between TI and the environment and provided evidence that TI harms the ecosystem in India. Other studies examined the linkage between TI and the environmental health and claimed that the quality of the environment is negatively impacted by TI (Cheng et al., 2019; Gu & Wang, 2018; Kivyiro & Arminen, 2014; Yongping, 2011). Similarly, BRICS countries experienced significant environmental degradation while employing innovative economic practices (Khattak et al., 2020).

Fourthly, the association between FDI and environmental deprivation has received considerable attention in recent years, due to ecological problems and global warming (York, 2007). Numerous researchers have empirically analyzed the influence of FDI on environmental performance. However, these studies show different and ambiguous results. For example, various studies have discovered a favorable linkage between FDI and the environmental health (Ali et al., 2020; Haug & Ucal, 2019; Shahbaz et al., 2018); however, some studies revealed an adverse connection between them (Jiang et al., 2018; Tang and Tan, 2015; Javed et al., 2023c). Bakhsh et al., (2017) examined the association between FDI, GDP and environmental health and showed that environmental degradation in Pakistan is exacerbated by foreign direct investment. Similarly, Lau et al., (2014) showed that FDI enhanced environmental contamination in Malaysia. Baloch et al., (2019) evaluated the connection between FDI and the EFP in 50 nations and demonstrated that the pollution haven theory is true in examined countries. Further, Liu and Kim (2018) claimed that there is a string correlation between EFP and foreign direct investment. A similar association in the context of China is also reported by Khan et al., (2020). The favorable linkage between FDI and the EFP in Organization of Islamic Cooperation (OIC) nations was also supported by Ali et al., (2020). Besides, Zhang and Zhou (2016) analyzed the effects of FDI on CO_2 emissions in 29 Chinese provinces and exposed that FDI lower the level of emissions. Moreover, Solarin and Al-Mulali (2018) assessed the association between FDI and environmental performance in 20 nations and found no statistically significant association. On the contrary, a negative linkage between FDI and the EFP was discovered by Ahmed et al., (2020b) and Zafar et al., (2019) which indicates that FDI help in lowering environmental deterioration.

Finally, with regard to the association between environmental quality and economic development, many scholars have documented the correlation between GDP and environmental pollution. However, the findings of those studies gave mixed results. Some studies, for example, discovered that economic growth hastens environmental deterioration (Liu & Kim, 2018; Khan et al., 2019a; Adedoyin et al., 2020; Sethi et al., 2020; Baz et al., 2020; Sharif et al., 2020; Javed and Rapposelli, 2023). On the contrary, other researchers found negative outcomes, such as Wang et al., (2021) and Dogan and Aslan (2017).

After reviewing the most relevant studies, it is evident that the connection between REM, FD, TI, FDI, GDP, and EFP is a hot topic. However, the literature mentioned above demonstrates that there is little debate regarding the connections between remittances, financial development, technological advancement, foreign direct investment, and EFP in the context of Pakistan. Additionally, it is possible to note that the ARDL technique is typically used to examine this relationship. As a result, the dynamic ARDL simulation methodology is used in this study as a methodological breakthrough. Due to its modification and use of both short and long-term estimations as well as the counterfactual variations (positive and negative shocks), the DARDL approach used in this study is better than traditional ARDL and other time series applications. Hence, this research intends to fill a considerable gap in the current literature on both the choice of country to analyze and the econometric approach to apply.

3 Data and Model

This work investigates the effect of REM, FD, TI, FDI, and GDP on the EFP in Pakistan by using yearly data from1990-2021. The chosen time period is based on the data accessibility. The dependent variable EFP is computed by aggregating six factors (built-up land, grazing land, forest products, agriculture area, fishing grounds, carbon footprint) and is measured in global hectare per capita (see Fig. 3). By focusing on the regressors, remittances are computed as the total personal inflows of remittances received (measured in US dollars), financial sector growth is defined as index of financial development, technological innovation is defined as the number of patents, foreign direct investment is defined as the net inflow as percentage of GDP, and economic growth is measured as per capita GDP at constant 2010 US dollars. Data regarding ecological footprint and technological innovation were obtained from Global Footprint Network (2022) (GFN) and World Intellectual Property Organization (WIPO), respectively. Financial development index data is collected from the International Monetary Fund (IMF). Further, the remaining data were extracted from the World Bank indicators (WDI) database. Table 1 represents the measurement of the utilized variables Further; Fig. 4 depicts the six-stage econometric process used in this investigation.

In order to eliminate heteroscedasticity problems, the values of variables (EFP, REM, TI, and GDP) have been transformed into logarithmic form. Table 2 illustrate the descriptive features of the examined variables for all the years considered and Table 3 reports the Pearson

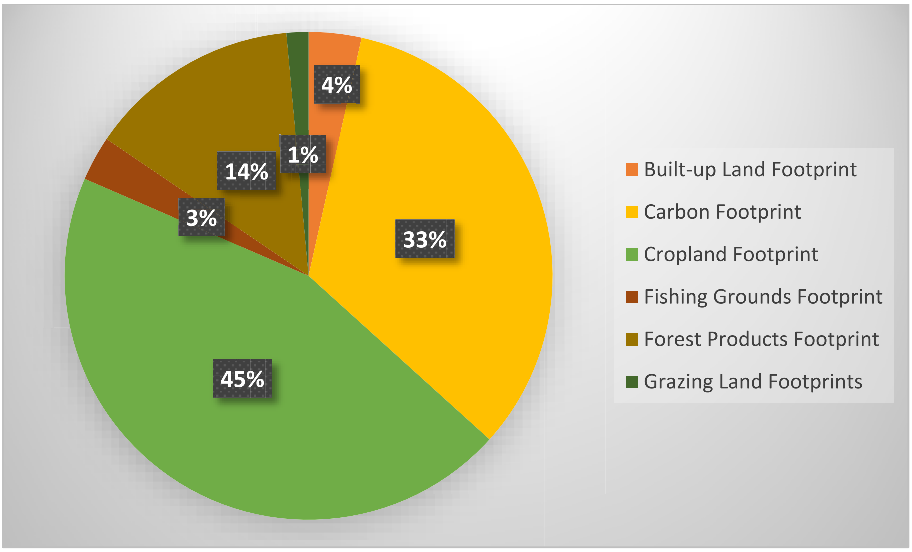


Fig. 3 Ecological footprint by land type. *Source*: Global Footprint Network, 2022

Table 1 Variables description

Variables	Symbol	Measurement	Source
Ecological footprint	EFP	Global hectares per capita (gha/person)	GFN
Remittances	REM	Remittances received (current US$) and deflated by using GDP deflator	WDI
Financial development	FD	Financial development index	IMF
Technological innovation	TI	Patent applications (resident)	WIPO
Foreign direct investment	FDI	Net inflows (% of GDP)	WDI
Gross domestic product	GDP	Per capita (constant 2010 US$)	WDI

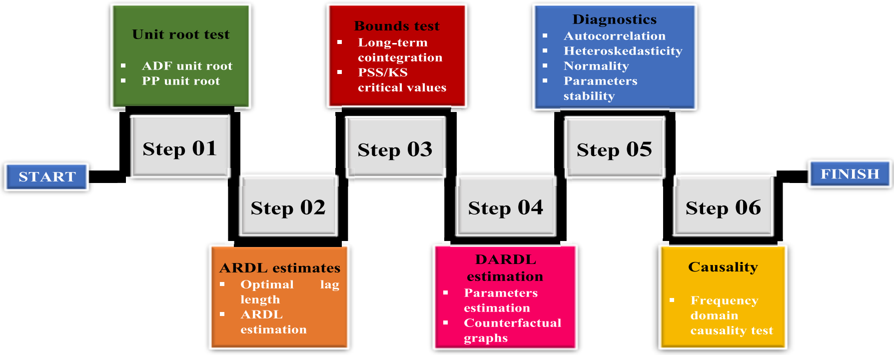


Fig. 4 Estimation strategy flowchart

Table 2 Descriptive statistics

	EFP	REM	FD	TI	FDI	GDP
Mean	−0.258	23.304	0.237	6.862	0.955	7.087
Median	−0.259	23.431	0.216	6.850	0.716	7.109
Maximum	−0.167	24.000	0.371	7.460	3.036	7.375
Minimum	−0.349	21.969	0.121	6.261	0.310	6.857
Std. dev	0.045	0.466	0.076	0.301	0.669	0.160
Skewness	0.240	−1.246	0.119	−0.173	1.974	0.338
Kurtosis	2.574	4.190	2.123	2.514	6.113	1.860
Jarque–Bera	0.549	10.167	0.101	0.475	33.709	2.341
Probability	0.760	0.006	0.577	0.789	0.002	0.789
Obs	32	32	32	32	32	28

correlation coefficient results between these variables. We may observe a positive connection between most of the study variables. On the contrary, REM and GDP shows a negative relationship with EFP. Further, Fig. 5 presents the trend plots for all the variables.

The econometric model we built to examine the correlation between the considered research factors is specified as below:

$$lnEFP_t = \beta_0 + \beta_1 lnREM_t + \beta_2 FD_t + \beta_3 lnTI_t + \beta_4 FDI_t + \beta_5 lnGDP_t + \varepsilon_t \tag{1}$$

Table 3 Correlation matrix

	EFP	REM	FD	TI	FDI	GDP
EFP	1.000					
REM	−0.479	1.000				
FD	0.419	−0.527	1.000			
TI	0.298	−0.486	0.907	1.000		
FDI	0.458	−0.041	0.505	0.556	1.000	
GDP	−0.314	0.498	0.109	0.194	0.024	1.000

where EFP_t denotes the ecological footprint, REM_t denotes the remittances, FD_t denotes the index of financial development, TI_t signifies the technological innovation, FDI_t indicates the foreign direct investment, GDP_t denotes the per capita GDP and ε_t indicates the error term.

4 Methodology

4.1 Bounds Testing Approach

We evaluated the presence of the long-term cointegration connection between the research factors by utilizing the ARDL cointegration technique. Based on the research hypothesis, the model we used to examine the long-term association is stated as below:

$$\begin{aligned}\Delta lnEFP_t = {} & \theta_0 + \theta_1 lnEFP_{t-1} + \theta_2 lnREM_{t-1} + \theta_3 FD_{t-1} + \theta_4 lnTI_{t-1} \\ & + \theta_5 FDI_{t-1} + \theta_6 lnGDP_{t-1} + \sum_{i=1}^{p} \beta_1 lnEFP_{t-1} + \sum_{i=1}^{q} \beta_2 lnREM_{t-1} + \sum_{i=1}^{q} \beta_3 FD_{t-1} \\ & + \sum_{i=1}^{q} \beta_4 lnTI_{t-1} + \sum_{i=1}^{q} \beta_5 FDI_{t-1} + \sum_{i=1}^{q} \beta_6 lnGDP_{t-1} + +\varepsilon_t\end{aligned} \tag{2}$$

where Δ stands for the first difference. Additionally, based on Akaike Information Criteria (AIC), t-1 represents the optimal lag options. θ and β are analysed for long-term cointegration among variables. If long-term cointegration exists, we examine long and short-term relationships. The null (H_0) and alternative (H_1) hypotheses of ARDL bounds test cointegration are explained as follows:

$$H_0 = \theta_1 = \theta_2 = \theta_3 = \theta_4 = \theta_5 = \theta_6 = 0$$

$$H_1 \neq \theta_1 \neq \theta_2 \neq \theta_3 \neq \theta_4 \neq \theta_5 \neq \theta_6 \neq 0$$

The F-statistic value is examined is to govern whether or not H_0 is rejected. Following the Pesaran et al., (2001) a long-run relationship exists between the research factors if the F-statistic computed value is higher than the upper bound threshold, while no relationship exists if the calculated value is less than the lower bounds threshold value. However, if the computed value is inside the minimum and maximum threshold boundaries, the results are inconclusive.

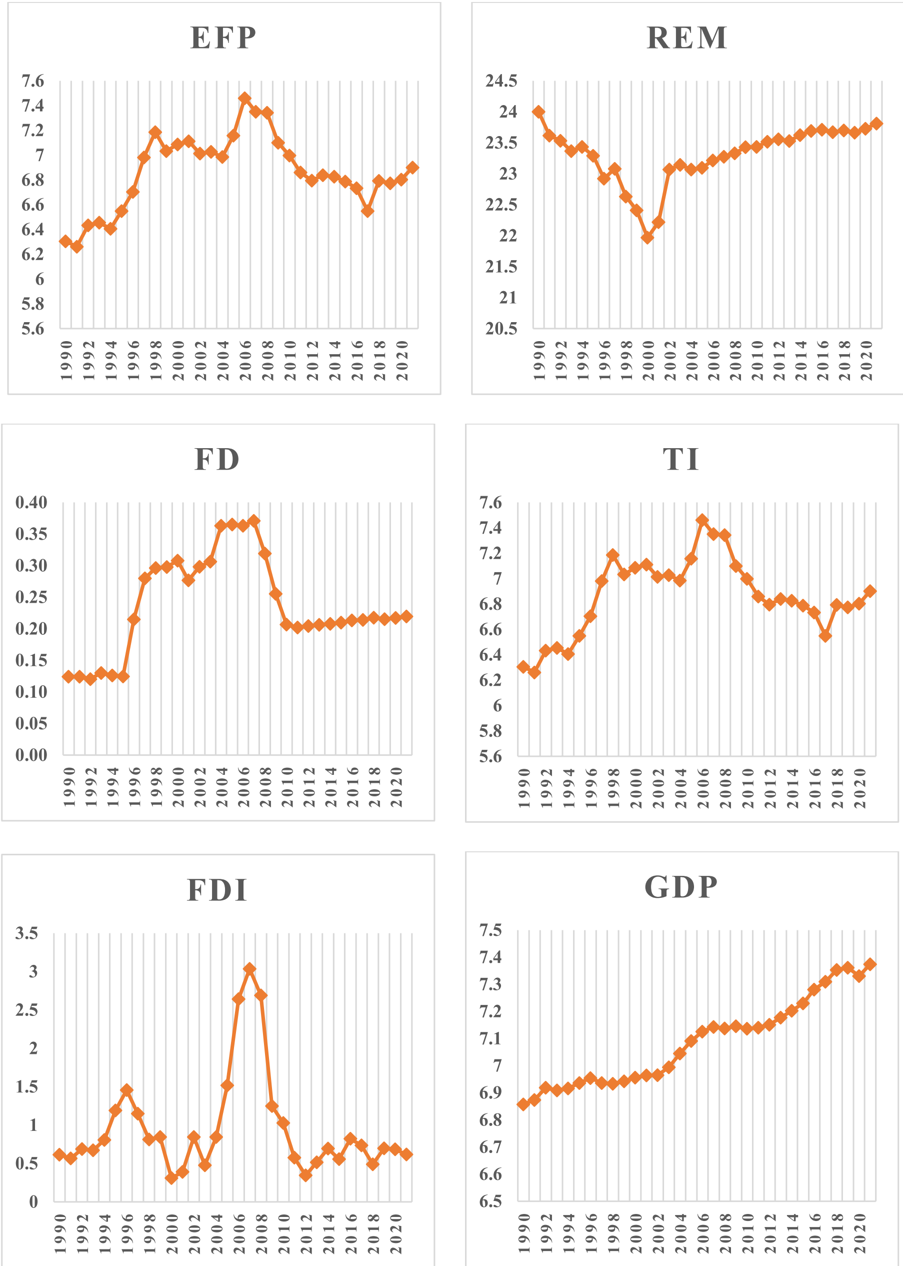


Fig. 5 Time trends plots

4.2 Autoregressive Distributed Lag (ARDL) Model

We apply the ARDL model of Pesaran et al., (2001). This approach has several benefits in contrast with other methods. The short-term data can be used with the ARDL approach

(Haug, 2002). This model can be employed in situations in which the regressors are integrated at order I(0) and I(1), or a mixture of them. Both explained and explanatory variables can use multiple lags. In order to explore the long-run association among the research factors, the ARDL model that is used is as follows:

$$\begin{aligned}\Delta lnEFP_t = \alpha_0 + \sum_{i=1}^{p} \sigma_1 lnEFP_{t-i} + \sum_{i=1}^{q} \sigma_2 lnREM_{t-\mathrm{i}} + \sum_{i=1}^{q} \sigma_3 FD_{t-\mathrm{i}} + \sum_{i=1}^{q} \sigma_4 lnTI_{t-\mathrm{i}} \\ + \sum_{i=1}^{q} \sigma_5 FDI_{t-\mathrm{i}} + \sum_{i=1}^{q} \sigma_6 lnGDP_{t-\mathrm{i}} + + \varepsilon_t\end{aligned} \tag{3}$$

where σ denotes the long-term fluctuation of variables. The Akaike Information Criterion is followed to select the optimum lag. The error correction model for the short-run ARDL model is stated as below:

$$\begin{aligned}\Delta lnEFP_t = \alpha_0 + \sum_{i=1}^{p} \gamma_1 lnEFP_{t-i} + \sum_{i=1}^{q} \gamma_2 lnREM_{t-i} + \sum_{i=1}^{q} \gamma_3 FD_{t-i} + \sum_{i=1}^{q} \gamma_4 lnTI_{t-i} + \sum_{i=1}^{q} \gamma_5 FDI_{t-i} \\ + \sum_{i=1}^{q} \gamma_6 lnGDP_{t-i} + \varphi ECT_{t-1} + \varepsilon_t\end{aligned} \tag{4}$$

where γ denotes the short-run changes in the variables, and the Error Correction Term (ECT) illustrate how fast the system will get back to its original state of equilibrium after a shock. The computed coefficient value of ECT must be significant and negative, recommending that every shock is altered towards the equilibrium point in the following period.

4.3 Dynamic Simulated ARDL (DARDL) Model

The present work uses a novel dynamic simulation ARDL approach developed by Jordan and Philips (2018), followed by Danish and Wang (2019), Sarkodie et al. (2019), Amin and Dogan (2021) and Javed et al., (2023b). This new approach overcomes the problems associated with the traditional ARDL model to observe long- and short- term relations among variables. The DARDL model estimates, stimulates, and predicts the plots automatically to analyze variations in the explained variable due to changes in explanatory variables while holding all other variables constant. On the contrary, the ARDL technique only estimates short- and long-term relationships. To apply the novel DARDL model, all research factors must be integrated at order I(0) and I(1), and cointegration must exist between explained and explanatory variables. This method employs up to 5000 simulations of parameter vectors using a multivariate normal distribution (Sarkodie et al., 2019). The resulting simulation graphs are also used to look at the real change in regressors and their influence on the dependent variable. According to previous studies (Javed et al., 2023b; Khan et al., 2019b), DARDL model is specified as follows:

$$\begin{aligned}\Delta lnEFP_t = \alpha_0 + \theta_0 lnEFP_{t-1} + \beta_1 \Delta lnREM_t + \theta_1 lnREM_{t-1} + \beta_2 \Delta FD_t + \theta_2 FD_{t-1} + \beta_3 \Delta lnTI_t \\ + \theta_3 lnTI_{t-1} + \beta_4 \Delta FDI_t + \theta_4 lnFDI_{t-1} + \beta_5 \Delta lnGDP_t + \theta_5 lnGDP_{t-1} + \varepsilon_t\end{aligned} \tag{5}$$

4.4 Frequency Domain Causality Approach

Finally, we confirmed the causal relationship and the direction of causality among research variables using the Breitung and Candelon spectral Granger-causality. In contrast to the standard causality test, the causality approach employed in this project makes much easier to predict the response factor at specified time frequencies (Breitung & Candelon, 2006). As a result, this test ensures that historical changes can be spotted, which allows for appropriate legal action to be taken. However, this method cannot project models with infinite horizons because it is only applicable to a certain time period. The Breitung and Candelon (2006) equation is specified as below:

$$x_t = \alpha_1 \chi_{t-1} + \alpha_p X_{t-p} \ldots + \beta_1 Y_{t-1} + \beta_p Y_{t-p} + \varepsilon_{1t} \tag{6}$$

The linear Eq. (6) conforms to the null hypothesis. However, the parameters have been determined in terms of time (t), lag (p); ε_t denotes the error term.

5 Results and Discussion

Before employing the innovative DARDL approach, it is necessary to verify that all the variables are stationary. Certain conditions must be fulfilled for the findings of the DARDL simulation approach to be considered legitimate. One of the primary conditions for this model is that the explained factor must be integrated at order I(1), while the explanatory variables must be at order I(0) or I(1). However, the explanatory variables cannot be at I(2). More precisely, if any explanatory variable is integrated at order I(2) or the explained variable at order I(0), the estimated outcomes of the DARDL model will be biased. Specifically, we applied the Augmented Dickey-Fuller (ADF) (Dicky and Fuller, 1979) and the Phillips-Perron (PP) (Phillips and Perron, 1988) tests to evaluate the stationarity and results are presented in Table 4. The findings show that all the series are non stationary at their level. However, at the first difference the research variables become stationary. These findings provide evidence that the novel DARDL approach can be implemented successfully because none of the series under analysis are integrated at order I(2).

Next, we check the long-term cointegration relationship between the research factors under analysis. For this purpose, we utilized the critical values of Kripfganz and Schneider (2018) to implement the ARDL bounds test cointegration approach. This choice is supported by a number of factors that improve the robustness and reliability

Table 4 Unit root results

	ADF test		PP test	
Variables	Level	Δ	Level	Δ
EFP	−2.993	−5.976***	−2.972	−9.011***
REM	−1.637	−4.537***	−1.770	−4.984***
FD	−1.624	−3.158**	−1.782	−3.210**
TI	−2.018	−4.564***	−2.042	−4.568***
FDI	−1.863	−3.686***	−1.863	−3.652**
GDP	0.495	−3.962***	0.450	−3.973***

*** & ** denotes the significance level at 1% and 5%

of the outcomes. Firstly, Kripfganz and Schneider (2018) provide more accurate critical values for finite sample sizes, addressing a significant drawback of earlier approaches such as Pesaran et al., (2001), which are primarily based on asymptotic distributions. Unlike Narayan (2005), which mainly concentrates on small samples, Kripfganz and Schneider (2018) offer more flexibility in accommodating different lag structures, functional forms, and degrees of integration (I(0) or I(1)). Thirdly, using these critical values enhances the power of the ARDL bounds test, improving its ability to correctly identify cointegration relationships. This is particularly important in studies involving complex economic and environmental interactions, where conventional methods may either overestimate or underestimate the existence of long-run equilibrium relationships. Given these advantages, the use of Kripfganz and Schneider (2018) critical values strengthens the validity of our cointegration analysis, ensuring that our findings are based on a more precise and reliable statistical framework. The results of the cointegration approach using all three commonly referenced critical value sources such as Kripfganz and Schneider (2018), Pesaran et al., (2001), and Narayan (2005) are displayed in Table 5. The computed F-statistics value is greater than the upper bound threshold values in all critical value sources. Hence, we can reject the null of (no long-term cointegration). These results confirm the presence of a cointegration relationship between EFP and all the independent variables.

This research aims to empirically examine the impact of REM, FD, TI, FDI, and GDP, on the EFP in Pakistan. For this purpose, we employed the DARDL model suggested by Jordan and Philips (2018), which overcomes the problems of traditional model in examining long and short-run relationships among variables. Table 6 presents the short- and long-run results of the novel dynamic simulated ARDL model. According to the results obtained, remittances negatively affect the EFP in the short-run and long-term. These findings demonstrate that a 1% increase in REM reduces ecological degradation by

Table 5 Bound test cointegration results

Test statistics	Value	H0	H1
F-statistics	6.156***	No relationship	Relationship exist
t- statistics	−4.980***		

Critical values of Kripfganz and Schneider (2018) and estimated p-values

	F-statistics		t- statistics		*p*-value F-statistics	
	I (0)	I (1)	I (0)	I (1)	I (0)	I (1)
10%	2.118	3.516	−1.604	−3.418	0.000	0.000
5%	2.653	4.293	−1.998	−3.899	*p*-value T-statistics	
1%	4.005	5.195	−2.794	−4.897	0.000	0.009

Critical values of Pesaran et al. (2001) and Naryan (2005)

	Pesaran et al. (2001)		Naryan (2005)	
	I (0)	I (1)	I (0)	I (1)
10%	1.750	2.870	2.407	4.193
5%	2.040	3.240	2.910	4.193
1%	2.660	4.050	4.134	5.761

***Indicates significant level at 1%

Table 6 Dynamic simulated ARDL results

Regressors	Coefficients	Std. error	Prob
ΔREM_{t-1}	−0.0585**	0.1842	0.041
REM_t	−0.0774***	0.0248	0.006
ΔFD_{t-1}	0.2032	0.2275	0.384
FD_t	0.4826*	0.2560	0.077
ΔTI_{t-1}	−0.2593***	0.0646	0.001
TI_t	−0.1869**	0.0801	0.032
ΔFDI_{t-1}	0.0225	0.0153	0.160
FDI_t	0.0590***	0.0144	0.001
ΔGDP_{t-1}	0.8896**	0.3522	0.022
GDP_t	2.2623***	0.6277	0.002
R^2	0.8032		
F-statistic (*p*-value)	6.31(0.000)		
Simulations	5000		
Diagnostics tests			(*P*-value)
Breush-Godfrey LM	0.449		0.646
Breush-Pagan	1.014		0.467
Jarque–Bera test	1.675		0.433
Ramsey Rest test	2.709		0.117

***,** &*Denotes the significance level at 1%, 5%,and 10%

0.058% in the short and 0.077% in the long-run. In other words, these findings support the notion that increasing remittances enhances environmental quality in Pakistan, while lowering them degrades it. The results are coherent with earlier studies on the association between remittance inflows and the environment (Wang et al., (2021) in the context of five remittance-receiving countries, Usman et al., (2020) for Ethiopia, Sharma et al., (2019) in the context of Nepal), which confirm the adverse correlation between REM and environmental degradation. The main reason behind this negative relationship is that the received remittances are being invested in environmentally friendly projects and clean and efficient sources of energy consumption, as suggested by Wang et al., (2021).

Besides, financial sector growth has a significant positive impact on EFP in Pakistan in the long-term. The computed coefficients show that a 1% upsurge in FD enhances the environmental deprivation by 0.482% in long-run. In the short-run financial sector development also harms the environment by increasing the EFP, but this impact is statistically insignificant. These results imply that Pakistan's environmental status is getting worse as the financial sector grows. The reason for this positive relationship is that rise in financial sector development facilitates people to get more money or loans, thus raising their purchasing power and enabling them to buy more energy-consuming machinery (i.e., refrigerators, air conditioners, automobiles). Our conclusions are consistent with the earlier literature (Ali et al., 2019; Baloch et al., 2019; Mrabet et al., 2017; Nathaniel et al., 2019; Salahuddin et al., 2018).

Moreover, our results demonstrate that technological advancements also show a significant negative effect on the EFP, meaning that a 1% rise in TI causes the EFP to decline by 0.259% in the short and 0.186% in the long-run. Thus, the estimated results show that TI improves ecological sustainability and has a negative connection with the EFP. By encouraging the use of clean energy, smart machinery, and other applications, the development of TI lowers the EFP and boosts the environmental sustainability. This, in turn, increases energy efficiency, lowers the use of resources, and generates less waste and ecological harm from human activity throughout the manufacturing and consumption procedures (Javed et al., 2023b). The findings of previous studies (Ali et al., 2016; Demir et al., 2020; Hao et al., 2020; Kumail et al., 2020; Mensah et al., 2018) validate our results.

Furthermore, by focusing on foreign direct investment, we observe that this variable has a positive but statistically not significant influence on the EFP in the short run. On the contrary, in the long-term the estimated coefficient indicates that a 1% surge in FDI accelerates environmental worsening by 0.059%. FDI inflows often negatively impact the environmental quality of developing nations such as Pakistan, primarily due to weak institutional and political structures (Ahmad et al., 2022). Usually, these systems are ineffective in enforcing strict environmental laws or effectively encouraging sustainable behaviors. Foreign investors who put profit maximization first may take advantage of lenient environmental regulations or regulatory gaps, which would increase resources exploitation and environmental degradation. Furthermore, the dependence on conventional, resource-intensive businesses that are frequently associated with foreign direct investment exacerbates environmental degradation. Without strong governance, there are insufficient systems in place to track and lessen the negative environmental effects of foreign direct investment, which permits unsustainable practices to continue and degrade ecological sustainability. These outcomes are steady with those of Zhang and Zhou (2016), Solarin and Al-Mulali (2018), Zafar et al., (2019) and Solarin et al., (2021).

Finally, with regard to the connection between GDP and EFP, the results obtained show that economic development significantly harms the environment. Based on the estimated coefficients, a 1% rise in GDP worsens the environmental health over the short- and long-term by 0.889% and 2.262%, respectively. The results of our study also confirm those of Uddin et al. (2017), Sharif et al., (2020), Solarin and Bello (2020), He et al., (2019) and Tufail et al., (2021). When economic expansion accelerates, environmental degradation also tend to rise. Fossil fuels, being a cornerstone of Pakistan's economy, significantly contribute to ecological footprint and ecological deprivation (Majeed et al., 2021). This connection is particularly evident in Pakistan, as developing nations often prioritize economic growth over environmental sustainability during the early stages of development (Ali et al., 2022). This trade-off is largely unavoidable because increased economic activity demands substantial energy consumption, which negatively impacts environmental performance by elevating ecological footprint. Therefore, it is indispensable for growth policies to emphasize the adoption of alternative energy sources (Ahmad et al., 2020).

The lower section of Table 6 provides the result for several diagnostic tests, including Breush-Godfrey LM, Breush-Pagan, normality, and RAMSEY Reset test. These tests were performed to evaluate the model stability. The Breush-Godfrey LM and Breush-Pagan test findings show that we are unable to rule out the hypothesis of no heteroscedasticity and serial correlation. These findings demonstrate that our estimated is free from the issues of heteroscedasticity and serial correlation. The Jarque–Bera test also verify the normal distribution of residuals. Further, the outcomes of RAMSEY Reset test suggest that our estimated model is free from the issue of specification bias. Finally, the model structural stability is checked using the CUSUM and CUSUM square test. A visual representation of

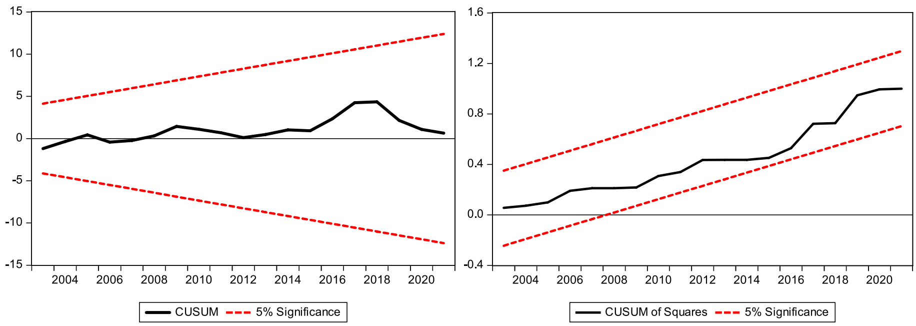
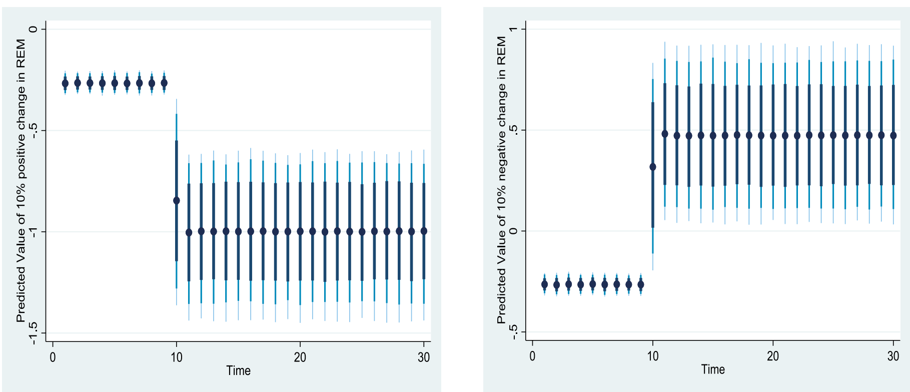


Fig. 6 CUSUM and CUSUM square test

the CUSUM and CUSMUM square analysis is shown in Fig. 6 and suggest the consistent stability of the outcomes.

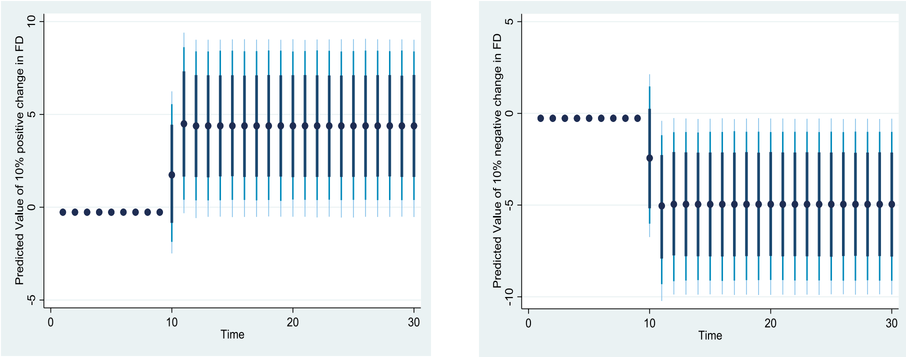
The simulation graphs of the DARDL model are also employed to analyze real changes in regressors and their effect on the explained factor. Figures 7, 8, 9, 10 and 11 plot impulse response graphs of 1% positive and negative variations in REM, FD, TI, FDI, and GDP and their effects on EFP for Pakistan. Figure 7a, b shows the connection between remittances and the EFP. More precisely, the Fig. 7a shows that a 10% increase in REM exert an adverse influence on the EFP in Pakistan. This infers that upsurge in the REM improves the environmental quality of Pakistan. Contrary to this, Fig. 7b illustrate that negative changes in REM enhance the EFP and as a results degrades the environmental quality. Further, Fig. 8a, b describes the impulse response visualization for the association between financial development and the EFP. According to the Fig. 8a, a 10% positive variation in FD has a rising impact on the EFP, suggesting that FD in Pakistan degrade the environmental health. On the flipside, a 10% negative shock in FD lowers the EFP (Fig. 8b).

Additionally. Figure 9a, b shows the impact of 10% positive and negative changes in TI on the EFP, suggesting that a 10% increasing shock in TI reduces the EFP and improves



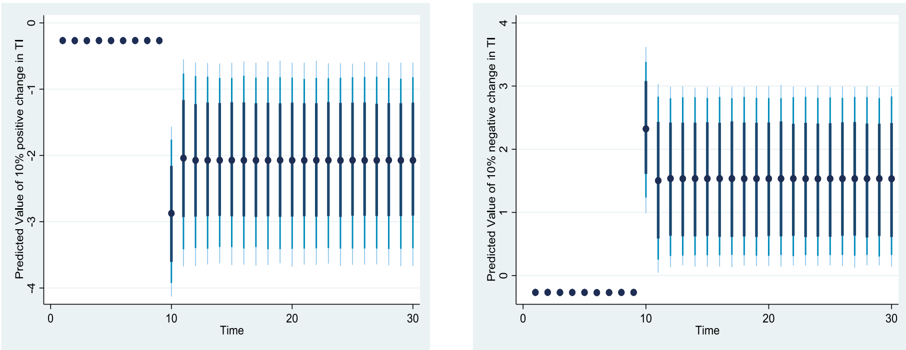
(a) (b)

Fig. 7 ±10% changes in REM on EFP



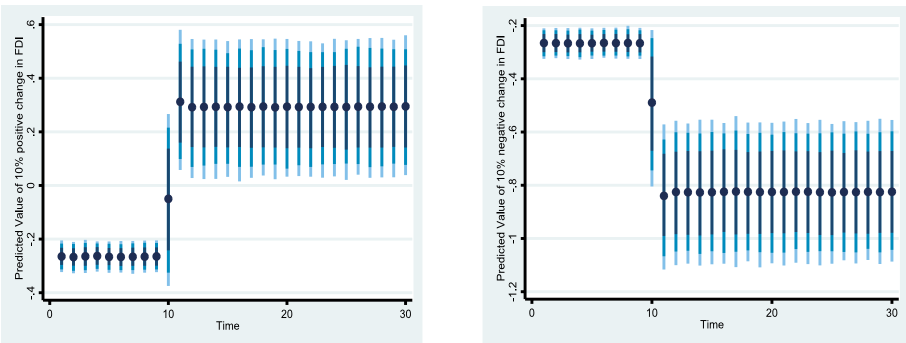
(a) (b)

Fig. 8 ±10% changes in FD on EFP



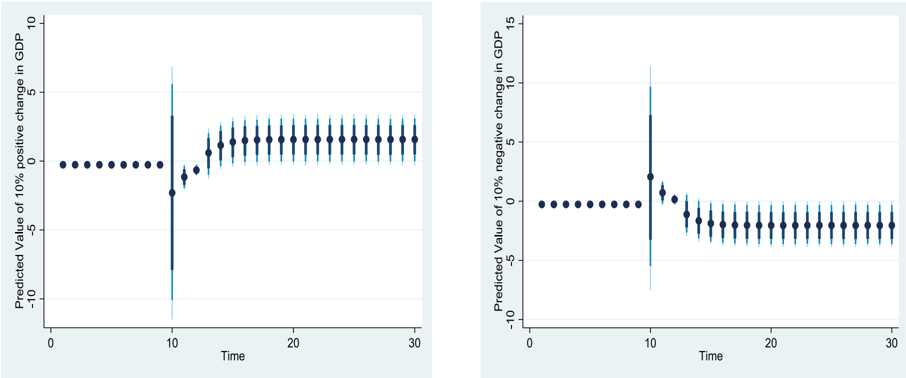
(a) (b)

Fig. 9 ±10% changes in TI on EFP



(a) (b)

Fig. 10 ±10% changes in FDI on EFP



(a) (b)

Fig. 11 ±10% changes in GDP on EFP

environmental sustainability (Fig. 9a). Contrary to this, Fig. 9b indicates that 10% decline in the TI degrades the environmental health by increasing the EFP level in Pakistan. Moreover, Fig. 10a, b explains the correlation between FDI and the EFP. Specifically, Fig. 10a showing that a 10% positive variation in FDI has a negative impact on the environmental health by increasing the EFP. However, 10% negative shock in FDI boosts the environmental health by reducing the EFP (Fig. 10b). Finally, Fig. 11a, b depicts the impact of variations in economic growth on the EFP. Figure 11a, illustrates that a 10% increase in GDP exerts a favorable impact on the EFP, meaning that a positive shock in GDP enhances ecological degradation in Pakistan. However, a 10% decrease in GDP lowers the environmental degradation (Fig. 11b).

In addition, following the earlier studies (Das et al., 2022; Abbasi et al., 2022; Javed et al., 2023b), the present work utilized FDC test of (Breitung & Candelon, 2006) to evaluate the causal relationship between REM, TI, FD, FDI, GDP, and EFP. By using the frequencies $\omega=0.05$, $\omega=1.65$, and $\omega=2.45$, the empirical results given in Table 7 demonstrate a long, medium, and short-term connection, respectively, between the factors under analysis. In other words, REM, TI, FD, FDI, and GDP have a long, medium, and short-term effects on environmental quality (EFP) in Pakistan. Furthermore, Figs. 12, 13, 14, 15, and 16 show spectral causality graphs. The first part of Figs. 12, 14, and 15 reveal that remittances, technological innovation, and foreign direct investment granger

Table 7 Causality results

Direction	Long-term $\omega=0.05$	Medium-term $\omega=1.65$	Short-term $\omega=2.45$
REM = > EFP	4.682 (0.096)*	0.812 (0.666)	5.126 (0.077)*
FD = > EFP	2.897 (0.023)**	5.019 (0.081)*	4.792 (0.091)*
TI = > EFP	9.636 (0.008)***	5.144 (0.076)*	1.405 (0.495)
FDI = > EFP	6.635 (0.036)**	4.903 (0.086)*	8.398 (0.015)**
GDP = > EFP	8.739 (0.013)**	6.252 (0.044)**	3.716 (0.156)

*** & **Denotes the significance level at 1%, 5%,and 10%

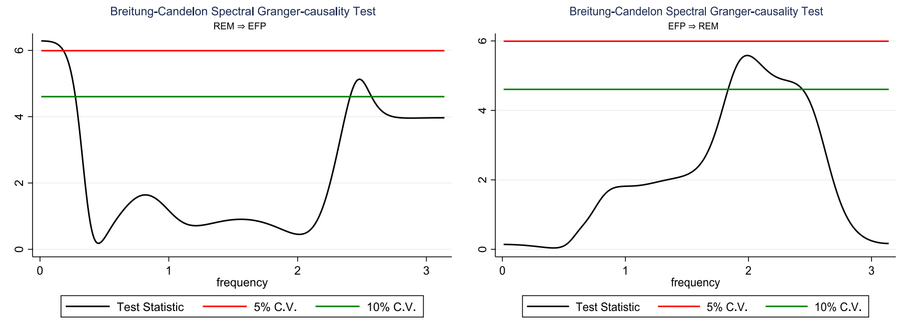


Fig. 12 Causality between REM and EFP

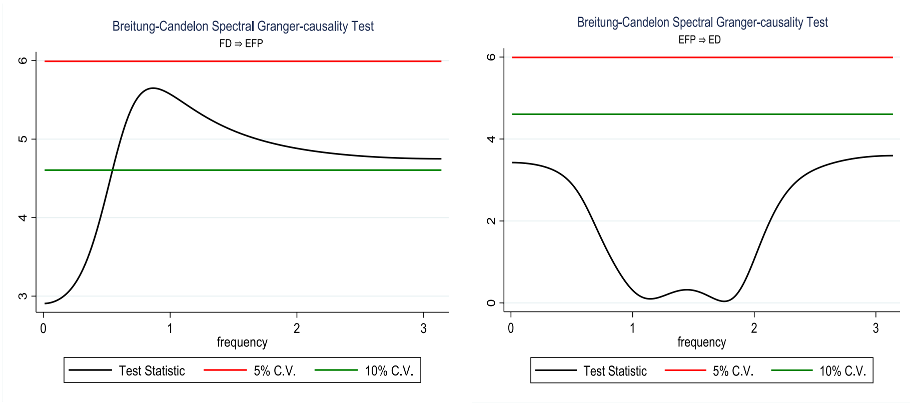


Fig. 13 Causality between FD and EFP

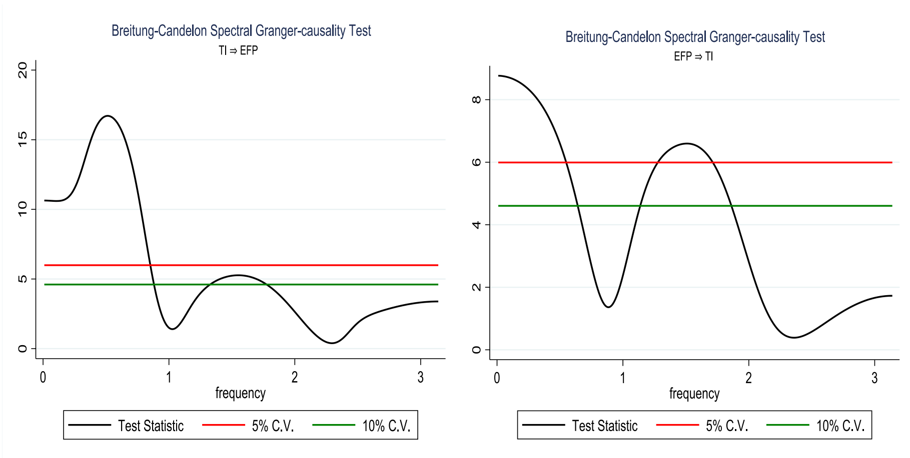


Fig. 14 Causality between TI and EFP

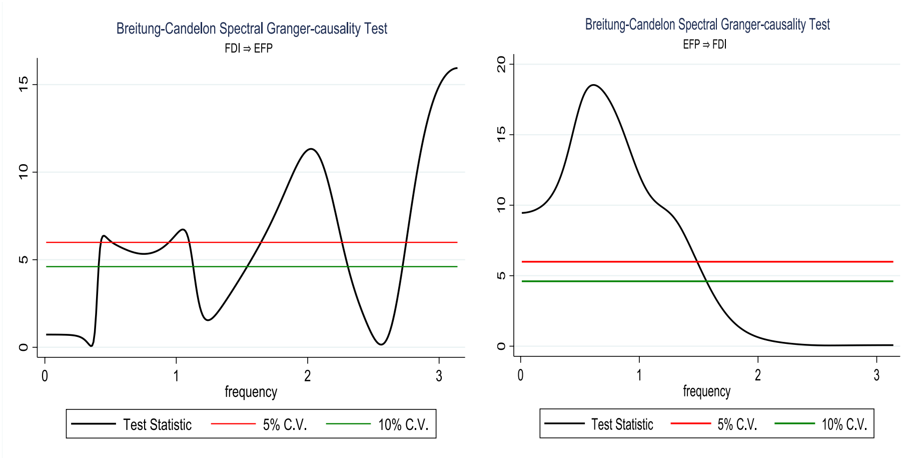


Fig. 15 Causality between FDI and EFP

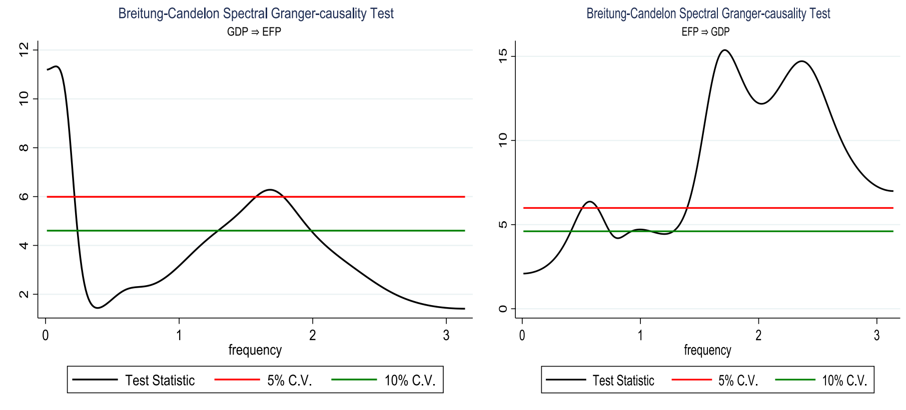


Fig. 16 Causality between GDP and EFP

cause the EFP, whereas the second parts also suggest a causality running from the EFP to REM, TI, and FDI. Moreover, Fig. 13 disclose that a unidirectional causality between financial development and the EFP, and the direction of connection flows from FD to the EFP (the first part of Fig. 13 confirm it). Furthermore, the first part of Fig. 16 demonstrates that economic expansion causes an increase in the EFP level, whereas the second panel illustrates a reverse causality between EFP and GDP.

This study thoroughly examined the impact of REM, FD, TI, FDI, and GDP on ecological sustainability in the context of Pakistan and provide useful insights. However, this study has some limitations/shortcomings, which necessitate further investigation. In this research, we used the ecological footprint as an environmental performance indicator. However, future studies can utilize the load capacity factor as a measure of environmental performance, which considers both the demand and supply sides of the ecosystem. Further, the present study focuses on a specific country and implements the proposed model for it.

However, researchers may use a time series or panel data from other developed and developing nations. Besides, expanding the range of the data will allow for a broader application of the findings to sustainable development practices. Moreover, future studies can incorporate other important factors such as institutional quality, environmental policy, human capital, and economic complexity. Finally, other econometric procedures, like quantile ARDL and non-linear ARDL approaches can be applied to validate our results. We will be able to construct a more extensive plan for the improvement of environmental conditions once we have additional findings from future studies.

6 Conclusion

This study examined the role of REM, FD, TI, FDI, and GDP on the EFP in Pakistan using yearly data from 1990–2021. To this purpose, we applied a novel DARDL model after testing the integration order and confirming the long-term cointegration relationship between the variables. We also utilized the FDC test to evaluate the causal relationships between the variables. The dynamic simulated ARDL model results show that remittances have a negative impact on the EFP. This finding provides evidence that increasing remittances improve environmental quality in Pakistan. Furthermore, our results indicate that financial development encourages the EFP in the long-run, suggesting that FD harms the environment in Pakistan. Besides, the outcomes suggest that technological progress has a beneficial influence on the environmental quality in Pakistan. With regard to foreign direct investment, the results obtained provide evidence of a positive impact on EFP, confirming that FDI promotes environmental degradation in Pakistan. Likewise, economic growth also enhances the EFP, thus degrading environmental health. In addition, the FDC analysis confirmed the existence of long-term, medium-term, and short-term causality connections between the examined variables.

Based on the above findings, we propose several insights for policymakers regarding environmental quality in Pakistan. Firstly, the positive association between FD and ecological footprint (EFP) indicates that the growth of the financial sector may adversely impact environmental quality. This appears to be driven by the prioritization of economic growth and scale expansion over credit financing for clean and eco-friendly technologies. The increased aggregate demand amplifies energy utilization, thereby linking remittances and financial sector expansion to environmental degradation through energy consumption. Given Pakistan's significant reliance on fossil fuels, the results propose that diversifying energy sources and increasing the share of clean energy in the total energy mix could contribute to environmental improvement. Further, the findings point to the potential benefits of strengthening financial guidelines to promote sustainable finance. Encouraging investments in renewable energy technologies, along with channeling funds toward industries adopting modern, efficient, and environmentally friendly production practices, may yield positive outcomes. Addressing institutional inefficiencies and fostering incentives, such as tax benefits, for eco-friendly technology adoption could also enhance environmental sustainability. Transitioning Pakistan's energy sector from traditional to clean energy sources appears vital for achieving sustainable growth with reduced environmental deprivation.

Secondly, the results highlight the importance of technological innovation in influencing environmental outcomes. Promoting technological advancements, particularly in green technologies, could support energy efficiency and mitigate environmental contamination. Considering the relatively low level of technological innovation in Pakistan compared to developed Asian regions, investing in environmentally friendly, low- or zero-carbon energy supply technologies for transportation and industry may prove beneficial. The analysis suggests that increasing R&D in clean energy sectors may enable higher production with reduced emissions, especially in industrial and agricultural contexts. Emphasizing the adoption of smart technologies in urbanization, transportation systems, and energy sources could further improve environmental quality. Policymakers might consider offering subsidies, tax breaks, and enhanced access to credit for businesses adopting smart, eco-friendly manufacturing practices. Carbon taxes on industries utilizing polluting technologies could also be explored as a measure to incentivize cleaner practices. Finally, leveraging remittances and FDI to increase government spending on technology infrastructure may help restructure the economy toward greater economic efficiency and reduced environmental pollution. These steps, supported by technological innovation and sustainable financial practices, could lead to long-term improvements in environmental quality and economic resilience.

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Data availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Conflict of interest The author declares that there is no financial/personal interest or belief that could affect the objectivity of this manuscript.

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