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RESEARCH

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The impact of eco-innovations, FDI, and financial development on environmental sustainability

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Abstract

While extensive research has explored the nexus between eco-innovations, financial development, foreign direct investment (FDI), and the ecological footprint (EFP), studies focusing specifically on Saudi Arabia—an oil-dependent economy where the Pollution Halo or Heaven effects are particularly relevant—remain limited. This study investigates the impact of eco-innovations, financial development, FDI, and clean energy on environmental quality (measured by EFP) in Saudi Arabia over the period 1995–2022, employing the autoregressive distributed lag (ARDL) model. The results indicate that eco-innovations and clean energy contribute to reducing environmental degradation, whereas financial development exacerbates it. Moreover, FDI improves environmental conditions by lowering EFP, providing evidence of the Pollution Halo effect in the Saudi context. Robustness checks, including alternative estimators, confirm the stability of these findings. Furthermore, the Granger causality analysis reveals a unidirectional causal flow from all explanatory variables to EFP, except for renewable energy. Based on these results, the study proposes several policy implications to help mitigate and manage environmental challenges in Saudi Arabia.

Keywords Eco-innovation, Financial development, Ecological footprint, Clean energy, Saudi Arabia

1 Introduction

Environmental degradation has become a pressing global concern in recent decades, contributing to biodiversity loss, resource depletion, climate change, and air pollution [1]. Since 1933, Saudi Arabia's economy has relied heavily on hydrocarbon exploration, generating significant export revenues but with limited attention to the resulting environmental consequences. Despite its economic dominance in the Arabian Peninsula, the country lacks sufficient biocapacity to meet the demands of human activities, which surpass its natural resource availability (Global Footprint Network, 2023). This imbalance underscores the need to explore the nexus between environmental quality and key economic drivers. Within this context, international platforms such as COP28 highlight the urgency of addressing environmental challenges to achieve the Sustainable Development Goals (SDGs). Saudi Arabia is increasingly promoting eco-innovation and technological advancements to support sustainable sectors and reduce its carbon footprint. By encouraging innovation and environmentally responsible practices, the nation aims to position itself as a regional leader in the transition toward a low-carbon economy, making it critical to examine its environmental challenges and policy responses.

Theoretically, eco-innovations and the use of clean energy can promote environmental sustainability in several ways. First, the advancement of environmentally sound technologies and the adoption of carbon–neutral energy sources can significantly reduce the ecological footprint by decreasing reliance on carbon-intensive fuels [2, 3]. Second, government investment in eco-innovation and energy R&D projects, particularly in the public sector, can create initial market conditions that stimulate private sector participation in eco-innovation and energy technology development. This, in turn, accelerates the deployment of renewable energy while reducing dependence on more polluting energy sources [4].

In recent years, Saudi Arabia has significantly advanced eco-innovation as it seeks to balance economic growth with environmental protection. This shift is driven by concerns over resource depletion, climate change, and the need to diversify beyond oil dependence. While some studies suggest that environmental challenges hinder innovation [5, 6], others argue that innovation mitigates the negative environmental effects of human activities [7, 8]. Most existing research, however, focuses on overall innovation rather than specifically on eco-innovation [9, 10]. As Hussain et al. [11] emphasize, environmental sustainability is best supported through green technologies. Such technologies enhance the efficiency of current energy sources while fostering the adoption of cleaner alternatives. These advancements not only reduce the ecological footprint but also improve air and water quality, support biodiversity, and strengthen environmental resilience for present and future generations [12].

There are several justifications for selecting Saudi Arabia as an appropriate setting for examining the impact of eco-innovation on environmental sustainability. Firstly, in recent decades, Saudi Arabia has experienced a significant decline in environmental quality, surpassing other nations in terms of the speed of degradation. According to Global Footprint Network (2023), Saudi Arabia's EFP has more than doubled in the last three decades, shifting from 2.40 gha per person in 1990 to 5.51 gha per person in 2020 (Fig. 1). Moreover, "Global Carbon Project Statistics" show that CO_2 emissions per capita annually increased from 11.55 tons in 1995 to 16.56 tons in 2020 in Saudi Arabia. These facts show a continuous decline in the quality of the environment over the last few decades in Saudi Arabia.

Second, the Vision 2030 of Saudi Arabia frames a comprehensive roadmap to expand the economy and lessen its reliance on oil exports. As an aspect of this vision, Saudi Arabia is capitalizing heavily on sectors which as renewable energy, eco-tourism, and sustainable agriculture. This assurance of economic transformation creates a favorable environment for eco-innovation, expertise, attracting investments, and collaboration in research aimed at addressing ecological challenges and making new sustainable industries.

Third, Saudi Arabia's unique geographical characteristics, including arid landscapes and water scarcity, present both opportunities and challenges for eco-innovation. Saudi

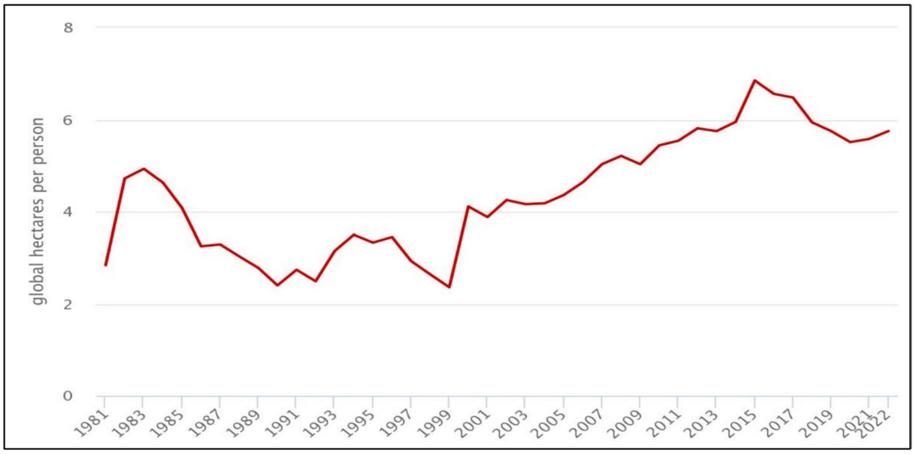

Fig. 1 Saudi Arabia's EFP. *Sources*: GFN, 2022. *Note* In the figure, the Y-axis denotes the global per hectare per person, and the X-axis refers to the year

Arabia's focus on water management, sustainable agriculture technologies, and efficient irrigation can lead to inventive solutions applicable in related regions globally. In addition, Saudi Arabia's commitment to addressing these issues can drive improvements in wastewater treatment, desalination, and water conservation technologies, participating in the global pursuit of water security. Certainly, Saudi Arabia introduced numerous eco-friendly projects recently, including the formation of the "Logistics Program and National Industrial Development", which proposes to increase the demand for sources of renewable energy through eco-friendly technologies. Therefore, eco-innovation can enhance the quality of the environment when used with green technologies for ecologically friendly projects. While this structural shift is regarded as a key pathway to achieving environmental sustainability, Saudi Arabia's heavy dependence on fossil fuels has been the subject of considerable debate. Fossil fuel-based products remain central to the Saudi economy, underpinning critical industries such as manufacturing, transportation, and power generation. Consequently, it is a challenging task for the government to maintain steady economic growth under Vision 2030 while simultaneously meeting its environmental commitments. Moreover, excessive allocation of resources to energy R&D and eco-innovation could produce unintended outcomes, as increased reliance on carbon–neutral technologies may stimulate higher overall consumption. This rebound effect underscores the need for strong environmental regulations and well-designed innovative policies to ensure a smooth transition toward a sustainable economy.

The growing evidence on environmental challenges has stimulated extensive research on sustainability. Prior studies highlight renewable and non-renewable energy, trade openness, financial inclusion, urbanization, economic growth, population, FDI, and innovation as major drivers of environmental outcomes [13–16]. However, limited attention has been given to the specific role of eco-innovation in ecological sustainability. This study addresses this gap by examining the impact of eco-innovation on environmental quality in Saudi Arabia. In addition, financial development and FDI are considered, as they can improve ecological quality by financing clean technologies, renewable energy, and pollution control projects [17], though they may also worsen conditions if directed toward polluting industries. Finally, renewable energy, widely acknowledged as a key contributor to ecological improvement [18, 19], is also analyzed. Together, these factors provide a comprehensive framework for assessing environmental sustainability in Saudi Arabia. This study addresses the following research questions pertaining to Saudi Arabia, considering the background information provided above.

(i) Do eco-innovations improve ecological quality in Saudi Arabia?

(ii) Does the financial expansion and influx of FDI have an impact on the environment in Saudi Arabia?

(iii) What is the likely effect of renewable energy on the EFP in Saudi Arabia?

This study contributes to the current corpus of knowledge in the following ways: Firstly, in the current era of technical advancements, the implementation of eco-innovation has emerged as a crucial factor in enhancing both industrial efficiency and environmental sustainability. While the literature has extensively investigated this topic, the nexus between eco-innovation and the environment in the context of Saudi Arabia has not been sufficiently explored. This is particularly pertinent in the context of Saudi Arabia, where significant emphasis has been placed on technological advancements and ecological efficiency in recent times within the 2030 vision. Thus, this study offers significant insights into the eco-innovation-environmental performance nexus in the context of Saudi Arabia for policymakers.

Secondly, despite the overwhelming investigation, previous studies exploring the link between eco-innovation, renewable energy, and environmental quality have largely utilized a partial indicator as a proxy for environmental quality, such as CO_2 emissions. However, CO_2 emissions capture only a single dimension of air pollution. To provide a more comprehensive evaluation, this study employs the ecological footprint as a broader measure of environmental quality, encompassing carbon emissions, land use, forest resources, grazing land, and fishing grounds.

Thirdly, in the present time, Saudi Arabia has been dealing with the intricate relationship of some key factors, such as financial development, FDI, and renewable energy transition, and their simultaneous effect on the country's ecological sustainability. The nation has initiated several eco-innovations and policy adjustments to increase its economy and reduce its reliance on fossil fuel usage. These revolutions' purpose is to endorse sustainable practices, lessen carbon emissions, and improve resource productivity. However, whereas these creativities hold potential, Saudi Arabia has faced obstacles in entirely appreciating their promise due to several environmental and economic limitations. To delve into the complex dynamics between these factors, this study would offer an appreciated vision for sustainable development policies in the country. Finally, to discover the short- and long-term relationship between the aforementioned factors and environmental quality, this study applied the ARDL approach. Although assembling this method is common in empirical and econometric research across various economic fields, it also provides robust estimations for analyzing time series data.

2 Summary of literature

2.1 Eco-innovation and environmental degradation

Theoretically, ecological modernization theory has consistently guided research on the dynamic relationship between eco-innovation and the environment. This theory posits that environmental impacts resulting from human activities can be mitigated by enhancing resource efficiency through the development of green technologies [3]. Meanwhile, an important strand of research argues that the deployment of eco-innovation alone may lead to further environmental deterioration in the absence of stringent environmental regulations. This is particularly true in developing countries that pursue growth-centric policies without fully considering environmental consequences, a phenomenon commonly referred to as the “green paradox” [20]. Empirical research, reflecting theoretical divergence, has not reached a consensus on the actual impact of eco-innovation on environmental sustainability. However, substantial evidence from the existing literature supports the ecological modernization theory, suggesting that eco-innovation (EI) plays a significant role in reducing environmental degradation [21, 22].

Similarly, Ali et al. [23] found that climate-focused patents significantly promote environmental sustainability in France during the period 2008–2019. Gormus and Aydin [24] estimated the relation among economic growth, eco-innovation, renewal energy consumption, and the EFP by using the “environmental Kuznets curve (EKC)” hypothesis for the ten most innovative countries and found that the induced innovations reduce the ecological destruction. Furthermore, Fethi and Rahuma [25] examined under the EKC hypothesis that EI played a vital role in mitigating environmental pollution. Similarly, Sun et al. [26] applied the QARDL model to find the impact of innovations in the case of Turkey and found negative results across most quantiles. Moreover, Olanrewaju et al. [27] studied various factors and revealed that trade openness and non-renewable energy contribute to environmental damage, while eco-innovation, renewable energy, and economic expansion improve the environmental quality. Similar findings are also assessed by previous studies [28, 29]. Conversely, Yunzhao [30] discovered that eco-innovations, renewable energy, and environmental taxes showed a positive impact on environmental degradation. Likewise, Hossain et al. [31] validated the presence of a positive connection between EI and environmental fineness in the US economy.

2.2 Financial development (FD) and environmental degradation

Recently, financial development has emerged as a key determinant of environmental sustainability. Finance-led Green Growth theories have frequently served as the theoretical foundation in related empirical studies, highlighting the critical role of a developed financial sector in supporting long-term economic growth and financing environmentally friendly technologies and sustainable practices [32]. Empirical research has further emphasized this role, noting that the relationship between financial development and a sustainable environment is among the most pressing issues in current discourse [33]. Several studies have investigated this topic, reporting a negative long-term relationship between financial innovations, patent innovations, and transport-induced pollution in China [23, 34].

Practically, it is argued that economies with well-developed and well-equipped financial markets have healthier environments than countries with less effective financial structures [35]. Yet, some contradicting outcomes are quite notable. For instance, Gill et al. [36] employed the NARDL approach,their findings unveiled that financial development upsurges environmental pollution in Pakistan. Similarly, Ozturk et al. [37] examined the dynamic relationship between EFP, economic development, FDI, financial development, and energy consumption. The authors reported that financial development declines the environmental quality in the region of South Asia. Moreover, Ju et al. [38] performed NARDL for the Arab countries and found that FD pollutes the environment. Similarly, other studies support the above-mentioned research [39]. In contrast, many researchers have discovered that FD also protects the environment by reducing ecological emissions. For example, Majeed et al. [40] examined a panel of 131 economies, Acar et al. [41] studied Azerbaijan, and Wu et al. [42] for the Nordic nations."

2.3 Foreign direct investment (FDI) and environmental degradation

Empirically, two contrasting theories underpin the scientific discourse on the relationship between FDI and environmental quality: the Pollution Haven Hypothesis and the Pollution Halo Hypothesis. On one hand, substantial evidence suggests that FDI can contribute to environmental degradation, as firms in pollution-intensive industries may relocate production to countries with weaker environmental regulations. On the other hand, the Pollution Halo Hypothesis emphasizes that FDI can improve environmental quality in host countries by promoting the transfer of cleaner technologies, advanced management practices, and stricter environmental standards to local firms and business models [43].

In support of the Pollution Hal Hypothesis, Wang et al. [44] claim that FDI plays a vital role in terms of sustainable development by reducing environmental degradation. Moreover, Kindo et al. [45] analyzed the effect of FDI in thirteen West African economies on environmental quality and found that FDI improves environmental quality. Furthermore, the FDI boosts the quality of the environment in the top ten solar-consuming economies [46]. These discoveries are also coherent with earlier findings by Roy [47] for India and [48] for Pakistan.

On the other hand, many researchers have found evidence supporting the argument put forward by the Pollution Haven Hypothesis, as a positive association between FDI and environmental footprint was emphasized. For instance, Nyeadi [49] found for 44 nations in sub-Saharan Africa, and Shabir et al. [50] studied a panel of 24 developed and emerging countries from 2001 to 2019. The comparative importance of FDI is determined by its dual influence on developed and developing nations. Because advanced nations have rigorous environmental regulations, FDI has a beneficial environmental impact,in emerging nations, however, FDI has a negative environmental impact due to lax regulations.

2.4 Renewable energy (RE) and environmental degradation

Empirical, numerous research emphasizes that the deployment of RE improves the environment. This prospect is supported by many empirical researchers. For illustration, Kartal et al. [51] used the Quantile approach during the period 1965/Q1 to 2018/Q4 and found that RE lessens environmental deterioration in the USA. Adebayo et al. [52] studied the impact of hydroelectricity consumption on CO_2 emissions. The study reveals a strong negative relationship between hydroenergy consumption and CO_2 emissions, particularly on long-term frequencies, in the USA. Jiang et al. [53] conducted the NARDL and found that RE has an asymmetric effect on China's environment,Murshed et al. [54] performed CCEMG and AMG and concluded that RE enhances the ecosystem. Furthermore, the aforementioned studies are supported by Javed et al. [55] for Italy, Sharif et al. [56] for Turkey, Wang and Dong [57] for 14 Sub-Saharan African economies, and Adebayo et al. [58] for BRICS.

Recently, Kirikkaleli et al. [59] uncovered that the use of green electricity significantly reduces environmental deterioration and fosters sustainable environmental practices in the United States. In contrast, despite most studies endorsing the negative effect of RE and alternatives of other energy origins on the environment in the present literature, a few studies offered conflicting outcomes as compared to the aforementioned literature. Such as some researchers have investigated that environmental pollution is significantly boosted using renewable energy [60, 61].

2.5 Literature gap

In summary, past research has extensively examined the "correlation between clean energy, eco-innovation, FDI, financial development, and environmental indicators" across different nations and groups of countries, employing a range of approaches. Based on the findings of the reviewers' investigations, a range of outcomes were seen regarding the influence of the aforementioned variable on both CO_2 and EFP. However, within the specific context of Saudi Arabia, there is a limited number of researchers who have explored the relationship between eco-innovation and EFP. It is worth noting that certain investigations have previously examined the effect of many other variables. Nevertheless, the influence of financial expansion on the EFP in Saudi Arabia remains confined. Thus, this study was undertaken within the setting of Saudi Arabia, in response to a lack of existing research on the topic. Furthermore, prior studies have extensively used carbon emissions as a proxy for environmental sustainability, which primarily captures air pollution. Finally, existing studies have utilized relatively conventional econometric approaches. To address these shortcomings, this study uses the ecological footprint and employs the ARDL technique to estimate relationships in both the short and long term simultaneously.

3 Data and methodological approach

3.1 Data and variables description

The key motive of this study is to determine the impact of eco-innovation, financial development, FDI, and renewable energy on the EFP during 1995–2022 in Saudi Arabia. The annual time series data of the variables, which is used in this study, is taken from various platforms; likewise, "Global Footprint Network [62]" for EFP, eco-innovation is taken from "Organization for Economic Co-operation and Development, the "International Monetary Fund for financial development and the source of FDI and renewable energy is "World Development Indicator [63]". The "EFP is measured by global hectares per person, the number of patents related to the environment with country fractional value is a proxy of EI, the financial market index is taken as FD, and FDI and RE are measured by net inflows (% of GDP and the % of total final energy use, respectively." Description and source of the data are explored in Table 1.

Table 1 Description and data sources of selected variables

Abbreviation	Variable	Description	Source
EFP	Ecological footprint	Gha per person	[62]
EI	Eco innovations	Number of patents for environmental technology, with country fractional value	
FD	Financial development	Financial market index	
FDI	Foreign direct investment	Net inflows (% of GDP)	[63]
RE	Renewable energy	% of total final energy use	[63]

Data sources: GFN (https://data.footprintnetwork.org/); OECD (https://data.oecd.org/); IMF (https://www.imf.org/en/Data); WDI (https://databank.worldbank.org/source/world-development-indicators)

3.2 Theoretical framework and model building

According to the empirical background, eco-innovations, financial development, FDI, and renewable energy play crucial roles in determining the EFP level [64]. Eco-innovations, considered by the advancement as well as employment of eco-friendly technologies and practices, are expected to lessen the degradation of the environment by endorsing resource efficiency and pollution reduction [27, 29]. However, the comprehensive and well-launched financial sector significantly affects the growth outline of an economy [36]. An efficient and well-structured financial sector enhances the overall functioning of the financial system by promoting technological advancement, reducing information costs, managing complex business transactions, and fostering transparency between borrowers and lenders. These improvements increase investment efficiency and productivity [38, 65]. However, the resulting rise in productivity also drives higher energy consumption, which directly influences environmental performance [66].

Scholars have conducted numerous assessments to determine the influence of investment flows on the environment. These assessments have revealed that the impact can be either detrimental or beneficial, resulting in what is known as a “Pollution Haven or a Pollution Halo” effect, respectively [67, 68]. Theoretically, the "Pollution Haven Effect" is a concept that arises from the presence of lax environmental rules (as stated by [69]) and a low degree of technical advancement (as mentioned by [70]) in the countries and regions where it occurs. Alternatively, the "Pollution Halo Effect" may occur when new investments provide more environmentally friendly and energy-efficient manufacturing practices [71] and sophisticated environmental management techniques [72]. The dominance of either the "Pollution Haven or Halo” effect is contingent upon the unique context, as well as the subject and design of the research. Therefore, we examined the inflow of FDI in Saudi Arabia to investigate its potential halo or heaven effect. The functional form of the model for the impact of eco-innovation, financial development, FDI, and renewable energy on Saudi Arabia’s EFP is measured as the following function:

$$\mathrm{EFP} = \mathrm{f}\ (\mathrm{EI},\ \mathrm{FD},\ \mathrm{FDI},\ \mathrm{RE}) \tag{1}$$

To tackle the problems of data sharpness, scale equivalence, heteroscedasticity, and autocorrelation, we transformed the model into a logarithmic form in this study. Hence, this transformation is intended to address these concerns properly. The empirical equational form can be derived as follows:

$$\begin{aligned} Ln\,(EFP_t) =& \propto_0 + \propto_1 Ln\,(EI_t) + \propto_2 Ln\,(FD_t) \\ &+ \propto_3 Ln\,(FDI_t) + \propto_4 Ln\,(RE_t) + \varepsilon_t \end{aligned} \tag{2}$$

Equation (2) describes the econometric equation of selected variables. “Where Ln represents natural logarithm, EFP signifies the ecological footprint, EI is eco-innovation, FD represents financial development, FDI explains foreign direct investment, and RE denotes renewable energy. Likewise, the subscript of each variable “t” expresses the time dimension of the associated variable. Furthermore, $\propto_0$ illustrates the intercept term, ε_t denotes a stochastic error term, and $\propto_1$ to $\propto_4$ represent the elasticity of the regressors.”

3.3 Methodology

A complete econometric procedure consists of three crucial steps as follows: (a) conducting unit root analysis of variables, (b) analysis of cointegration between intended variables, and (c) estimation of short- and long-run coefficients/elasticities.

The first segment in the data analysis of the time series is a test for stationarity because the results from regression analysis present inconsistent or misleading information if the opted variables represent a random trend [73]. Hence, the Phillips-Perron (PP) test proposed by Phillips and Perron [74] and the Augmented Dickey–Fuller (ADF) test developed by Dickey and Fuller [75] are used to solve this issue. Moreover, this study also used the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) stationarity test. The KPSS stationarity test is recognized by Kwiatkowski et al. [76] to determine the stationarity and integration order of the observed variables for small samples of the time series. The stationarity of time series data can be measured by using the mathematical methods of the PP and ADF tests. These approaches can be used for the autoregressive (AR) model, including the first-order AR model, the AR model with an intercept but no trend, and the AR model with both an intercept and a trend.

The second phase of this research is to discover the long-run connection between the selected variables. In this sense, the two-time series are viewed as long-run cointegrated if they move together over time while keeping a constant gap between them. Thus, to find out the steady-state equilibrium and long-period constancy among the opted variables, Johansen's [77] long-run cointegration method is applied in this study through the following mathematical equation or expression:

$$\Delta \mathrm{X_t} = \lambda_{\mathrm{t}-1} + \sum_{\mathrm{i}=1}^{\mathrm{p}-1} \theta_{\mathrm{i}} \Delta \mathrm{X}_{\mathrm{t}-1} + \mu_{\mathrm{t}} \tag{3}$$

$$\lambda = \sum_{i=1}^{p} M_i - I, and\, \theta_i = \sum_{i=t+1}^{p} M_j \tag{4}$$

In the above Eqs. (3) and (4), the parameter matrix term λ denotes the adjusted disequilibrium. The term θ shows dynamic short-term adjustment, and the stacking of the coefficient M enhanced the rate of adjustment of the unobserved factors to the restoration of equilibrium association.

The ARDL bounds test is also used to explore the long-term interrelation among the series and is broadly employed due to its numerous advantages. Likewise, this process tackles many issues, such as endogeneity issues and the inability to evaluate hypotheses regarding the estimated parameters in the long term. The ARDL method is capable of examining long-period association amongst the analyzed time series, even if the core independent variables are purely cointegrated at level (I(0)), entirely different (I(1)), or mutually (I(0,1)). Furthermore, the ARDL technique can estimate both short- and long-term elasticities of the models. Additionally, as compared to multivariate approaches, the bound testing approach has extra advanced properties for small samples [78]. Moreover, it can be additionally employed to establish the long-run relationship, as indicated in Eqs. (5) and (6) below:

$$\Delta Y = \propto_0 + \sum \propto_i \Delta Y_{t-i} + \sum \tau_j X_{1,t-j} + \sum \varphi_k \Delta X_{2,t-k} + \gamma ECT_{t-1} \tag{5}$$

$$\Delta Y = \propto_0 + \sum \propto_i \Delta Y_{t-i} + \sum \tau_j X_{1,t-j} + \sum \varphi_k \Delta X_{2,t-k} + \delta_0 Y_{t-1} + \delta_1 X_{1,t-1} + \delta_2 X_{2,t-1} + \varepsilon_t \tag{6}$$

Before employing the ARDL bounds cointegration test to measure the long-term association, Eq. (7) represents the unrestricted error correction model as follows:

$$\Delta CE_t = \sigma + \sum_{i=1}^{k} \beta_0 \Delta CE_{t-i} + \sum_{i=1}^{k} \beta_1 \Delta X_{1,t-i} + \sum_{i=1}^{k} \beta_2 \Delta X_{2,t-i} + \sum_{i=1}^{k} \beta_3 \Delta X_{3,t-i} + \sum_{i=1}^{k} \beta_4 \Delta X_{4,t-i} + \lambda_0 L\Delta CE_{t-i} + \lambda_1 L\Delta X_{1,t-i} + \lambda_2 L\Delta X_{2,t-i} + \lambda_3 L\Delta X_{3,t-i} + \lambda_4 L\Delta X_{4,t-i} + \beta_5 T + \beta_6 B + \nu_t \tag{7}$$

where i represents the cross-section, Δ stands for the first difference operator, and t denotes the time span. The null hypothesis, indicating the nonappearance of long-term interrelation among the indicators of time series, can be described in Eq. (8):

$$\lambda_0 = \lambda_1 = \lambda_2 = \lambda_3 = \lambda_4 = 0 \tag{8}$$

$$\Delta CE_t = \sigma + \sum_{i=1}^{k} \beta_0 \Delta CE_{t-i} + \sum_{i=1}^{k} \beta_1 \Delta X_{1,t-i} + \sum_{i=1}^{k} \beta_2 \Delta X_{2,t-i} + \sum_{i=1}^{k} \beta_3 \Delta X_{3,t-i} + \sum_{i=1}^{k} \beta_4 \Delta X_{4,t-i} + \lambda_0 L\Delta CE_{t-i} + \lambda_1 L\Delta X_{1,t-i} + \lambda_2 L\Delta X_{2,t-i} + \lambda_3 L\Delta X_{3,t-i} + \lambda_4 L\Delta X_{4,t-i} + \beta_5 T + \beta_6 B + \beta_7 ECT_{t-1} + \omega_t \tag{9}$$

The ARDL bounds technique employs non-standard asymptotic dispersal and employs the consolidated F-statistic to investigate the absence of a long-term association as described in Eqs. (10) and (11). This technique requires the computation of two separate categories of critical values (CV): a lower critical bound and an upper critical bound. If the assessed combined F-statistic surpasses the upper critical bound, we accept the alternative hypothesis (H_1) and reject the null hypothesis (H_0). On the other hand, if the estimated combined F-statistic falls under the lower critical bound, then we accept the H_0 and reject the H_1.

Following the variation of variables, the ARDL-based error correction model assesses the elasticity of the aforementioned variables in the short-term, as follows in Eq. (10):

$$LY_t = \eta_0 + \sum_{i=1}^{i=1} \eta_{1i} LY_{t-i} + \sum_{i=0}^{q} \eta_{2i} LX_{1,t-i} + \sum_{i=0}^{q} \eta_{3i} LX_{2,t-i} + \sum_{i=0}^{q} \eta_{4i} LX_{3,t-i} + \sum_{i=0}^{q} \eta_{5i} LX_{4,t-i} + \lambda ECM_{t-1} + \xi_t \tag{10}$$

In Eq. (10), ECM_{t-1} denotes the error correction term that is obtained through the following equation:

$$\begin{aligned}\mathrm{ECM_t} = \mathrm{LY_t} - \pi_0 - \sum_{\mathrm{i=1}}^{\mathrm{q}} \pi_{1\mathrm{i}}\mathrm{LY_{t-i}} - \sum_{\mathrm{i=0}}^{\mathrm{q}} \beta_{2\mathrm{i}}\mathrm{LX_{1,t-i}} \\ - \sum_{\mathrm{i=0}}^{\mathrm{q}} \beta_{3\mathrm{i}}\mathrm{LX_{2,t-i}} - \sum_{\mathrm{i=0}}^{\mathrm{q}} \beta_{4\mathrm{i}}\mathrm{LX_{3,t-i}} - \sum_{\mathrm{i=0}}^{\mathrm{q}} \beta_{5\mathrm{i}}\mathrm{LX_{4,t-i}}\end{aligned} \tag{11}$$

where λ represents the rate of adjustment for stable equilibrium from short-term to long-term, and from η_1 to η_5 illustrates all coefficients of the parameters.

When predictors' elasticities are confirmed in the short- and long-term, it is crucial to check the causal connection among the selected time series variables. In pursuit of this, the Granger Causality method was employed to examine causal relations. The Granger causality approach supports the vector autoregressive method estimation of the causal connection among the variables, which was developed by Granger [79]. Concerning this, the current research follows the procedure of revealing causal association among variables in the following Eqs. (12) and (13) as follows:

$$Y_t = \delta_0 + \sum\nolimits_{i=1}^{m} \delta_i Y_{t-i} + \sum\nolimits_{i=1}^{m} \varphi_i X_{t-i} + \mu_t \tag{12}$$

$$X_t = \alpha_0 + \sum\nolimits_{j=1}^{k} \alpha_j Y_{t-j} + \sum\nolimits_{j=1}^{k} \phi_j X_{t-j} + \mu_t \tag{13}$$

Furthermore, this research also utilized the Fully Modified Ordinary Least Squares (FMOLS), Dynamic Ordinary Least Squares (DOLS), and Canonical Cointegrating Regression (CCR) methods to assess the robustness of the ARDL model's findings. The research roadmap is depicted in Fig. 2.

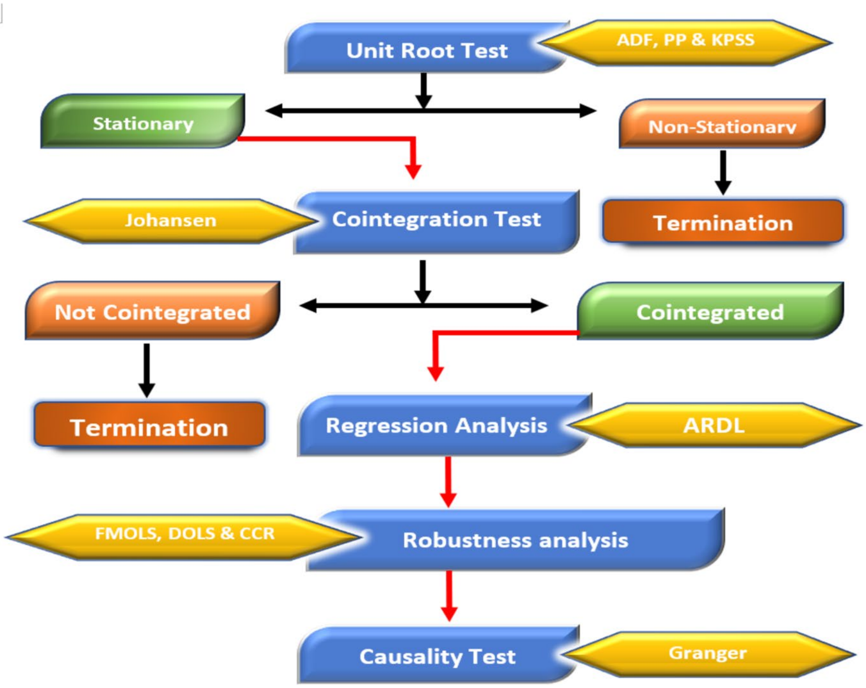

Fig. 2 Roadmap of methodological strategy.
Source: Authors' own creation

Table 2 Descriptive statistics

Stats	EFP	EI	FD	FDI	RE
Mean	4.813	211.085	0.490	1.150	0.014
Median	5.030	65.980	0.504	1.750	0.010
Maximum	6.853	877.290	0.673	3.200	0.060
Minimum	2.358	4.080	0.224	− 1.300	0.010
Std. dev	1.233	262.965	0.144	1.020	0.011
Skewness	− 0.315	1.278	− 0.267	1.575	3.399
Kurtosis	2.190	3.374	1.818	4.551	14.101
Jarque–Bera	1.141	2.234	1.823	3.354	183.559
Probability	0.565	0.2269	0.402	0.101	0.000
Sum	125.141	5488.210	12.731	2.980	0.350
Sum Sq. dev	38.027	17.288	0.515	2.590	0.003

Table 3 Correlation matrix

Variable	LEFP	LEI	LFD	LFDI	LRE
LEFP	1.000				
	–				
LEI	0.726	1.000			
	(0.000)	–			
LFD	0.803	0.702	1.000		
	(0.000)	(0.000)	–		
LFDI	0.179	0.081	0.342	1.000	
	(0.382)	(0.690)	(0.087)	–	
LRE	0.056	0.245	− 0.085	− 0.054	1.000
	(0.785)	(0.227)	(0.677)	(0.791)	–

() denotes the *p*-value.

4 Results and discussion

4.1 Basic data properties

The very first step of empirical analysis is to report the descriptive statistics for the selected variables (EFP, EI, FD, FDI, and RE), which are shown in Table 2. The outcomes of the statistics show that EI has the highest mean and median values of 211.08 and 65.98, respectively. Whereas, RE has the lowest mean and median values at 0.01 and 0.01, respectively. Moreover, the results of skewness show that EFP and FD are negatively skewed, while EI, FDI, and RE are positively skewed. Besides, the outcomes of kurtosis show that the kurtosis values of EFP and FD are more than three, which means the curves of both variables are platykurtic, while the kurtosis values of the remaining variables are less than three, which shows that the curves are leptokurtic. The Jarque–Bera test indicates that the RE data are not normally distributed, while other variables are normally distributed. However, this does not undermine the validity of our analysis for several reasons. The outcomes of descriptive statistics suggest that this dataset is suitable for the intended empirical study.

This study also checks the association among the variables through a correlation matrix, which is shown in Table 3. The correlation matrix reveals a significant positive relationship between EI, FD, and the ecological footprint, while FDI and RE exhibit an insignificant positive relationship. Correlation coefficients are small for FDI and RE but high for EI and FD. The Variance Inflation Factor (VIF)[1] test confirms no

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[1] VIF values of EI, FD, FDI, and RE were 3.71, 4.24, 1.015, and 0.531.

multicollinearity issues, with all values below the threshold of 10, indicating reliable results for the selected series.

4.2 Unit root tests outcomes

Table 4 shows the outcomes of the ADF and PP stationarity approaches with intercept and intercept and trends. The empirical outcomes of the ADF and PP test expose that all the opted variables are insignificant at their level (I (0)) with intercept, except FDI, and also insignificant at their level (I (0)) with trend and intercept, except EI and FDI. But all the opted variables are significant in their first order (I (1)) with both intercept and trend and intercept. Furthermore, this study also used the KPSS unit root approach to find the integration order of the selected series (Table 4). KPSS test statistics show that FDI and RE are not significant at their level, I(0); however, all the other variables are significant at their level, I(0). The outcomes of KPSS also report that all the variables are significant at their first difference I (1), so for further econometric analysis, the ARDL method is suitable to discover the long- and short-run association for the selected time series.

4.3 ARDL bounds and Johansen cointegration approaches results

ARDL bounds test outcomes are summarized in Table 5. This study selected the optimum lag order of the model derived from the "Akaike Information Criteria (AIC)". The Empirical analysis reveals that the value of the F-test statistic is 4.566, which is more than the value of the 5% significance level region, which means the cointegration relationship exists at the 5% level of significance. Moreover, the results of the long-term cointegration analysis of the Johansen approach are shown in Table 6.

The Johansen long-run co-integration analysis utilizes two types of test statistics, the first one is the trace test, and another is the maximum eigenvalue test. To establish the

Table 4 Stationarity analysis of selected series

Series	Intercept			Trend and intercept		
	Level		First difference	Level		First difference
ADF test						
LEFP	−1.181		−2.202	−3.557**		−5.536***
LEI	−0.374		−5.101***	−5.378***		−5.210***
LFD	−1.512		−1.476	−5.106***		−4.136**
LFDI	−3.823***		−3.784**	−5.511***		−5.396***
LRE	−0.981		−1.159	−4.353***		−4.755***
PP test						
LEFP	−1.371		−2.450	−5.619***		−5.538***
LEI	0.265		−5.096***	−14.265***		−14.112***
LFD	−1.438		−1.524	−5.106***		−7.223***
LFDI	−3.808***		−3.769**	−18.205***		−18.072***
LRE	−1.694		−1.656	−4.300***		−4.687***
KPSS test						
LEFP	0.444*		0.125*	0.376*		0.410***
LEI	0.502**		0.088	0.467**		0.462***
LFD	0.376*		0.148**	0.230		0.232***
LFDI	0.126		0.105	0.188		0.199**
LRE	0.253		0.174**	0.493**		0.131*
Critical values	1%	5%	10%	1%	5%	10%
	0.739	0.463	0.347	0.216	0.146	0.119

*** denotes 1%, ** stands for 5%, and * represents a 10% significance level. H_0 for the KPSS approach is the existence of stationarity

Table 5 ARDL bounds test results

Test statistics	F-stats		K	Decision
EFP function	4.586*		4	Cointegrated
Significance level		**Lower bound**		**Upper bound**
CV				
10%		3.030		4.060
5%		3.470		4.570
2.5%		3.890		5.07
1%		4.400		5.720

** represents 5% significance level

Table 6 Johansen cointegration test

Trace test analysis				
Hypothesized no. of CE(s)	**Eigenvalue**	**Trace stat**	**5% CV**	**Prob**
None*	0.995***	283.519	88.804	0.000
M1*	0.917***	139.612	63.876	0.000
M2*	0.796***	72.3681	42.915	0.000
M3*	0.573**	29.411	25.872	0.017
M4	0.212	6.428	12.518	0.408
Maximum eigenvalue test analysis				
Hypothesized no. of CE(s)	**Eigenvalue**	**Max-eigen stat**	**5% CV**	**Prob**
None*	0.995***	143.908	38.331	0.000
M1*	0.917***	67.243	32.118	0.000
M2*	0.796***	42.958	25.823	0.000
M3*	0.573**	22.981	19.387	0.014
M4	0.212	6.429	12.518	0.408

M denotes at most

*** denotes 1%, ** stands for 5%, and * represents a 10% significance level

occurrence of long-term cointegration among selected variables, the null hypothesis should be rejected to confirm the long-run association between variables at a 5% level of significance. Consistent with both tests' figures (trace and maximum eigenvalue) that there are four out of five cointegrated equations that occur at the 5% significance level. Meanwhile, the statistically significant test results show the existence of a significant long-term relationship among the variables."

4.4 Long- and short-run elasticity estimates

After confirming the presence of long-run association among the variables, this study analyzed the dynamic impacts of explanatory variables (EI, FD, FDI, and RE) on Saudi Arabia's EFP through the ARDL model. Table 7 presents the outcomes of the long and short-term ARDL model (1, 0, 1, 1, 0), designated based on the AIC. The outcomes show that eco-innovation has a negative impact on the EFP, which indicates that the ecological footprint will decrease when eco-innovation increases. More evidently, a 1% positive change in eco-innovation decreases the EFP by 0.219 and 0.753% in the long and short term, respectively. Thus, these findings confirm the positive environmental outcomes derived from eco-innovation in Saudi Arabia. Eco-innovation, also known as environmental technology, facilitates the optimization of resource utilization, including energy, water, and raw materials, hence mitigating waste production and resource exhaustion. In Saudi Arabia, where there is a shortage of water and high energy consumption, implementing eco-innovative solutions like water-saving technologies and renewable energy

Table 7 Results of the ARDL model for EFP (1, 0, 1, 1, 0)

Variables	Coeff	S.E	T-stat	Prob
Long-run estimates				
LEI	−0.219**	0.080	−2.744	0.014
LFD	0.530***	0.012	45.377	0.000
LFDI	−0.037***	0.006	−6.163	0.000
LRE	−0.031**	0.014	−2.221	0.040
Short-run estimates				
C	1.910**	0.852	2.243	0.039
@TREND	0.046**	0.020	2.258	0.037
LEFP(-1)	−0.753***	0.201	−3.751	0.002
LEI	−0.165*	0.095	−1.740	0.010
LFD(-1)	0.399**	0.158	2.528	0.022
LFDI(-1)	−0.028	0.024	−1.144	0.268
LRE	−0.024	0.059	−0.340	0.694
D(LFD)	0.139	0.156	0.893	0.384
D(LFDI)	−0.008	0.017	−0.443	0.664
CointEq(-1)	−0.753***	0.148	−5.101	0.000

S.E. stands for standard error

***, **, and * denote 1%, 5%, and 10% levels of significance, respectively

systems can effectively save resources and alleviate environmental stress. A multitude of studies have supported this finding. For instance, Usman et al. [80] for Mercosur economies and Wang et al. [81] for India studied that technological progress plays a crucial role in promoting environmentally sustainable approaches. Furthermore, Saqib et al. [82] and Wen et al. [83] studied that technological advancement leads to improved environmental outcomes in developing and African countries, respectively.

Moreover, the impact of financial development on EFP is significantly positive. To be precise, a 1% positive change in financial development would increase EFP by 0.530% and 0.399% in both the long and short term, respectively. These findings reveal that the impact of financial development on EFP is diminishing the scale effect. The rise of energy-intensive businesses in Saudi Arabia, such as petrochemicals, manufacturing, and large infrastructure projects, can be propelled by financial development. These sectors utilize substantial quantities of energy and resources, releasing GHG and other contaminants that contribute to climate change and environmental deterioration. Moreover, this positive effect of financial development on the ecological footprint aligns with Saudi Arabia's longstanding dependence on oil revenues, as financial deepening typically bolsters fossil fuel ventures over eco-friendly alternatives. To counteract this, Saudi Vision 2030's emphasis on economic diversification and renewable energy adoption may channel financial resources into sustainable efforts, possibly inverting the pattern. This finding is consistent with previous studies discovered by Makhdum et al. [84] for China, Balsalobre-Lorente et al. [85] for APEC countries, and Wang et al. [86] for emerging European countries. Therefore, financial institutions, along with their allied markets and firms, tend to prioritize financial expansion over environmental regulations.

Furthermore, the FDI has a significantly negative effect on the EFP. Therefore, these findings confirm that foreign direct investment has a negative impact on the environment in Saudi Arabia, which further proves the Pollution Halo effect of FDI. In Saudi Arabia, the negative impact of FDI on the ecological footprint underscores the kingdom's strategic shift under Vision 2030 to attract foreign investments in diversified, non-oil sectors like renewable energy and technology, which promote cleaner production and resource efficiency. This results in a 0.037% long-term and 0.008% short-term reduction in EFP per 1% FDI increase, reflecting how targeted inflows can mitigate environmental strain from traditional hydrocarbon reliance. Hence, FDI has the potential to enhance competitiveness and foster innovation within the economy of Saudi Arabia. This can lead to increased efficiency and breakthroughs in technology, which in turn can have positive impacts on the environment. However, sustained policy focus is needed to ensure FDI prioritizes sustainable projects over polluting industries. The finding of FDI in this study is consistent with Roy [47] for India and Dhrifi et al. [87] for developing economies. Contrarily, Usman et al. [88] observed that FDI has a positive impact on environmental degradation in G-7 countries.

Finally, the impact of RE on EFP is significantly negative, which indicates the inverse relationship between RE and EFP. In Saudi Arabia, this negative impact reflects the kingdom's transition from oil dominance toward sustainable energy under Vision 2030, where RE investments in solar and wind projects reduce carbon-intensive activities and enhance environmental resilience. This inverse relationship demonstrates that a 1% increase in RE leads to a 0.031% long-term and 0.024% short-term decrease in EFP, aligning with efforts to diversify the economy and meet global climate goals. Accelerating RE adoption could further amplify these benefits, though challenges like infrastructure development remain. Saudi Arabia's reliance on oil and gas for generating electricity makes it vulnerable to fluctuations in global energy markets. Saudi Arabia can increase energy security, decrease susceptibility to supply disruptions, and develop a more robust and sustainable energy infrastructure by incorporating renewable sources like solar and wind power. This, in turn, would enhance environmental performance. The results of renewable energy are consistent with Xue et al. [89], who revealed that renewable energy decreases the EFP in E-7 and G-7 countries and South Asian countries, respectively. Hence, the findings recommend that the government and policymakers in Saudi Arabia make beneficial policies to boost investment in the sector of renewable energy.

Table 7 shows the estimated "error correction model (ECM)" outcomes by using the ARDL model. The outcomes show that the value of ECM is significant with a negative sign, showing the 75.31% rate of adjustment to long-term equilibrium from short-term disequilibrium in the model.

4.5 Robustness analysis

This study measures the accuracy and effectiveness of the primary findings by using some other tests. The results of FMOLS, DOLS, and CCR models are presented in Table 8. The findings of these models are much the same as the empirical results obtained from the ARDL model, confirming the robustness of the model. Hence, it is confirmed that the

Table 8 Robustness analysis of FMOLS, DOLS, and CCR

Variables	**FMOLS**	**DOLS**	**CCR**
	EFP function		
LEI	−0.142***	−0.141***	−0.149**
LFD	0.304***	0.307***	0.308***
LFDI	−0.008**	−0.008	−0.005
LRE	−0.053***	−0.048**	−0.066*
C	1.405***	1.443***	1.314***
@TREND	0.053***	0.052***	0.054***

*** denotes 1%, ** stands for 5%, and * represents a 10% significance level

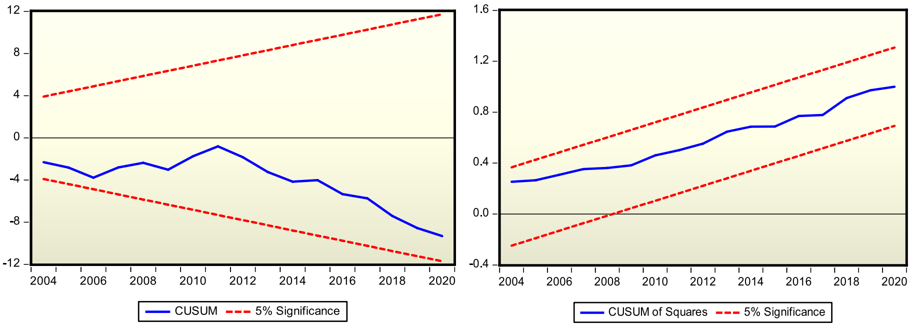

Fig. 3 CUSUM and CUSUM of squares plots

Table 9 Results of the pairwise Granger causality test

Null hypothesis	F-stat	Prob	Interpretation
LEI ~ LEFP	1.976	0.166	Unidirectional causality occurs
LEFP ~ LEI	3.472	0.052	
LFD ~ LEFP	6.724	0.006	Unidirectional causality occurs
LEFP ~ LFD	0.0978	0.907	
LFDI ~ LEFP	0.232	0.795	Unidirectional causality occurs
LEFP ~ LFDI	9.149	0.002	
LRE ~ LEFP	1.604	0.227	No causality occurs
LEFP ~ LRE	0.872	0.434	

~ represents "does not granger cause"

estimated long-term elasticity of this series is consistent, reliable, and robust. The indicators of the robustness estimator align with the ARDL coefficient, indicating that the findings remained consistent without any large diversion. Moreover, the outcomes of all the selected variables are significant in all models, and the signs are also consistent with predictions. The findings of all four models indicate that EI, FDI, and RE can defend the atmosphere, whereas FD declines the environmental quality in Saudi Arabia.

Additionally, this study applied the cumulative sum test (CUSUM) and the cumulative sum of squares test (CUSUM of squares) recursive estimation tests to diagnose the stability of the estimated model. Figure 3 represents the recursive residual plots of CUSUM and CUSUM of squares. In these figures, the red dotted lines represent the acceptance region of a 5% level of significance, while the blue line represents recursive residual plots. For a stable model, this blue line should lie between both red dotted lines. Hence, the blue line of the model is within the 5% significance level, which shows that the model is properly stated. Finally, this study confirms that all the parameters are stable and reliable.

4.6 Granger causality analysis

The causal relationship plays a key role as it establishes long-run connections between variables; therefore, if the unit root exists in the series, the Granger causality test is employed to assess this relationship. For this reason, a test will be conducted for the unidirectional or bidirectional causality between the selected variables. If the existing value of x could be predicted by using the lagged value of y, then the Granger causality should exist between the two series (x and y). Table 9 shows the outcomes of Granger causality, which confirms the presence of unidirectional causality from EFP to eco-innovation, FD, and FDI. The association among the aforementioned variables contributes to enhancing the stability and effectiveness of environmental policy, which ultimately supports the achievement of the SDGs.

5 Conclusion and policy implications

This study investigates how Saudi Arabia's ecological footprint has been influenced by eco-innovations, financial development, FDI, and renewable energy over the period 1995–2022. The ARDL model serves as the primary analytical framework, complemented by Granger causality tests to assess the direction of the relationships. The findings indicate that eco-innovation contributes to reducing the ecological footprint, whereas financial development—by expanding resource- and energy-intensive activities—exerts additional environmental pressure. In contrast, both FDI and renewable energy show long-run environmental benefits. The causality analysis reveals primarily one-way relationships among the variables, with renewable energy being the notable exception.

These findings add nuance to the sustainability debate in resource-dependent economies. They show that factors like eco-innovation, financial development, and FDI are not inherently beneficial or harmful; their environmental impact depends on the surrounding institutional and policy context. In Saudi Arabia, financial development appears to intensify ecological pressure by channeling capital into heavy industries, whereas FDI—often associated with pollution havens—may instead produce a "halo effect" by introducing cleaner technologies. Eco-innovation, measured through indicators such as patents or R&D activity, also proves effective in improving environmental outcomes when supported by appropriate policies.

The results carry several policy implications. First, expanding eco-innovation should be a priority, with investment directed to water-saving systems, renewable energy technologies, and carbon capture solutions. Allocating part of oil revenues to R&D in these areas would help Saudi Arabia reconcile economic growth with ecological sustainability. This requires not only funding but also stronger regulatory frameworks and greater cooperation between government, academia, and industry. Second, financial development needs to be steered toward green outcomes. Without clear oversight, it risks worsening environmental degradation. Green finance instruments such as sustainability-linked bonds, concessional credit for clean projects, and tax incentives for environmentally responsible investment could help redirect financial flows. Tying credit allocation more explicitly to environmental performance standards would also ensure that the growth of the financial sector contributes to ecological balance. Third, FDI can act as a constructive force for environmental sustainability when managed strategically. For instance, in 2024, Saudi Arabia attracted approximately $20.25 billion in FDI net inflows, representing about 1.6% of its GDP [90],by imposing stringent environmental stipulations on these investments, the kingdom could compel foreign companies to introduce not just financial capital but also cutting-edge green technologies, efficient resource management systems, and eco-friendly operational standards. This approach, aligned with Saudi Vision 2030's goals for economic diversification, would heighten market competition, encourage domestic firms to adopt sustainable innovations, and ultimately diminish the overall ecological footprint through reduced emissions and waste.

Finally, renewable energy remains essential for Saudi Arabia's long-term strategy. Greater reliance on solar and wind power would reduce dependence on fossil fuels, enhance energy security, and lower ecological vulnerability. Integrating renewables into industrial clusters and promoting decentralized energy systems would reinforce national infrastructure and align with Vision 2030 and the SDGs, particularly SDG 7 (affordable and clean energy) and SDG 13 (climate action).

Despite its contributions, this study is not without limitations. The dataset spans a relatively short time period, which constrains the ability to fully capture long-term structural transformations in Saudi Arabia's economy and environment. Future research would benefit from extending the time horizon and incorporating sector-specific data to better reflect the varying environmental impacts across industries such as energy, manufacturing, and services. Moreover, the current analysis relies on a linear ARDL framework, which may not adequately capture heterogeneous or non-linear dynamics. Employing asymmetric, nonlinear ARDL, Fourier, or quantile-based approaches could provide deeper insights into how eco-innovation, financial development, and renewable energy affect the ecological footprint under different economic and policy regimes. Another fruitful direction would be to assess Saudi Arabia's progress toward the SDGs during distinct phases of economic expansion and downturn. Comparative studies with other oil-rich Gulf economies could also illuminate how variations in institutional frameworks, governance quality, and resource dependency influence environmental outcomes. Such extensions would enrich the broader understanding of sustainable development pathways in resource-dependent economies.

Abbreviations

ADF	Augmented dickey–fuller
AMG	Augmented mean group
ARDL	Autoregressive distributed lag
CCEMG	Common correlated effects mean group
CCR	Canonical cointegration regression
CO_2	Carbon dioxide
COP28	28th conference of the parties
DOSL	Dynamic ordinary least squares
EFP	Ecological footprint
EI	Eco innovations
FD	Financial development
FDI	Foreign direct investment
FMOLS	Fully modified ordinary least squares
GDP	Gross domestic product
GHG	Greenhouse gas
KPSS	Kwiatkowski–Phillips–Schmidt–Shin
NARDL	Nonlinear autoregressive distributed lag
PP	Phillips-perron
QARDL	Quantile autoregressive distributed lag
RE	Renewable energy
R&D	Research and development
SDG	Sustainable development goals
USA	United States of America
US$	US dollar

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Author contributions

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Declarations

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References
1. Pata UK, Kartal MT, Adebayo TS, Ullah S. Enhancing environmental quality in the United States by linking biomass energy consumption and load capacity factor. Geosci Front. 2023;14(3):101531. https://doi.org/10.1016/j.gsf.2022.101531.
2. Bekun FV, Fumey MP, Staniewski MW, Sun L, Agboola PO. Energy intensive growth and the transition pathways: insights into the role of renewable energy and open market conditions in developing countries. Energy. 2025;322:135192.
3. Kocak E, Alnour M. Energy R&D expenditure, bioethanol consumption, and greenhouse gas emissions in the United States: non-linear analysis and political implications. J Clean Prod. 2022;374(7):133887. https://doi.org/10.1016/j.jclepro.2022.133887.
4. Altıntaş H, Kassouri Y. The impact of energy technology innovations on cleaner energy supply and carbon footprints in Europe: a linear versus nonlinear approach. J Clean Prod. 2020;276:124140. https://doi.org/10.1016/j.jclepro.2020.124140.
5. Koçak E, Ulucak ZŞ. The effect of energy R&D expenditures on CO_2 emission reduction: estimation of the STIRPAT model for OECD countries. Environ Sci Pollut Res Int. 2019;26:14328–38. https://doi.org/10.1007/s11356-019-04712-2.
6. Park Y, Meng F, Baloch MA. The effect of ICT, financial development, growth, and trade openness on CO_2 emissions: an empirical analysis. Environ Sci Pollut Res Int. 2018;25:30708–30719. https://doi.org/10.1007/s11356-018-3108-6.
7. Ahmed K. Environmental policy stringency, related technological change and emissions inventory in 20 OECD countries. J Environ Manage. 2020;274:111209. https://doi.org/10.1016/j.jenvman.2020.111209.
8. Khurshid A, Rauf A, Qayyum S, Calin AC, Duan W. Green innovation and carbon emissions: the role of carbon pricing and environmental policies in attaining sustainable development targets of carbon mitigation—evidence from Central-Eastern Europe. Environ Dev Sustain. 2023;25(8):8777–8798.
9. Chu LK, Hoang DP. The complementarity of income equalization and innovation for more effective emission reduction. J Environ Manage. 2021;284:112007. https://doi.org/10.1016/j.jenvman.2021.112007.
10. Khattak SI, Ahmad M, Khan ZU, Khan A. Exploring the impact of innovation, renewable energy consumption, and income on CO_2 emissions: new evidence from the BRICS economies. Environ Sci Pollut Res Int. 2020;27(12):13866–81. https://doi.org/10.1007/s11356-020-07876-4.
11. Hussain M, Mir GM, Usman M, Ye C, Mansoor S. Analysing the role of environment-related technologies and carbon emissions in emerging economies: a step towards sustainable development. Environ Technol. 2022;43(3):367–75. https://doi.org/10.1080/09593330.2020.1788171.
12. Ahmad M, Ahmed Z, Alvarado R, Hussain N, Khan SA. Financial development, resource richness, eco-innovation, and sustainable development: does geopolitical risk matter? J Environ Manage. 2024;351:119824.
13. Abid M, Gheraia Z, Abdelli H. Does renewable energy consumption affect ecological footprints in Saudi Arabia? A bootstrap causality test. Renew Energy. 2022;189:813–21. https://doi.org/10.1016/j.renene.2022.03.043.
14. Iqbal A, Tang X, Rasool SF. Investigating the nexus between CO_2 emissions, renewable energy consumption, FDI, exports and economic growth: evidence from BRICS countries. Environ Dev Sustain. 2023;25(3):2234–63.
15. Ullah S, Luo R, Adebayo TS, Kartal MT. Paving the ways toward sustainable development: the asymmetric effect of economic complexity, renewable electricity, and foreign direct investment on the environmental sustainability in BRICS-T. Environ Dev Sustain. 2024;26(4):9115–39.
16. Wen Y, Onwe JC, Haseeb M, Saini S, Matuka A, Sahoo D. Role of technological innovation, renewable and non-renewable energy, and economic growth on environmental quality. Evidence from African countries. Front Energy Res. 2022;10:958839. https://doi.org/10.3389/fenrg.2022.958839.
17. Wang J, Yang L, Yang J. How sustainable environment is influenced by the foreign direct investment, financial development, economic growth, globalization, innovation, and urbanization in China. Environ Sci Pollut Res Int. 2023;30(17):49889–904. https://doi.org/10.1007/s11356-023-25634-0.
18. Haseeb M, Hossain ME, Hossain MR, Rehman MZ, Bekun FV. Do the United States' fiscal decentralization, money supply, and environmental policies promote the clean energy transition? Haseeb M et al. Environ Dev Sustainability, 2025;1–34.

19. Onwe JC, Bandyopadhyay A, Hamid I, Rej S, Hossain ME. Environment sustainability through energy transition and globalization in G7 countries: what role does environmental tax play? Renew Energy. 2023;218:119302.
20. Bilgili F, Önderol S, Kuşkaya S, Alnour M, Hoque ME, Balsalobre-Lorente D. Renewable energy and technology adoption: mitigating CO_2 emissions through implementation strategies. Nat Resour Forum. 2025;49(2):1478–535. https://doi.org/10.1111/1477-8947.12441.
21. Ahmad M, Khan Z, Rahman ZU, Khattak SI, Khan ZU. Can innovation shocks determine CO2 emissions (CO2e) in the OECD economies? A new perspective. Econ Innov New Technol. 2021;30(1):89–109. https://doi.org/10.1080/10438599.2019.1684643.
22. Wei Z, Lihua H. Effects of tourism and eco-innovation on environmental quality in selected ASEAN countries. Environ Sci Pollut Res. 2023;30(15):42889–903. https://doi.org/10.1007/s11356-021-17541-z.
23. Ali K, Zhang Q, Khan MK, Boulanouar Z, Hamza F, Ullah S. China's transition to sustainable transport assessing the impact of financial innovation, patent innovation, and bioenergy: evidence from an innovative time–frequency analysis. Financ Innov. 2025;11(1):116. https://doi.org/10.1186/s40854-025-00785-w.
24. Gormus S, Aydin M. Revisiting the environmental Kuznets curve hypothesis using innovation: new evidence from the top 10 innovative economies. Environ Sci Pollut Res. 2020;27:27904–13. https://doi.org/10.1007/s11356-020-09110-7.
25. Fethi S, Rahuma A. The role of eco-innovation on CO2 emission reduction in an extended version of the environmental Kuznets curve: evidence from the top 20 refined oil exporting countries. Environ Sci Pollut Res. 2019;26:30145–53. https://doi.org/10.1007/s11356-019-05951-z.
26. Sun Y, Duru OA, Razzaq A, Dinca MS. The asymmetric effect eco-innovation and tourism towards carbon neutrality target in Turkey. J Environ Manage. 2021;299:113653. https://doi.org/10.1016/j.jenvman.2021.113653.
27. Olanrewaju VO, Irfan M, Altuntaş M, Agyekum EB, Kamel S, El-Naggar MF. Towards sustainable environment in G7 nations: the role of renewable energy consumption, eco-innovation and trade openness. Front Environ Sci. 2022;10:925822. https://doi.org/10.3389/fenvs.2022.925822.
28. Mehmood U, Tariq S, Aslam MU, Agyekum EB, Uhunamure SE, Shale K, et al. Evaluating the impact of digitalization, renewable energy use, and technological innovation on load capacity factor in G8 nations. Sci Rep. 2023;13(1):9131.
29. Sharif A, Kartal MT, Bekun FV, Pata UK, Foon CL, Depren SK. Role of green technology, environmental taxes, and green energy towards sustainable environment: insights from sovereign Nordic countries by CS-ARDL approach. Gondwana Res. 2023;117:194–206. https://doi.org/10.1016/j.gr.2023.01.009.
30. Yunzhao L. Modelling the role of eco innovation, renewable energy, and environmental taxes in carbon emissions reduction in E– 7 economies: evidence from advance panel estimations. Renew Energy. 2022;190:309–18. https://doi.org/10.1016/j.renene.2022.03.119.
31. Hossain MR, Rana MJ, Saha SM, Haseeb M, Islam MS, Amin MR, et al. Role of energy mix and eco-innovation in achieving environmental sustainability in the USA using the dynamic ARDL approach: accounting the supply side of the ecosystem. Renew Energy. 2023;215:118925.
32. Tufail M, Song L, Khan Z. Green finance and green growth nexus: evaluating the role of globalization and human capital. J Appl Econ. 2024;27(1):2309437. https://doi.org/10.1080/15140326.2024.2309437.
33. Ahmed Z, Zhang B, Cary M. Linking economic globalization, economic growth, financial development, and ecological footprint: evidence from symmetric and asymmetric ARDL. Ecol Indic. 2021;121:107060. https://doi.org/10.1016/j.ecolind.2020.107060.
34. Ali K, Zhang Q, Paolo F. Technological forecasting & social change sustainable futures : what ' s driving France ' s eco-revolution ? Technol Forecast Soc Change. 2025;219:124284. https://doi.org/10.1016/j.techfore.2025.124284.
35. Bu J, Ali K. Environmental degradation in terms of health expenditure, education and economic growth. Evidence of novel approach. Front Environ Sci. 2022;10:1046213. https://doi.org/10.3389/fenvs.2022.1046213.
36. Gill AR, Riaz R, Ali M. The asymmetric impact of financial development on ecological footprint in Pakistan. Environ Sci Pollut Res Int. 2023;30(11):30755–65. https://doi.org/10.1007/s11356-022-24384-9.
37. Ozturk I, Farooq S, Majeed MT, Skare M. An empirical investigation of financial development and ecological footprint in South Asia: Bridging the EKC and pollution haven hypotheses. Geosci Front. 2023. https://doi.org/10.1016/j.gsf.2023.101588.
38. Ju S, Andriamahery A, Qamruzzaman M, Kor S. Effects of financial development, FDI and good governance on environmental degradation in the Arab nation: dose technological innovation matters? Front Environ Sci. 2023;11:1094976. https://doi.org/10.3389/fenvs.2023.1094976.
39. Ali K, Jianguo D, Kirikkaleli D, Oláh J, Altuntaş M. Do green technological innovation, financial development, economic policy uncertainty, and institutional quality matter for environmental sustainability? All Earth. 2023;35(1):82–101. https://doi.org/10.1080/27669645.2023.2200330.
40. Majeed MT, Mazhar M. Financial development and ecological footprint: a global panel data analysis. Pakistan J Commer Soc Sci (PJCSS). 2019;13(2):487–514.
41. Acar S, Altıntaş N, Haziyev V. The effect of financial development and economic growth on ecological footprint in Azerbaijan: an ARDL bound test approach with structural breaks. Environ Ecol Stat. 2023;30(1):41–59. https://doi.org/10.1007/s10651-022-00551-6.
42. Wu L, Adebayo TS, Yue XG, Umut A. The role of renewable energy consumption and financial development in environmental sustainability: implications for the Nordic Countries. Int J Sustain Dev World Ecol. 2023;30(1):21–36. https://doi.org/10.1080/13504509.2022.2115577.
43. Bashir MF. Discovering the evolution of Pollution Haven Hypothesis: a literature review and future research agenda. Environ Sci Pollut Res. 2022;29(32):48210–32. https://doi.org/10.1007/s11356-022-20782-1.
44. Wang R, Usman M, Radulescu M, Cifuentes-Faura J, Balsalobre-Lorente D. Achieving ecological sustainability through technological innovations, financial development, foreign direct investment, and energy consumption in developing European countries. Gondwana Res. 2023;119:138–52. https://doi.org/10.1016/j.gr.2023.02.023.
45. Kindo M, Ouoba Y, Kabore FP. Effect of foreign direct investment on environmental quality in West Africa. Environ Sci Pollut Res Int. 2023;30(20):57788–800. https://doi.org/10.1007/s11356-023-26545-w.
46. Yasmeen R, Yao X, Padda IUH, Shah WUH, Jie W. Exploring the role of solar energy and foreign direct investment for clean environment: evidence from top 10 solar energy consuming countries. Renew Energy. 2022;185:147–58. https://doi.org/10.1016/j.renene.2021.12.048.

47. Roy A. The impact of foreign direct investment, renewable and non-renewable energy consumption, and natural resources on ecological footprint: an Indian perspective. Int J Energy Sect Manag. 2023. https://doi.org/10.1108/IJESM-09-2022-0004.
48. Jan A, Xin-Gang Z, Babar SF, Khan MK. Role of financial development, foreign direct investment inflow, innovation in environmental degradation in Pakistan with dynamic ARDL simulation model. Environ Sci Pollut Res Int. 2023;30(17):49381–96. https://doi.org/10.1007/s11356-023-25631-3.
49. Nyeadi JD. The impact of financial development and foreign direct investment on environmental sustainability in Sub-Saharan Africa: using PMG-ARDL approach. Econ Res-Ekonomska Istraž. 2023;36(2):2106270. https://doi.org/10.1080/1331677X.2022.2106270.
50. Shabir M, Ali M, Hashmi SH, Bakhsh S. Heterogeneous effects of economic policy uncertainty and foreign direct investment on environmental quality: cross-country evidence. Environ Sci Pollut Res Int. 2022;29(2):2737–52. https://doi.org/10.1007/s11356-021-15715-3.
51. Kartal MT, Samour A, Adebayo TS, Depren SK. Do nuclear energy and renewable energy surge environmental quality in the United States? New insights from novel bootstrap Fourier Granger causality in quantiles approach. Prog Nucl Energy. 2023;155:104509. https://doi.org/10.1016/j.pnucene.2022.104509.
52. Adebayo TS, Kartal MT, Ullah S. Role of hydroelectricity and natural gas consumption on environmental sustainability in the United States: evidence from novel time-frequency approaches. J Environ Manage. 2023;328:116987.
53. Jiang Y, Batool Z, Raza SMF, Haseeb M, Ali S, Zain Ul Abidin S. Analyzing the asymmetric effect of renewable energy consumption on environment in STIRPAT-Kaya-EKC framework: a NARDL approach for China. Int J Environ Res Public Health. 2022;19(12):7100. https://doi.org/10.3390/ijerph19127100.
54. Murshed M, Haseeb M, Alam MS. The environmental Kuznets curve hypothesis for carbon and ecological footprints in South Asia: the role of renewable energy. GeoJournal. 2022;87(3):2345–72. https://doi.org/10.1007/s10708-020-10370-6.
55. Javed A, Rapposelli A, Khan F, Javed A. The impact of green technology innovation, environmental taxes, and renewable energy consumption on ecological footprint in Italy: fresh evidence from novel dynamic ARDL simulations. Technol Forecast Soc Change. 2023;191:122534. https://doi.org/10.1016/j.techfore.2023.122534.
56. Sharif A, Baris-Tuzemen O, Uzuner G, Ozturk I, Sinha A. Revisiting the role of renewable and non-renewable energy consumption on Turkey's ecological footprint: evidence from Quantile ARDL approach. Sustain Cities Soc. 2020;57:102138. https://doi.org/10.1016/j.scs.2020.102138.
57. Wang J, Dong K. What drives environmental degradation? Evidence from 14 Sub-Saharan African countries. Sci Total Environ. 2019;656:165–73. https://doi.org/10.1016/j.scitotenv.2018.11.354.
58. Adebayo TS, Kartal MT, Ağa M, Al-Faryan MAS. Role of country risks and renewable energy consumption on environmental quality: evidence from MINT countries. J Environ Manage. 2023;327:116884. https://doi.org/10.1016/j.jenvman.2022.116884.
59. Kirikkaleli D, Ali K, Zhang Q, Ozrecberoglu N. Environmental sustainability in the USA : role of artificial intelligence. Sustain Futures. 2025;9:100823. https://doi.org/10.1016/j.sftr.2025.100823.
60. Bulut U. The impacts of non-renewable and renewable energy on CO 2 emissions in Turkey. Environ Sci Pollut Res. 2017;24:15416–26. https://doi.org/10.1007/s11356-017-9175-2.
61. Farhani S, Shahbaz M. What role of renewable and non-renewable electricity consumption and output is needed to initially mitigate CO2 emissions in MENA region? Renew Sustain Energy Rev. 2014;40:80–90. https://doi.org/10.1016/j.rser.2014.07.170.
62. GFN (2023). Global footprint network. Available at https://www.footprintnetwork.org/our-work/ecological-footprint/ Accessed on date 30th June, 2023.
63. WDI (2023). World Bank (world development indicators). (accessed date 30-JUNE-2023), https://databank.worldbank.org/source/world-development-indicators#.
64. Ul-Durar S, Awan U, Varma A, Memon S, Mention AL. Integrating knowledge management and orientation dynamics for organization transition from eco-innovation to circular economy. J Knowl Manag. 2023;27(8):2217–48. https://doi.org/10.1108/JKM-05-2022-0424.
65. Adebayo TS, Ullah S, Kartal MT, Ali K, Pata UK, Ağa M. Endorsing sustainable development in BRICS: the role of technological innovation, renewable energy consumption, and natural resources in limiting carbon emission. Sci Total Environ. 2023;859:160181.
66. Xu P, Adebayo TS, Khan KA, Özkan O, Shukurullaevich NK. United States' 2050 carbon neutrality: myth or reality? Evaluating the impact of high-tech industries and green electricity. J Clean Prod. 2024;440:140855. https://doi.org/10.1016/j.jclepro.2024.140855.
67. Ashraf A, Doytch N. Does investing abroad reduce the ecological footprints at home? Analysis of outward GFDI and M&a from developed and developing countries. Environ Dev Sustain. 2023;25(7):6689–710.
68. Zugravu-Soilita N. How does foreign direct investment affect pollution? Toward a better understanding of the direct and conditional effects. Environ Resource Econ. 2017;66:293–338.
69. Copeland BR, Taylor MS. Trade, growth, and the environment. J Econ Lit. 2004;42(1):7–71.
70. Dean JM, Lovely ME, Wang H. Are foreign investors attracted to weak environmental regulations? Evaluating the evidence from China. J Dev Econ. 2009;90(1):1–13.
71. Zarsky L. Havens, halos and spaghetti: untangling the evidence about foreign direct investment and the environment. Foreign Direct Invest Environ. 1999;13(8):47–74.
72. Albornoz F, Cole MA, Elliott RJ, Ercolani MG. In search of environmental spillovers. World Econ. 2009;32(1):136–63.
73. Langnel Z, Amegavi GB. Globalization, electricity consumption and ecological footprint: an autoregressive distributive lag (ARDL) approach. Sustain Cities Soc. 2020;63:102482. https://doi.org/10.1016/j.scs.2020.102482.
74. Phillips PC, Perron P. Testing for a unit root in time series regression. Biometrika. 1988;75(2):335–46. https://doi.org/10.1093/biomet/75.2.335.
75. Dickey DA, Fuller WA. Distribution of the estimators for autoregressive time series with a unit root. J Am Stat Assoc. 1979;74(366a):427–31. https://doi.org/10.1080/01621459.1979.10482531.
76. Kwiatkowski D, Phillips PC, Schmidt P, Shin Y. Testing the null hypothesis of stationarity against the alternative of a unit root: how sure are we that economic time series have a unit root? J Econom. 1992;54(1–3):159–78. https://doi.org/10.1016/0304-4076(92)90104-Y.

77. Johansen S. Statistical analysis of cointegration vectors. J Econ Dyn Control. 1988;12(2–3):231–54. https://doi.org/10.1016/0165-1889(88)90041-3.
78. Pesaran MH, Shin Y, Smith RJ. Bounds testing approaches to the analysis of level relationships. J Appl Econom. 2001;16(3):289–326. https://doi.org/10.1002/jae.616.
79. Granger CW. Investigating causal relations by econometric models and cross-spectral methods. Econometrica. 1969. https://doi.org/10.2307/1912791.
80. Usman M, Balsalobre-Lorente D, Jahanger A, Ahmad P. Are Mercosur economies going green or going away? An empirical investigation of the association between technological innovations, energy use, natural resources and GHG emissions. Gondwana Res. 2023;113:53–70. https://doi.org/10.1016/j.gr.2022.10.018.
81. Wang X, Sarwar B, Haseeb M, Samour A, Hossain ME, Kamal M, et al. Impact of banking development and renewable energy consumption on environmental sustainability in Germany: novel findings using the bootstrap ARDL approach. Heliyon. 2023. https://doi.org/10.1016/j.heliyon.2023.e20584.
82. Saqib N, Ozturk I, Usman M. Investigating the implications of technological innovations, financial inclusion, and renewable energy in diminishing ecological footprints levels in emerging economies. Geosci Front. 2023. https://doi.org/10.1016/j.gsf.2023.101667.
83. Wen Y, Shabbir MS, Haseeb M, Kamal M, Anwar A, Khan MF, et al. The dynamic effect of information and communication technology and renewable energy on CO2 emission: fresh evidence from panel quantile regression. Front Environ Sci. 2022;10:953035. https://doi.org/10.3389/fenvs.2022.953035.
84. Makhdum MSA, Usman M, Kousar R, Cifuentes-Faura J, Radulescu M, Balsalobre-Lorente D. How do institutional quality, natural resources, renewable energy, and financial development reduce ecological footprint without hindering economic growth trajectory? Evidence from China. Sustainability. 2022;14(21):13910. https://doi.org/10.3390/su142113910.
85. Balsalobre-Lorente D, Topaloglu EE, Nur T, Evcimen C. Exploring the linkage between financial development and ecological footprint in APEC countries: a novel view under corruption perception and environmental policy stringency. J Clean Prod. 2023. https://doi.org/10.1016/j.jclepro.2023.137686.
86. Wang Y, Villanthenkodath MA, Haseeb M. The dynamic link between eco-innovation and ecological footprint in India: does the environmental Kuznets curve (EKC) hold? Manag Environ Qual. 2023. https://doi.org/10.1108/MEQ-05-2022-0136.
87. Dhrifi A, Jaziri R, Alnahdi S. Does foreign direct investment and environmental degradation matter for poverty? Evidence from developing countries. Struct Change Econ Dyn. 2020;52:13–21. https://doi.org/10.1016/j.strueco.2019.09.008.
88. Usman M, Jahanger A, Makhdum MSA, Radulescu M, Balsalobre-Lorente D, Jianu E. An empirical investigation of ecological footprint using nuclear energy, industrialization, fossil fuels and foreign direct investment. Energies. 2022;15(17):6442. https://doi.org/10.3390/en15176442.
89. Xue L, Haseeb M, Mahmood H, Alkhateeb TTY, Murshed M. Renewable energy use and ecological footprints mitigation: evidence from selected South Asian economies. Sustainability. 2021;13(4):1613. https://doi.org/10.3390/su13041613.
90. WDI (2025). Foreign direct investment, net inflows (BoP, current US$) - Saudi Arabia. Available at https://data.worldbank.org/indicator/BX.KLT.DINV.CD.WD?locations=SA Accessed on 22nd October 2025.

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