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Testing the impact of external sovereign debt on Turkey's ecological footprint: New evidence from the bootstrap ARDL approach

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As is glaringly apparent, the world is now bedeviled with environmental challenges and ecological complications. This may not be unconnected with the persistent ecological challenges emanating from fossil fuel consumption and changing lifestyles. This is why various attempts are ongoing to advance the course of renewable energy and economic growth as a response to environmental change. Therefore, this study seeks to investigate the dynamic effect of external debt, energy usage, and real income on the ecological footprint in Turkey, covering the period 1985–2017. To achieve the stated objective, the study used the newly developed Bootstrap Autoregressive Distributed Lag (BARDL) test and the Granger causality test to unravel the co-movement as well as the direction of causality among the variables. The results revealed that external debt influences environmental quality in both the short and the long run. However, energy consumption and real income have been found to have retarded environmental quality in both the short and the long run. The Granger causality test results revealed that the causal flow direction runs from external debt, economic growth, and energy usage to environmental quality. Therefore, the study argues that for the Turkish government to achieve a long-term plan of environmental sustainability, there is a need for the government to venture into debt consolidation programs such

Abbreviations: ARDL, autoregressive distributed lag model; VAR, vector autoregressive; CO_2, carbon dioxide; EKC, Environmental Kuznets Curve; BRICS-T, Brazil, Russia, India, China, South Africa, and Turkey; OLS, ordinary least square; OECD, The Organisation for Economic Co-operation and Development; MENA, Middle East and North Africa; FDI, foreign direct investment; USA, United States of America; STIRPAT, the stochastic (ST) estimation of environmental impacts (I) by regression (R) on population (P), affluence (A) and technology (T); G20, group of twenty; MINT, Mexico, Indonesia, Nigeria, Turkey; SANE, South Africa, Algeria, Nigeria and Egypt; BRICS, Brazil, Russia, India, China, and South Africa; AMG, augmented mean group; GMM, generalized method of moments; FE, ecological footprint; EG, economic growth; ED, external debt; EC, energy consumption; CV, critical values; ECM, error correction model; CUSUM, cumulative sum.

as implementing tax increases and cutting public spending in order to increase fiscal space that would finance long-term environmental protection policies.

KEYWORDS

external sovereign debt, energy, ecological footprint, bootstrap ARDL, real income, Turkey

1 Introduction

The relationship between public debt and environmental degradation is a renewable phenomenon, with extant literature suggesting that further studies could unravel a novel path through which the international community could reduce to the barest minimum the negative effect of rising human demand (or economic activity) on natural capital (or ecological footprint) (Ibrahim et al., 2017; Mert et al., 2019). Certainly, a plethora of literature has explored this effect via both supply and demand. A strand of literature dealing with the supply aspect of this effect argues that public debt is the feedback that affects economic activities and hence their impact on environmental degradation (Mert et al., 2019). On the other hand, the demand side effect is rooted in the inclusion development drive, which increases public spending and thereby demands goods and services produced by companies, particularly those using production technologies that adversely affect the environment (Ibrahim et al., 2017).

The role of sovereign public debt in the development and stability of the Turkish economy cannot be emphasized too much, particularly the aftermath of the global financial meltdown of the last decade that revived discussion on the significant roles played by the public sector in stimulating the development of the real sector of the economy (Shahbaz et al., 2018). In the context of this debate, researchers have documented evidence that public spending and economic stability are seen not only as intertwined but also as two sides of the same coin. In this way, examining the ecological consequences of sovereign public debt (Shahbaz et al., 2019) is pertinent, particularly the impact of shocks driven by debt volatility on the ecological footprint. Two key pathways can be explained through the relationship between sovereign public debt and environmental footprint. First, rising sovereign public debt could free up local enterprises, which will, in turn, facilitate investment leading to rapid economic growth, which causes an unprecedented surge in the demand for natural capital. Second, an increase in sovereign public debt generates income expansion through a multiplier effect and leads to the rise in demand for energy-consuming goods and services (for a review, see Ibrahim et al., 2017; Shahbaz et al., 2019). Indeed, it is an understatement in the environmental context to argue about whether public expenditure increases CO_2 emissions, as the main question is whether the dynamic interaction of shocks driven by sovereign public debt and some key macroeconomic variables would lead to ecological degradation (Ibrahim et al., 2017).

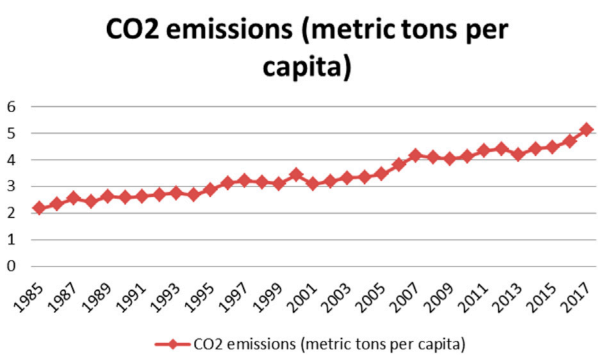

FIGURE 1
CO_2 emissions (metric tons per capita) in Turkey over the tested period.

There exist mixed, inconclusive, and sometimes inconsistent findings in the extant studies that unravel the dynamic effect of public expenditure on environmental degradation (Ibrahim et al., 2017; Mert et al., 2019). Interestingly Cheng (2015) posits that a sound and effective financial system may offer the options needed to develop green energy by funding more innovative firms, which could pave the way for more technological innovation capable of reducing energy intensity (Shahbaz et al., 2019). An important aspect of Turkey's financial institutions is the robustness in supporting the energy sector, as highlighted in Ibrahim et al. (2017). However, capital market support for conservational policy is pathetically weak, due to the low potential return. The study's objective is to apply the newly developed bootstrap ARDL test in exploring the nexus between external sovereign debt and ecological footprint in Turkey. This will contribute to the debate on the impact of the public sector on environmental quality, which is pertinent to the attainment of sustainable development (Gani and Ibrahim, 2015). This study builds on the extant studies and fills a gap in the existing literature dealing with the environmental question in three strands. Firstly, several existing studies examined public sector and ecological quality relations by focusing primarily on internal funding. Since the economic meltdown of the last decade, countries with a rapidly rising CO_2 emission, particularly Turkey, also face considerable global warming challenges due to their rising external sovereign debt economic development drive. In this context, Turkey's CO_2 emissions (metric tons per capita) increased from 2.17 to 5.16 from 1985 to 2017 (see Figure 1).

It is pertinent to investigate the impact of sovereign external debt on environmental quality. Secondly, a plethora of extant research explored the environmental quality of Turkey within the analytical framework of CO_2 emission (Ibrahim et al., 2017; Katircioglu and Celebi, 2018), which largely omitted the potential roles of human activity in relation to the carrying capacity of the environment. In this way, this study adopted an ecological footprint that proved superior to the traditional CO_2. This provides significant ground premised on recommendations to governments, policymakers, and literature, to avoid the negative impacts of sovereign external debt on environmental sustainability. Lastly, several methodologies such as vector autoregressive (VAR) and traditional ARDL were used in existing empirical studies to investigate the debt-environment relation. The bootstrap ARDL approach is not commonly employed. This novel technique is superior to other alternative estimation models because it was proved to be efficient with respect to the variability of integration order among the estimating factors. Similarly, the model will permit policy implications to be drawn with efficient estimation devoid of small sample size bias (Cavusoglu et al., 2019). The remainder of the paper is configured into five sections. Section 2 is devoted to presenting the relevant literature. Section 3 describes the data and methodology applied in the study. Empirical results and discussion are presented in Section 4, while Section 5 concludes.

2 Literature review

Recent decades have witnessed a proliferation of studies that unravel the interplay between energy usage, income, and environmental quality. But studies that unravel the influence of external debt on environmental quality proxied by ecological footprint are limited and still emerging. Therefore, the first strand of studies examined the linkage between economic growth and environmental quality. Jardon et al. (2017) considered a sample of 20 countries selected in Latin America and the Caribbean to investigate whether economic growth affected CO_2 emissions during 1971–2011. The study utilized group means regressions and lent support to the Environmental Kuznets Curve (EKC) hypothesis. Another study focused on 31 developing countries: Aye and Edoja (2017) studied the extent to which economic growth affected CO_2 emissions via the application of the dynamic panel threshold model and showed that economic growth negatively influences CO_2 emissions in the low growth regime, but after a certain threshold turns to positive, disputing the EKC hypothesis. In addition, Uddin et al. (2017) studied how economic growth affected the ecological footprint by controlling for financial development and trade openness in the 27 highest emitting countries, through the application of first-generation panel methodologies, and confirmed that economic growth stimulates ecological footprint. However, both financial development and trade openness reduce environmental degradation insignificantly by the latter. Mikayilov et al. (2018) unraveled how economic growth influenced environmental degradation proxied by CO_2 emissions in Azerbaijan during 1992–2013 and found that economic growth positively stimulates CO_2 emissions. Also, Erdogon et al. (2019) demonstrated how income influences CO_2 emissions in BRICS-T countries during 1992–2016 via the application of fully modified ordinary least squares and documented that income stimulates CO_2 emissions. In contrast, the study showed that economic growth and CO_2 emissions cause each other. Taking a sample of 43 African countries, Olulubusoye and Musa (2020) utilized panel ARDL, mean group, and pooled mean group to unravel how economic growth influences CO_2 emissions and evidenced an EKC hypothesis in 8 countries representing only 21% of the sampled countries. However, the remaining 79% of the countries contradicted the EKC hypothesis.

Moreover, Ehigiamusoe et al. (2022) studied 31 African countries by applying the Pedroni cointegration test and the fully modified OLS test to the extent to which energy consumption stimulates CO_2 emissions by controlling for urbanization, financial sector development, and income and found that energy use, urbanization, and financial development stimulate environmental degradation. Also, financial development and urbanization moderated energy utilization, respectively, showing positive and negative effects on CO_2 emissions. Furthermore, the findings justified the presence of the U-shaped hypothesis.

The second group of studies focused on how energy consumption affects environmental quality by controlling for income from both panel and time series frameworks. Mercan and Karakaya (2015) unraveled the contribution of energy consumption to environmental quality by controlling for economic growth in 11 selected countries in the Organisation for Economic Co-operation and Development (OECD), and demonstrated that the more the energy utilization, the more the destruction of the environmental quality. However, the findings revealed that economic growth influences ecological quality. Similarly, in a more expanded sample, Ozcan et al. (2020), in their study of 35 OECD countries, demonstrated the extent to which energy usage affects environmental quality, taking into cognizance the effect of economic growth and showing that both energy usage and income degraded the environmental quality. Charfeddine and Mrabet (2017) used the Pedroni cointegration test, fully modified OLS, as well as dynamic OLS, to unravel the effect of energy consumption on environmental quality through controlling for economic growth, urbanization, fertility, political institutional index, and life expectancy rate in 15 Middle East and North Africa countries. The findings revealed that energy use and institutional quality proxied by political institutional index deteriorates environmental quality. However, the demographic variables were found to have positively stimulated environmental quality.

Further restricting the sample to 7 oil-dependent MENA countries and employing multivariate regression, Ardakani and Seyedaliakbar (2019) studied the extent to which energy consumption affected CO_2 emissions by controlling for income. The findings showed that energy utilization degrades the quality of the environment in all the countries with the exclusion of Bahrain and Algeria. Also, the findings showed that the EKC hypothesis holds only in Qatar, Oman, and Saudi Arabia.

However, studies based on the time series modeling framework were also conducted. For instance, Charfeddine (2017) studied the extent to which energy consumption influences the ecological footprint in Qatar by controlling for financial development, income, urbanization, and trade openness. The study utilized Markov switching error correction model and documented that energy use, trade openness, financial sector development, and urbanization retard environmental quality. However, the findings also justified the EKC hypothesis by showing that income and its square have a positive and negative effect, respectively. Katircioglu and Celebi (2018) studied the extent to which energy consumption and external debt contribute to environmental quality by controlling for income in Turkey through the application Maki cointegration test. The findings demonstrate that energy consumption improves environmental quality. Also, external debt showed a negative result but was insignificantly related to environmental quality. The study upholds the EKC hypothesis in the case of income and its square. Another recent study by Jian et al. (2019) applied the Johansen maximum likelihood test of cointegration to study the extent to which energy use affects environmental degradation by controlling for financial sector development and income in China.

The study evidenced that energy usage alongside the development of the financial sector stimulates environmental degradation. However, the study revealed that economic growth influences environmental quality. A more recent study by Zafar et al. (2020) applied an ARDL bound test to find out how energy consumption, income, human capital, natural resources, and foreign direct investment (FDI) affected environmental quality in the USA during the period 1970–2015. The study evidenced that energy use and income deteriorate environmental quality. However, natural resources, human capital, and FDI were found to significantly improve environmental quality. In a more recent study, Shan et al. (2021) used a bootstrap ARDL methodology to explore the extent to which energy use and green technology innovation affect CO_2 emissions within the framework of the STIRPAT model in Turkey. The study showed that renewable energy usage and green technology play a significant role in improving the quality of the environment. In contrast, the findings demonstrated that income, energy usage, and population worsen environmental quality.

The third strand of studies revealed the extent to which renewable energy utilization affects environmental quality. Considering the G20 economies, Tian et al. (2021) used the Pedroni cointegration test and fully modified OLS to study the linkage of renewable energy use and environmental quality by controlling for tourism and income, and evidenced that the more the increase in the utilization of renewable energy and tourist arrivals, the higher the quality of the environment. Also, the coefficient of income and its square confirmed the EKC hypothesis. Using the same sample of G20 countries, Habiba et al. (2021) tested the effect of renewable energy utilization but controlled for financial development, income, stock market, and trade openness on environmental degradation. The study applied a second-generation methodology and discovered that urbanization, FDI, and renewable energy use reduce environmental degradation. Stock market development stimulates and degrades the environmental quality in developed countries and developing countries, respectively. Also, Adebayo and Rjoub (2021) revealed how renewable energy utilization affects environmental degradation in MINT member countries by controlling for trade and financial development, and demonstrated that renewable energy use and exports retard environmental degradation.

However, imports and income stimulate environmental degradation. Furthermore, Akam et al. (2021) employed second-generation methodology to study how external debt, energy utilization, and income influence environmental quality in SANE countries and found that the EKC hypothesis holds only in South Africa and Egypt. Also, energy utilization damages the quality of the environment in all four countries. However, external debt was found to have stimulated the environmental quality in Nigeria but destroyed the environment in South Africa and Algeria. Furthermore, Nathaniel et al. (2021) tested the extent to which renewable energy usage stimulates the ecological footprint by controlling for rents received from natural resources, income, urbanization, and human capital in BRICS. The study applied the Westerlund cointegration test, common correlated effect mean-group, and pooled mean group. Empirical findings demonstrated that renewable energy use, human capital, and urbanization retard the ecological footprint. However, rents received from natural resources and income stimulate an ecological footprint.

In their more recent study, Khezri et al. (2022) studied the extent to which economic complexity affects CO_2 emissions of 29 Asian Pacific countries spanning the period 2000–2018. The authors controlled for renewable energy use, urbanization, income, energy intensity, and trade openness. Similarly, the authors incorporated the moderating influence of economic complexity with renewable energy utilization and economic growth, and its square. The authors utilized fixed, random, and fully modified OLS, and showed that income and its square have a positive and negative influence on CO_2 emissions, respectively, upholding the EKC hypothesis. Also, energy intensity, trade openness, and urbanization positively influence CO_2 emissions. Using a country-specific study, Kirikkaleli and Adebayo (2021) used the Maki cointegration test to find out the influence of government investment via partnering with private investors in energy and renewable energy utilization on environmental quality, by controlling for income and technological innovation in India. The study demonstrated that renewable energy usage improves environmental quality. However, the study revealed that joint investment by both government and private investors in energy deteriorates ecological quality.

The fourth strand of literature disaggregated energy use into renewable and non-renewable energy usage. Starting from a time series framework, Sharif et al. (2020) utilized Quantile ARDL methodology and disaggregated energy consumption into renewable and non-renewable energy in Turkey, by taking economic growth as an intermittent variable on environmental degradation during the period 1965Q1–2017Q4. The results showed that renewable energy use stimulates environmental degradation in all the quantiles. However, non-renewable energy utilization and income degrade the quality of the environment. Also, modeling from the nonlinear lens by segmenting energy into renewable end non-renewable energy consumption in Turkey, Adebayo et al. (2021) applied nonlinear ARDL by controlling for economic growth and structural change, and found that renewable energy use shocks stimulate environmental quality, while the shocks of non-renewable energy usage reveal a conflicting impact on environmental quality.

In the same vein, results show that positive shocks of economic growth and structural change, respectively, impact positively and negatively on environmental quality. In addition, Li and Haneklaus (2021) re-explored the EKC hypothesis in China during 1990 –2020 by employing a cointegration test in the form of the ARDL model. The study controlled for urbanization and confirmed the presence of the EKC hypothesis. The study also showed that in the long run, both fossil fuel consumption and renewable energy utilization influence CO_2 emissions positively and negatively, respectively. More so, the study demonstrated that the coefficient of urbanization improves and retards environmental quality in the long run as well as short run, respectively. Recent studies affirmed the impact of economic growth on the level of environmental quality: Awosusi et al. (2022) in BRICS countries, Adebayo et al. (2022) in some selected developing countries, Du et al. (2022) in MENA countries, and Alola et al. (2022) in China.

Altintas and Kassouri (2020) studied the dynamic linkage between renewable energy usage, fossil fuel utilization, income, and environmental quality represented by the ecological footprint in 14 European member countries. The study applied interacting fixed-effects and showed that economic growth and its square exert positive and negative effects on environmental quality, respectively, supporting the EKC hypothesis. Similarly, renewable energy and fossil fuel consumption demonstrate negative and positive effects on environmental quality. Another study by Destek and Sinha (2020) unraveled how renewable energy usage and non-renewable energy consumption affect environmental quality in 24 OECD countries, by considering economic growth and trade openness as control variables through second-generation panel modeling techniques. The findings concluded that renewable energy utilization influences environmental quality.

However, the coefficient of non-renewable energy worsens ecological degradation. The results of economic growth and its square support the EKC hypothesis. Radmehr et al. (2021) employed a simultaneity spatial analysis in the form of generalized spatial two-stage least square, to unravel the extent to which renewable energy use, urbanization, and non-renewable energy utilization affect environmental quality in 21 European member countries. The findings demonstrated that renewable energy use, income, and non-renewable energy usage and urbanization have a mixed influence on environmental quality. Finding out how the simultaneous effect of renewable energy and non-renewable energy usage stimulates the quality of the environment in the 15 highest emitting countries by controlling for trade openness and financial sector development, Usman et al. (2021) utilized augmented mean group (AMG) and evidenced that renewable energy utilization, trade openness, and financial sector development contribute to environmental quality. Recently studies affirmed the impact of renewable energy on the level of environmental quality: Pata and Samour (2022) in France, Samour et al. (2022) in South Africa, Qashou et al. (2022) and Habeşoğlu et al. (2022) in Turkey, and Baskaya et al. (2022) in BRICS nations.

Using global evidence from 188 countries, Khan et al. (2021) used the GMM system to examine the effect of renewable and non-renewable usage on environmental quality by controlling for institutional quality, foreign direct investment, income, labor force, population, capital formation, and financial development. The findings showed that renewable energy consumption, FDI, and institutional quality have a negative effect on environmental quality. However, the findings revealed that non-renewable energy consumption, financial development, labor force, income, capital formation, and population worsen environmental quality.

From the literature reviewed, there seems to be a sizable number of researches examining various determinants that stimulate environmental quality, such as energy consumption at both aggregate and disaggregate levels, economic growth, trade openness, FDI, institutional quality, and urbanization, to mention but a few. However, a limited number of studies have investigated the extent to which external debt affects CO_2 emissions from a country-specific perspective, let alone an ecological footprint. Therefore, this study intends to fill this gap in the energy and environmental economics literature.

3 Data and methodology

This study sets out to unravel the influence of external debt (ED^{X1}), energy consumption (EC^{X2}), economic growth (EG^{X3}), and ecological footprint ($ln FE^{Y1}$). Therefore the primary model of this research takes the following functional form:

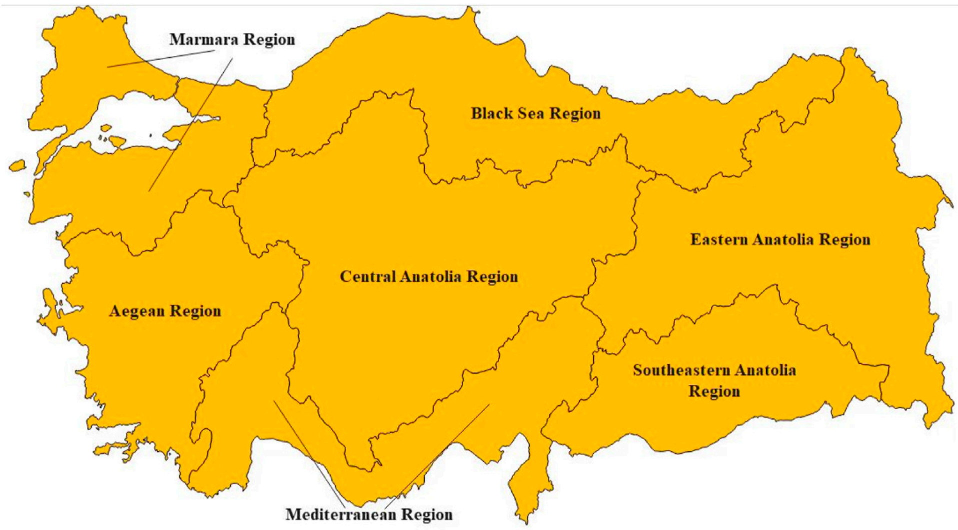

FIGURE 2
Geographical coverage of Turkey's economy.

TABLE 1 Abbreviation and description of the focused variables and sources of the tested data.

Variable name	Abbreviation	Unit of measurement	Source
Ecological footprint	$ln\, FE^{Y1}{}_t$	Ecological footprint of consumption of gha per capita	GFN
External debt	$ln\, ED^{X1}{}_t$	External debt—Million USD	MTF
Energy consumption	$ln\, EC^{X2}{}_t$	kt of oil equivalent	WB
Economic growth	$ln\, EG^{X3}{}_t$	2010 = 100) USD	MTF

Note: WB, World Bank; MTF, Ministry of Treasury and Finance of Turkey; GFN, global footprint network.

TABLE 2 Descriptive statistics.

Variable	Obs	Mean	Std. Dev	Min	Max
LnEF	32	0.171664	0.096068	−0.00876	0.306015
LnED	32	11.08354	0.366547	10.41518	11.61217
LnEG	32	3.667578	0.309542	3.136214	4.10088
LnEC	32	3.071299	0.090505	2.903242	3.217842

$$\ln FE_t^{Y1} = \beta_0 + \ln ED_t^{X1} + \ln EC_t^{X2} + \ln EG_t^{X3} + \mu_t \qquad (1)$$

In Eq. 1, FE^{Y1} denotes the logarithm of ecological footprint, $ED^{X1}$the logarithm of external debt, EC^{X2} and the logarithm of energy consumption; EG^{X3} is the logarithm of economic growth. The data was retrieved from the World Bank Data and the Ministry of Treasury and Finance of Turkey (see Figure 2 for the geographical coverage of Turkey's economy). The data retrieved is yearly data ranging from 1985 to 2016. The abbreviation and description of the focused variables and sources of the tested data are displayed in Table 1 and the results of the descriptive statistics for the dataset utilized in the study are displayed in Table 2. The summary statistics of the concerned variables from 1990 to 2016 through plot-boxes are shown (see Figure 3).

3.1 Stationary and cointegration tests

This research employs two-unit roots tests that include structural break dates. The first is the Perron and Vogelsang (PV) test of Perron and Vogelsang (1992) with one date of structural break (1^{SB}); and the Clemente, Montanes, and Reyes (CMR) test of Clemente et.al. (1998) with two dates of structural break (2^{SB}). To explore the linkage of cointegration between external debt (ED^{X1}), energy consumption (EC^{X2}), economic growth (EG^{X3}), and ecological footprint ($ln FE^{Y1}$), the research used the ARDL testing model. The ARDL modeling was proposed by Pesaran et al. (2001) and updated by McNown et al. (2018). It is worth noting that bootstrap ARDL, as proposed by McNown et al. (2018) has numerous advantages as follows: first, the updated technique of the ARDL model is preferred over the

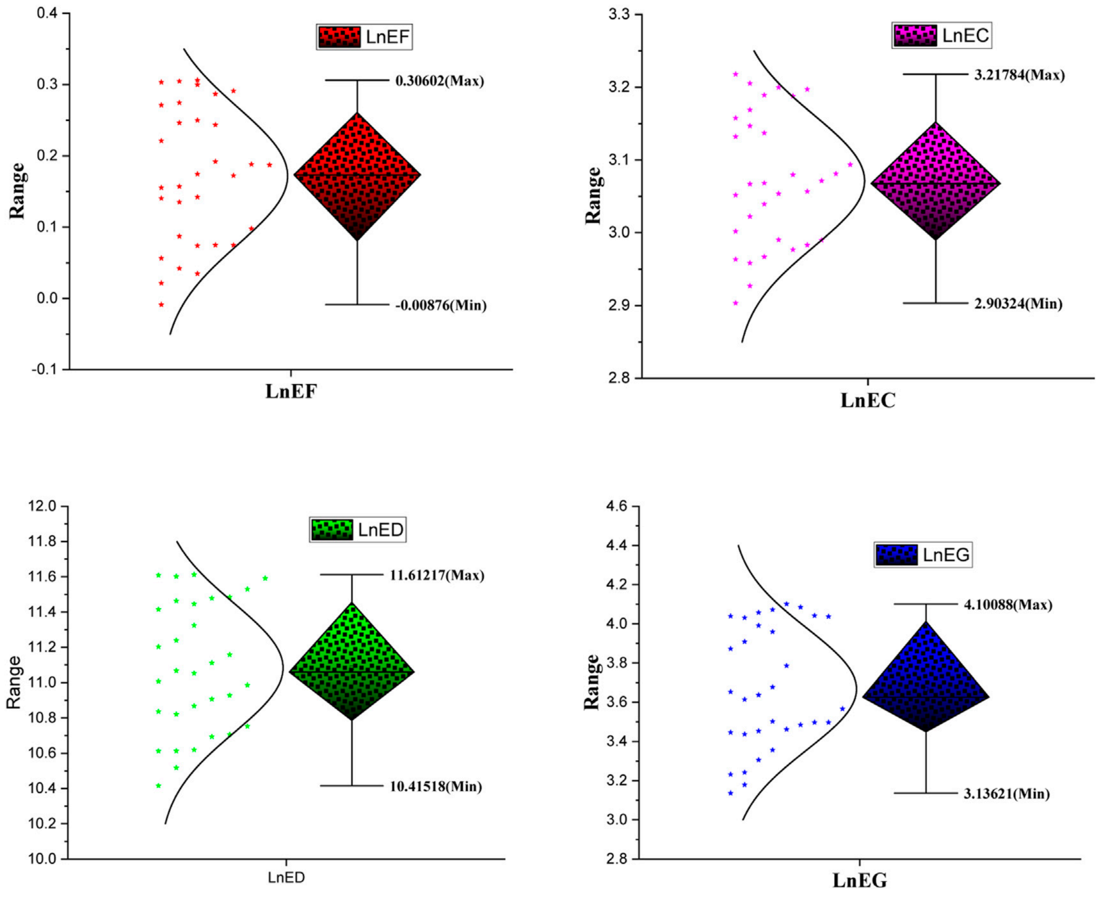

FIGURE 3
Box-plot summary for the selected variables.

classical ARDL cointegration assessments because of its capability of estimating while overcoming the issues of power and small sample size weakness. Secondly, the novel technique is more appropriate because of having no problem with respect to the integration order. Finally, McNown et al. (2018) upgraded the classical ARDL approach by adding the independent variable's lag to complement the existing F-statistic and *t*-test for cointegration. One of the core advantages of utilizing the bootstrap ARDL model is that the integration properties in this test are not complex; it increases the power of the *t*-test and F-test.

Based on the ARDL testing approach, Eq. 2 is formulated in the following equation:

$$\Delta ln\,\mathrm{FE}^{Y1}{}_{t} = \alpha_0 + \sum_{i=1}^{ol} \delta_1 \Delta ln\,\mathrm{FE}^{Y1}{}_{t-i} + \sum_{i=1}^{ol} \delta_2 \Delta ln\,\mathrm{ED}^{X1}{}_{t-i} + \sum_{i=1}^{ol} \delta_3 ln\,\mathrm{EC}^{X2}{}_{t-i} + \sum_{i=1}^{ol} \delta_4\, ln\,\mathrm{EG}^{X3}{}_{t-i} + \partial_1 ln\,\mathrm{FE}^{Y1}{}_{t-i} + \partial_2\, ln\,\mathrm{ED}^{X1}{}_{t-i} + \partial_3\, ln\,\mathrm{EC}^{X2}{}_{t-i} + \partial_4 ln\,\mathrm{EG}^{X3}{}_{t-i} + u_t \quad (2)$$

In Eq. 2, Δ is the operator of the first difference process, α_0 is the constant term, $\delta_1, \delta_2, \delta_3, \delta_4$ are short-run estimated coefficients, $\partial_1, \partial_2, \partial_3, \partial_4$ are long-run coefficients, and ol is optimal of lags.

The error correction term (EC^{term}) is used to examine the velocity of adjustment of the dependent variable. The EC^{term} is estimated as the following equation:

$$\Delta ln\,\mathrm{FE}^{Y1}{}_{t} = \alpha_0 + \sum_{i=1}^{ol} \delta_1 \Delta ln\,\mathrm{FE}^{Y1}{}_{t-i} + \sum_{i=1}^{ol} \delta_2 \Delta ln\,\mathrm{ED}^{X1}{}_{t-i} + \sum_{i=1}^{ol} \delta_3 ln\,\mathrm{EC}^{X2}{}_{t-i} + \sum_{i=1}^{ol} \delta_4\, ln\,\mathrm{EG}^{X3}{}_{t-i} + \omega ECT_{t-1} + u_t \quad (3)$$

where ωECT_{t-1} is the one period lagged EC^{term}. It shows the velocity of adjustment among the short-term and long-term levels of the dependent variable to affirm the outcomes of the ARDL testing approach. One of the striking advantages of the bootstrap ARDL test of McNown et al. (2018) is the ability to add the coefficients of lagged independent variables with the aid of either the *t*-test $t_{dependent}$ or F-test $F_{independent}$. The null hypothesis of the$t_{dependent}$ test is: $\partial 1 = 0$, against the alternative hypothesis of

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the $t/_{dependent}$ test being: $\partial_1 \neq 0$. Similarly, the null hypothesis of the $F/_{independent}$ test is:H_0: $\partial_2 = \partial_3 = \partial_4 = 0$ will be tested against the alternative hypothesis of the $F/_{independent}$ test being:H_1: : $\partial_2 \neq \partial_3 \neq \partial_4 \neq 0$.

The critical values of the newly developed bootstrap ARDL (CV) are generated based on the combination of integration features of each focused variable (Samour et al., 2022). Hence, it solves the problems posed as a result of the instability identified in the findings of other co-integration assessments (Alhodiry et al., 2021). However, McNown et al. (2018) updated the bootstrap ARDL testing technique by using a table of CVs obtained by the newly developed bootstrap ARDL simulation. In particular, the novel approach of the ARDL model allows for the explanatory focused variables to be endogenous. The cointegration between the focused variables will be determined if the values of $F/_{Pesaran}$, $t/_{dependent}$, and $F/_{independent}$ are higher than the critical values of the novel techniques of ARDL as encapsulated by McNown et al. (2018).

The battery of diagnostic tests was employed in the form of the normality test (N^t) to check for normality distribution of the tested model, the Breush-Pagan Godfrey heteroscedasticity ($BPG - H^t$) to ensure that there is no heteroscedasticity, the B-Godfrey serial correlation test (B-GLM^t) to confirm the absence of autocorrelation in the model, and the Ramsey-Reset test (RR^t) to affirm that the investigated model is correctly specified.

Furthermore, the Granger causality approach is applied to test the direction of causality between the time series. In this, (EC^{Term}) described how deviations of the variables in the short run are determined from the long-term equilibrium level. Thus, the ECM equation is formulated in Eqs 4–7:

$$\Delta ln\,\mathrm{FE}^{Y1}{}_t = \alpha_0 + \sum\nolimits_{i=1}^{ol} \delta_1 \Delta ln\,\mathrm{FE}^{Y1}{}_{t-i} + \sum\nolimits_{i=1}^{ol} \delta_2 \Delta ln\,\mathrm{ED}^{X1}{}_{t-i} + \sum\nolimits_{i=1}^{ol} \delta_3 ln\,\mathrm{EC}^{X2}{}_{t-i} + \sum\nolimits_{i=1}^{ol} \delta_4\, ln\,\mathrm{EG}^{X3}{}_{t-i} + \omega ECT_{t-1} + u_t \tag{4}$$

$$\Delta ln\,\mathrm{ED}^{Y1}{}_t = \alpha_0 + \sum\nolimits_{i=1}^{ol} \delta_1 \Delta ln\,\mathrm{ED}^{Y1}{}_{t-i} + \sum\nolimits_{i=1}^{ol} \delta_2 \Delta ln\,\mathrm{FE}^{X1}{}_{t-i} + \sum\nolimits_{i=1}^{ol} \delta_3 ln\,\mathrm{EC}^{X2}{}_{t-i} + \sum\nolimits_{i=1}^{ol} \delta_4\, ln\,\mathrm{EG}^{X3}{}_{t-i} + \omega ECT_{t-1} + u_t \tag{5}$$

$$\Delta ln\,\mathrm{EC}^{Y1}{}_t = \alpha_0 + \sum\nolimits_{i=1}^{ol} \delta_1 \Delta ln\,\mathrm{EC}^{Y1}{}_{t-i} + \sum\nolimits_{i=1}^{ol} \delta_2 \Delta ln\,\mathrm{FE}^{X1}{}_{t-i} + \sum\nolimits_{i=1}^{ol} \delta_3 ln\,\mathrm{ED}^{X2}{}_{t-i} + \sum\nolimits_{i=1}^{ol} \delta_4\, ln\,\mathrm{EG}^{X3}{}_{t-i} + \omega ECT_{t-1} + u_t \tag{6}$$

$$\Delta ln\,\mathrm{EG}^{Y1}{}_t = \alpha_0 + \sum\nolimits_{i=1}^{ol} \delta_1 \Delta ln\,\mathrm{EG}^{Y1}{}_{t-i} + \sum\nolimits_{i=1}^{ol} \delta_2 \Delta ln\,\mathrm{FE}^{X1}{}_{t-i} + \sum\nolimits_{i=1}^{ol} \delta_3 ln\,\mathrm{EC}^{X2}{}_{t-i} + \sum\nolimits_{i=1}^{ol} \delta_4\, ln\,\mathrm{ED}^{X3}{}_{t-i} + \omega ECT_{t-1} + u_t \tag{7}$$

where FE^{Y1}, ED^{X1}, EC^{X2} and $ln\,\mathrm{EG}^{X3}{}_{t-i}$ are the tested variables, and $\omega\,\mathrm{ECT}_{t-1}$ is the lagged EC^{Term} The direction of causal flow in the short run is determined by Wald's $F-_{\mathrm{statistics}}$ testing approach to detect the significance of the related estimated coefficient by utilizing the first operator of the first difference. To explore the direction of causal flow in the long run, the test of the related estimated coefficient of the lagged (EC^{Term}) is employed.

TABLE 3 indings of the PV test.

	At level			At first, difference (Δ)	
Variable	$t-^{STAT}$	1^{SB}	Variables	$t-^{STAT}$	1^{SB}
$ln\,\mathrm{FE}^{Y1}{}_t$	−1.420	2010	$ln\,\mathrm{FE}^{Y1}{}_t$	−5.321**	1994
$ln\,\mathrm{ED}^{X1}{}_t$	−2.335	2011	$ln\,\mathrm{ED}^{X1}{}_t$	−7.451**	2013
$ln\,\mathrm{EC}^{X2}{}_t$	−2.001	1999	$ln\,\mathrm{EC}^{X2}{}_t$	−6.151**	2001
$ln\,\mathrm{EG}^{X3}{}_t$	−3.11	2001	$ln\,\mathrm{EG}^{X3}{}_t$	−5.151**	1998

Note: ** indicate significance of variables at 5% level.

4 Empirical findings and discussions

This section begins by checking the stationary properties of study variables with the aid of PV and CMR unit root tests, and their results are presented in Tables 3 and 4. The findings show thatFE^{Y1}, ED^{X1},EC^{X2}, and EG^{X3} variables are not stationary at their level values, but stationary at the first difference (Δ). The findings affirm that the examined variables have I (1) order of integration.

The outcomes of the bootstrap ARDL model are presented in Table 5. The findings show that the $F/_{Pesaran}$, $t_{dependent}$, and $F/_{independent}$ values are higher than the bootstrap CV. These findings provide sufficient evidence to conclude that there is cointegration among EF, ED, EC, and EG variables. This implies that there is co-movement among the study variables, suggesting the existence of a causal correlation among the variables in at least one direction.

The results of both short- and long-term impacts of the coefficients are presented in Table 6. The findings of the ARDL testing approach show that the coefficient of economic growth positively stimulates the ecological footprint in not only the short but also in the long run. Numerically, a 1% rise in economic growth in Turkey will boost its ecological footprint by 0.47% in the short run and 0.60% in the long run, respectively. This finding suggests that economic growth is an inducing factor in the ecological footprint. As an emerging economy, Turkey might have been using heavy productive equipment that requires a huge energy supply, emitting high environmental emissions. Therefore, the government opting for eco-friendly factors of production would go a long way in stimulating the output with less effect on the environmental quality. The findings are corroborated with those of Mikayilov et al. (2018) for Azerbaijan; Ardakani and Seyedaliakbar (2019) for Qatar, Oman, and Saudi Arabia; Ozcan et al. (2020) for 35 OECD

TABLE 4 indings of the CMR test.

At level				At first difference (Δ)			
Variable	$t-^{STAT}$	1^{SB}	2^{SB}	Variables	$t-^{STAT}$	1^{SB}	2^{SB}
$ln\,FE^{Y1}{}_t$	−1.420	1996	2010	$ln\,FE^{Y1}{}_t$	−5.321**	1994	2002
$ln\,ED^{X1}{}_t$	−2.335	2005	2011	$ln\,ED^{X1}{}_t$	−7.451**	2010	2013
$ln\,EC^{X2}{}_t$	−2.001	2001	2012	$ln\,EC^{X2}{}_t$	−6.151**	1999	2001
$ln\,EG^{X3}{}_t$	−3.11	1993	2001	$ln\,EG^{X3}{}_t$	−5.151**	1998	2010

Note: ** indicates significance of variables at a 5% level.

TABLE 5 esults of the bootstrap ARDL approach.

ARDL)1,2,1,0)		$F_{Pesaran}$	$t_{dependent}$	$F_{independent}$
(FP, ED, EC, EG)		6.11**	−4.81**	6.10**
Bootstrap-based table C-V	5%	3.95	−4.035	4.77

Note: ** indicates significance at a 5% level.

TABLE 6 Results of the ARDL approach in the short and long term.

Variable	Coefficient	t-statistics
$\Delta ln\,ED^{X1}{}_t$	−0.099***	−3.776
$\Delta ln\,EC^{X2}{}_t$	2.271***	2.813
$\Delta ln\,EG^{X3}{}_t$	0.470***	1.565
$ln\,ED^{X1}$	−0.019***	−4.004
$ln\,EC^{X2}{}_t$	0.501**	2.637
$ln\,EG^{X3}$	0.607**	2.188
ECT_{t-1}	−0.310***	−2.41
Diagnostic tests		
N^{test}	1.010 (0.585)	Adjusted. R^2 0.98
$BPG-H^t$	1.987 (0.661)	DW-$stat$ 1.80
A^t	0.701 (0.125)	
LM^t	1.118 (0.851)	
RR^t	0.414 (0.831)	

Note: *,**, and *** denote statistical significance at 10%, 5% and 1% levels, respectively.

countries; Adebayo et al. (2021) for Turkey; and Ehigiamusoe et al. (2022) for 31 African economies. The findings further demonstrate that the coefficient of energy consumption in both the short and long run is positive, elastic, and statistically significant at the 1% and 5% % levels, respectively. Numerically, a 1% and 5% rise in energy consumption in Turkey will stimulate the ecological footprint by 2.27% and 0.50% in the short and the long run, respectively. This signifies that Turkey's energy usage is either high or using inefficient technology capable of deteriorating the environmental quality. To improve and even maintain the environmental quality, it has become imperative for Turkey's government to employ energy efficient technology, in addition to exploring renewable energy technologies options that would stimulate environmental quality. This is because the finding from this study implies that energy consumption in Turkey induces an ecological footprint. The findings are in line with Charfeddine (2017) for Qatar, Zafar et al. (2020) for the USA, and Shan et al. (2021) for Turkey. However, the findings contradict those of Jian et al. (2019) who confirmed that energy use retards Chinese environmental degradation.

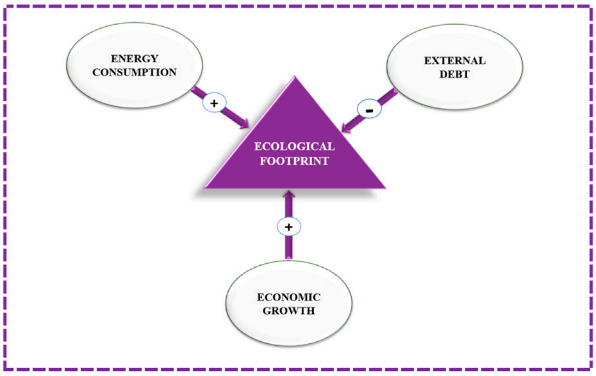

FIGURE 4
Graphical exhibition of empirical conclusions.

Furthermore, the findings of this research demonstrate that the coefficient of external debt has a negative and statistically significant influence on the ecological footprint at a 1% level of significance in both the short and long run. Numerically, a 1% rise in external debt in both the short and the long run will reduce Turkey's ecological footprint by 0.09% and 0.019%, respectively. This finding also supposes that external debt is inverse to the ecological footprint. Currently, Turkey is facing an external debt crisis. In this context, the high external debt jumped significantly, due to the decline in government revenues. Hence, any decline in government revenues will negatively affect economic performance, decreasing energy consumption and ecological footprint. The finding is in line with that of Akam et al. (2021) for Nigeria but contradicted in South Africa and Algeria. Similarly, the study finding is contradicted by the finding of Katircioglu and Celebi, (2018) for Turkey, by demonstrating that external debt impacts negatively but insignificantly on environmental quality. The graphical presentation of empirical findings is presented in Figure 4.

Also, the result of the error correction model is displayed in Table 6. The ECM coefficient of −0.310 is both statistically significant and correctly signed at a 1% significance level. The ECM results validated the long-run equilibrium association

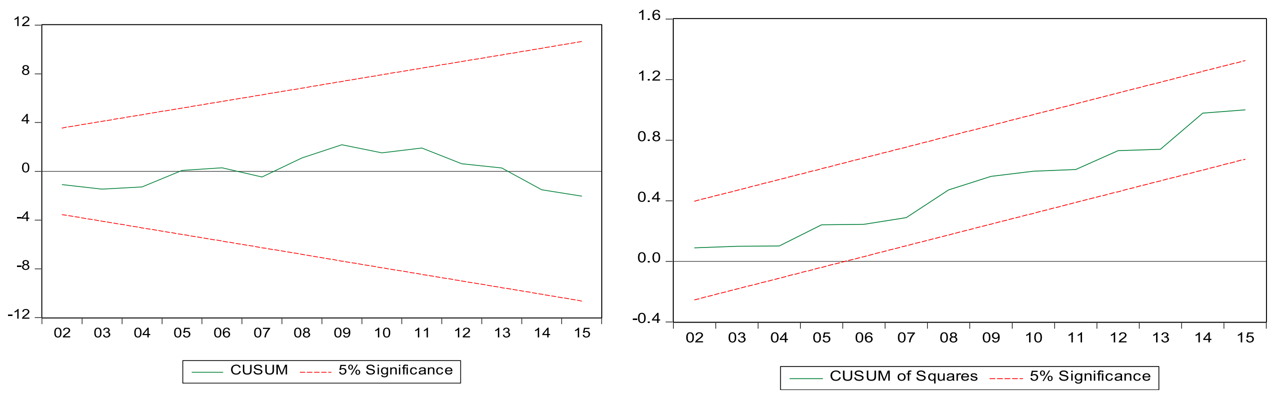

FIGURE 5
Stability test using (CUSUM) and (CUSUMQ).

TABLE 7 Findings of the Granger causality testing approach.

	Short run				Long run
(Y/X)	$\Delta ln\,FE^{Y1}{}_t$	$\Delta ln\,ED^{X1}{}_t$	$\Delta\, ln\,EC^{X2}$	$\Delta ln\,EG^{X3}{}_t$	ECTt−1
$\Delta ln\,FE^{Y1}{}_t$	-	6.310*	7.315**	7.411**	−0.056 (−2.927) ***
$\Delta ln\,ED^{X1}{}_t$	2.12	-	2.10	3.11	
$\Delta\, ln\,EC^{X2}{}_t$	3.397	6.997**	-	6.113**	−0.760 (−0.970)
$\Delta ln\,EG^{X3}{}_t$	1.431	5.499*	0.951	-	−0.004 (−0.142)

Note: ***, **, and * denote significance at 1%, 5%, and 10% levels, respectively.

between sovereign external debt, energy use, economic growth, and ecological footprint. This demonstrates that deviations correct 31.1% of environmental quality changes in the short to the long run.

Table 6 reports the diagnostic assessments of the findings. The normality test N^t findings provide evidence that the model of this paper is normally distributed. Similarly, the results of the $BPG - H^t$ ARCH test A^t, and the BG-LM test LM^t confirmed the absence of autocorrelation in the examined model, and this model is homoscedastic. In addition to that, the finding of Ramsey-Reset assessments confirmed that the explored model is correct and well specified. Furthermore, Figure 5 implies the CUSUM and CUSUM of Squares (CUSUM-Q) charts. The figures confirmed that the studied model is not mis-specified over the studied period.

The findings of Granger causality report a long-run causal relationship between external debt$ln\,ED^{X1}{}_t$, energy consumption $ln\,ED^{X1}{}_t$, and economic growth $ln\,EG^{X3}{}_t$ to ecological footprint $ln\,FE^{Y1}{}_t$ in Turkey. The tabulated (F) statistics values (Table 7) demonstrate that unidirectional causality runs from external debt, energy consumption, and economic growth to the ecological footprint. Thus, this outcome reinforces the fact that there is a powerful influence of external debt $ln\,ED^{X1}{}_t$, energy consumption $ln\,ED^{X1}{}_t$, and economic growth $ln\,EG^{X3}{}_t$ on footprint ecological $ln\,FE^{Y1}{}_t$ in Turkey. The findings further demonstrate that causality runs from external debt to energy consumption and economic growth. This implies that external debt indirectly stimulates the ecological footprint via energy utilization and economic growth channels. Hence, this study provides strong evidence that an increase in external debt will retard environmental degradation.

5 Conclusions and policy implications

The present study explored the effect of external debt on environmental quality in Turkey by controlling for energy utilization and income spanning the period 1985–2016. The study employed the newly developed bootstrap autoregressive distributed lag (BARDL) approach to cointegration to unravel the specific effect of the short- and long-term coefficients of the studied variables. Also, the study utilized the Granger causality test to unravel the direction of causal flow among the variables. Findings from the study demonstrated that there exists long-run co-movement among external debt, energy consumption, economic growth, and environmental quality. The results also showed that external debt stimulates environmental quality in Turkey in the short and the long run. However, the findings demonstrate that the quality of the environment is deteriorated by both energy consumption and economic growth in the short and the long run. The study's findings have important policy implications for Turkey's policymakers: though public debt must be used with extreme caution, the findings from the study demonstrate that public debt stimulates environmental quality. This suggests that most of the debts might have been used to purchase abatement technologies, which invariably led to a reduction in carbon concentration, stimulating environmental quality. Therefore, the study recommends that for the Turkish government to achieve a long-term environmental sustainability plan, there is a need to venture into debt consolidation programs such as implementing tax increases and cutting public spending, to increase fiscal space that would finance long-term environmental protection policies. As one of the OECD member countries, it is recommended that Turkey should also make use of OECD's debt-for-environment swap program for environmental quality, where borrowed funds would be strictly used towards financing green public goods and brown projects in the form of sustainable tourism, nature reserves, and efficient power and district heating facilities. As against the traditional production-enhanced emissions growth, green growth is another option for the Turkish government, to boost production and supply through the application of eco-friendly factors of production, which in turn stimulate environmental quality.

Similarly, urgent and drastic action is needed by policymakers to improve and sustain the environmental quality by controlling the consumption of fossil fuels through the application of energy efficient and environmentally friendly technologies. As a result, the present work provides valuable recommendations for policymakers in Turkey to sustain the environment by reinforcing the investments and projects in green investment. In addition, this paper's findings pave the way for other countries to do so. Thus, with the help of enhanced green energy investment, overcoming global warming issues could be much easier. However, the limitation of the present study is the unavailability of examined data after 2017 for some selected valuables. Future empirical work should be devoted to evaluating the impact of external debt on environmental quality using different panel testing models.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material, and further inquiries can be directed to the corresponding author.

Author contributions

Conceptualization: AS, NI, and AJ; methodology: AJ and NI; software: AS, NI, and AJ; formal analysis: AS and NI; data collection: SI, AS, NI, AJ, and WX; writing original draft preparation: SI, AS, NI, AJ, and WX; revised draft: SI, AS, NI, AJ, and WX; writing, review, and editing: SI, AS, NI, AJ, and WX; supervision: AJ; project administration: WX. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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