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RESEARCH ARTICLE

Heading towards sustainable environment: exploring the dynamic linkage among selected macroeconomic variables and ecological footprint using a novel dynamic ARDL simulations approach

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Abstract

Ever since the emancipation of a country, its environmental quality has undergone a significant transition during the development phases; Bangladesh is no exception. Bangladesh is facing a serious threat in the age of global warming, and climate change as the country is looking forward in achieving the SDGs by 2030. Yet, there is a dearth of study regarding the relationship among crucial macroeconomic drivers and ecological footprint (a proxy for environmental degradation). Under the circumstances, this study explores the effects of economic growth, capital formation, urbanization, trade openness, energy use, and technological innovation on the ecological footprint by adopting the novel dynamic Autoregressive Distributed Lag (ARDL) simulations approach for Bangladesh, using annual frequency data from 1972 to 2017. Empirical results from the bounds test ascertained that there exists a long-run equilibrium association among the outlined variables. Furthermore, the novel dynamic ARDL simulation results revealed that Bangladesh is yet to achieve the environmental Kuznets curve (EKC) hypothesis. It was observed that the Bangladesh economy is still at the scale stage of its economic trajectory, emphasizing economic growth relative to her environmental status. However, capital formation, urbanization, and energy use seemed to degrade environmental quality, while trade openness and technological innovation upgraded the environmental quality. Putting it more elaborately, a unit escalation in GDP per capita increases the ecological footprint by 0.829% in the long run, while a unit increase in energy consumption upsurges the ecological footprint by 1.074% and 0.761% in the long run and short run, respectively. As regards technology innovation, one unit increase in it cutbacks the ecological footprint by 0.596% in the long run. Furthermore, the frequency domain causality unveiled the long-run feedback effect between economic growth and ecological footprint. The study further presents possible recommendations that can sustainably address environmental issues, keeping the economy buoyant.

Keywords Ecological footprint · Environmental sustainability · EKC hypothesis · Dynamic ARDL simulation · Frequency domain causality · Bangladesh

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Abbreviations

SDGs	Sustainable Development Goals
EKC	Environmental Kuznet curve
EF	Ecological footprint
ADF	Augmented Dickey-Fuller
PP	Philips-Perron
ZA	Zivot and Andrew
AIC	Akaike information criterion
SIC	Schwarz information criterion
HQ	Hannan-Quinn information criterion
VAR	Vector autoregressive
ARDL	Auto-regressive distributed lag

Introduction

Economic progress demands the improvement in energy, infrastructure, water, technology, and others which create pressure on the environmental condition. However, policymakers of the nation face two main challenges, i.e., ensuring sustainable economic development and preserving environmental quality (Dogan et al. 2019). Alternatively, the process of economic development becomes a downside when the growth rate is given more affluence than the ecological condition (Yasmeen et al. 2019). The impact on the environmental condition due to unplanned economic growth has captured world economics' interest, which is informed in both Paris Agreement in 2015 and Kyoto Protocol 1997 (Nathaniel and Iheonu 2019). Several studies have also confirmed economic growth and energy consumption as a major cause of environmental deterioration (Ito 2017; Wang et al. 2017). Hitherwards, increasing urbanization and trade openness also lead to increased carbon emission (Al-Mulali et al. 2015a; Dogan and Turkekul 2016). Like other developing nations, the economic progression of Bangladesh is accompanied by the extreme level of pollution, land erosion, deforestation, and depletion of resources (Masukujjaman et al. 2016). Therefore, the conflicted relationship with the environment quality and economic growth draws attention to raising awareness about the eco-friendly economy (Ozturk et al. 2016). Moreover, to promote sustainable development, it is critical to minimize conflicts between energy use, economic activities, and environmental deterioration. Instead, the interdependence between the variables should be encouraged (Ozcan et al. 2020).

Furthermore, despite several studies devoted to this purpose, the magnitude of various determinants and their directions to the environmental situation has yet to be proven. Nations' economics, income level, methodological difference, and variable nature can lead to the discrepancy. On the other hand, according to the EIA (2013), emissions in developing countries are predicted to be 127% greater by 2040 than in industrialized economies. If this is any indication, it is important to investigate and comprehend the factors that influence environmental degradation in Bangladesh to offer policy options for reducing emissions and promoting long-term growth, given that Bangladesh is one of the world's most populous developing countries. Our study has considered ecological footprint as an indicator of environmental deterioration and different macroeconomics drivers to study their relationship in Bangladesh. Finally, this manuscript was carried out to shed some light on the concern of the environment and economic growth in Bangladesh.

The ecological footprint concept was first developed in the early 1990s and defined as the collective capacity of the earth to produce the resource consumed by humans and other parties, as well as the ability to absorb the waste generated by all these parties (Destek and Sinha 2020; Hassan et al. 2019). The average consumption of ecological goods and services increased over the last decades, leading to a rise in ecological footprint (Destek and Sinha 2020). Besides, the continuously growing population is depleting the rate of per capita biological capacity. This situation leads to a deficit in the ecological capacity of different nations (WWF 2008, 2006). Although the ecological footprint of Bangladesh (0.8 gha per capita) is lower than the world average, the biocapacity is only 0.4 gha per capita (Global Footprint Network 2021). Sustainability of the environment requires biocapacity higher than ecological footprint (Ahmed et al. 2020a); however, Bangladesh is dealing with an ecological deficit of 107% in 2017 (Global Footprint Network 2021). This ecological deficit advocates that the supply of ecological goods and services is lower than their demand. Besides, Bangladesh's per capita income and economic growth are rising due to heavy industrialization and urbanization in recent years. Eventually, the amount of consumption of the ecological resources also increases, which creates pressure on the environment and stimulates environmental degradation.

However, taking the ecological footprint into account as a measure for environmental quality is an emerging concept in the extant literature (Wiedmann and Barrett 2010). Several studies used CO_2 emission as a proxy for environmental degradation in studying the nexus between environmental sustainability and economic growth (Wang et al. 2016; Salahuddin et al. 2015). But CO_2 emission represents only the partition of environmental degradation and fails to give a holistic perspective on environmental status (Ahmed et al. 2021; Destek and Sarkodie 2019). In recent years, researchers preferred ecological footprint as a more suitable indicator to explore environmental degradation as it represents the human dependency on the environmental system (Dogan et al. 2020; Moore et al. 2013). In this study, we considered ecological footprint for several reasons. Firstly, the lone pointer reflects the earth's carrying capacity and biological capacity for buoying the economic activity considering the Sustainable Development Goals (SDGs) (Rashid et al.

2018). Secondly, economic growth stirs the consumption of forest, water, and land resources. Therefore, choosing the emission as an indicator for environmental degradation may focus on only industrialized activities (Liu et al. 2017). In the same way, the sustainability of ecological balance also depends on the absorbing capacity of waste by nature (Pan et al. 2019), and several countries are struggling with balancing the ecological deficit, which is crucial to address the SDGs 13 and 15.

Before proceeding further in this study, it is imperative to discuss the relationship between the economy and the environment. Environmental quality can be disrupted by several indicators of economic development, i.e., economic growth, trade, urbanization, capital flow, energy consumption, technology, and many others. The linkage between environmental degradation and economic growth is explained by the environmental Kuznets curve (EKC) hypothesis. According to this hypothesis, environmental pollution increases in an economy at the first stage of growth. After a certain point, the environmental quality starts to upgrade with the growth of the economy. So, there is an inverted U-patterned linkage between economic growth and environmental pollution (Esteve and Tamarit 2012). Although there are several studies related to EKC, the evidence of this hypothesis is heterogeneous. This is because the validity of this hypothesis depends on the characteristics of the individual economy and the level of development in that economy. Thus, the study about EKC including suitable indicators is important for the policymaker as it provides vital information about environmental sustainability.

Previously, all of the available studies substantiated the presence of the EKC hypothesis in Bangladesh's economy (Murshed et al. 2020; Islam et al. 2013). These studies examined the association between environmental quality and economic growth by considering carbon dioxide as a proxy for environmental degradation. However, our research has a notable distinction from preceding studies regarding collecting variables and using advanced methods such as the dynamic ARDL simulations approach. This method used a certain percentage change in the explanatory variables as a counterfactual shock over thirty years from 2017 to 2037 to explore the changes in ecological footprint. Thus, policymakers can be able to comprehend the existing state and future prospects of the country's environmental quality. Also, it will help adopt policies and adjust to further shocks that might bar Bangladesh from achieving the SDGs by 2030.

This study extends and contributes to the extant literature in several ways. First of all, we consider ecological footprint as an index for environmental quality. To our best knowledge, this is one of the first empirical studies that considered ecological footprint for analyzing not only the EKC hypothesis but also for exploring environmental degradation in the context of Bangladesh. The current research adds to the theory of income-induced environmental degradation hypothesis taken Bangladesh as a case study, popularly known as the Environmental Kuznets Curve. Secondly, this study considers new factors such as the effect of technological innovation on environmental degradation since the world is running after innovation in terms of technology. Thus, it is important to address how technologies affect the environment, and previous literature overlooked the association of these variables. Lastly, an advanced econometric technique, the dynamic ARDL simulation approach (Jordan and Philips 2018) model, is used to determine the association among the determinants. Besides, we employed the frequency domain causality approach (Breitung and Candelon 2006) since it supports the long-, short-, and medium-term causality differences among time series variables. These modern econometric techniques offer various advantages and are suitable for reliable, valid, and robust estimates; therefore, the obtained results will be more policy-oriented. Moreover, this research will help policymakers develop suitable environmental and energy policies while considering the effects of trade, economic growth, and urbanization.

The remainder of the paper is formatted as follows: Sect. 2 represents the detailed review of relevant literature. Section 3 briefly outlines the data and econometrics methodology of this study. The results from the econometric analyses are presented and explained in the "Results and discussion" section with proper literature support. Finally, Sect. 5 describes the conclusion and provides some policy findings.

Review of existing literature

Empirical review

This section represents the review of relevant research on environmental degradation and its determinants across various contexts, thereby ascertaining the selection of variables for this study. Several studies explored the causes of environmental degradation by taking only negative indicators like pollutants of the environment into account. Most of the researchers deal with CO_2 emission; however, it only reveals partial information on environmental degradation. In the recent past, scholars altered their attention, and the adoption of the ecological footprint as an index of environmental issues is flourishing because of its comprehensiveness. The utilization of ecological footprint as an environmental indicator has developed after the research of Al-Mulali and Ozturk (2015), who claimed that ecological footprint is an adequate measure of the ecological effects. Following this argument, Al-Mulali et al. (2015b) reported that the EKC exists in the high- and upper-middle-income nations, while it does not hold in the middle- and low-income panels. Ahmed and Wang (2019) illustrated the EKC hypothesis exists in India. Similarly, an inverted U-patterned linkage between economic growth and environmental pollution is found in Pakistan (Hassan et al. 2019). However, economic growth has a long-run effect on the ecological footprint that forces environmental degradation (Danish and Wang 2019; Abbasi et al. 2021a, 2021b; Iqbal et al. 2021). Contrarily, Mrabet et al. (2017) and Dogan et al. (2020) found no EKC in Qatar and BRICS, respectively.

Several studies considered the association between financial development (credit to the private sector) and ecological footprint (Ahmed et al. 2021; Nathaniel et al. 2020), only emphasizing the private sector. They found financial development deteriorates the environmental quality both in the short and long run. Conversely, Destek and Sarkodie (2019) revealed the positive effect of financial development on environmental quality for the Philippines, Singapore, Thailand, and Turkey. However, this study considered capital formation as a proportion of GDP by bringing the shed of light on both the private and public sectors of the overall economy. Capital formation has a significant positive effect on environmental quality both in the short and long run (Baz et al. 2020). However, Zheng et al. (2018) found that every percentage increase in capital formation as a share of GDP increases the ecological footprint.

Urbanization goes hand-in-hand with economic growth (Abbasi et al. 2021c). This study includes urbanization because Bangladesh is experiencing a hasty growth in urbanization. The urban population in Bangladesh has expanded from 7.9% in 1971 to 38.2% in 2020, growing at 3.29% annually (World Bank 2021). Therefore, rural to urban migration tends to upsurge in the forthcoming years, fostering environmental degradation (Ahmed et al. 2020a). Indeed, urbanization enhances deforestation (Defries et al. 2010), demand for natural resources, waste generation, and ecological degradation (Ahmed et al. 2020b). Likewise, Charfeddine (2017) and Al-Mulali and Ozturk (2015) found that urbanization stimulates ecological footprint in the context of MENA countries and Qatar, respectively. On the contrary, Charfeddine and Mrabet (2017) reported that urbanization is conducive to environmental quality, as it curtails the ecological footprint in MENA countries. Danish et al. (2020) supported this claim as they argued that urbanization reduces the ecological footprint in BRICS.

Trade openness can have either a positive or negative impact on ecological footprint. However, the direction of impact depends on the level of industrialization and development of a country. For instance, industrialized and developed countries import advanced cleaner and eco-friendly technologies, and thereby, trade openness exhibits a technological effect on the environment (Destek and Sinha 2020). Al-Mulali and Ozturk (2015) found that trade openness positively impacts the ecological footprint for MENA countries. Similar to this study, a positive impact of trade openness on ecological footprint was unveiled in lower-middle and upper-middle-income countries (Al-Mulali et al. 2015b). Besides, Charfeddine (2017) revealed a positive linkage between trade openness and the ecological footprint in Qatar for the period 1970–2015. Likewise, Ulucak and Bilgili (2018) affirmed that trade openness leads to an increase in ecological footprint through using updated fully modified ordinary least squares (CUP-FM) and continuously updated bias-corrected (CUP-BC) approach for the high, middle, and low-income nations. A similar result was also found in the study of Imamoglu (2018) for Turkey and Kongbuamai et al. (2020) for Thailand. On the contrary, some studies (Alola et al. 2019; Destek et al. 2018; Mrabet et al. 2017) noted a negative effect of trade openness on the ecological footprint.

Apart from the aforementioned determinants, this study also considered energy use as a possible catalyst for environmental degradation. Using a panel error correction model for nineteen developing and developed nations, Apergis et al. (2010) proved that energy use and economic development positively affect environmental degradation. Tiwari et al. (2013) revealed that the use of energy positively affects environmental degradation in India. Mohiuddin et al. (2016), by using a time series data spanning from 1971 to 2013, scrutinized that energy use positively affected the environmental degradations in Pakistan. The study by Rehman and Rashid (2017) tested the association between environmental degradation and energy consumption under a multivariate approach for emerging Asian countries. The examined results revealed that energy consumption and environmental degradation are positively related. Sarkodie and Adams (2018) exposed that renewable energy technologies advocate a limpid environment, while fossil fuel energy degrades the environment. Likewise, energy consumption degrades the environmental quality in Singapore, China, Mexico, India, and top forested countries (Destek and Sarkodie 2019; Abbasi et al. 2021d). By using the dynamic simulation ARDL approach in Pakistan, Khan et al. (2019) scrutinized the effect of energy consumption on carbon dioxide emissions. They elicited that energy consumption has a significant negative effect on environmental quality. Renewable energy use promotes environmental quality and curtails carbon dioxide emission, while the use of traditional energy does damage the environment in Pakistan (Khan et al. 2020a). Similar results were also reported by Abbasi and Adedoyin (2021) in the context of China.

Technological innovation is considered one of the most legitimate means to abate environmental degradation (Chen and Lee 2020). Although several researches exposed the association between technological innovation and environmental quality by using distinguish country-level data, models and methods produce mixed outputs. Kumail et al. (2020) found that technological innovation yields a lower amount of emission, thus improving the environmental quality in the context of Pakistan using the data from 1970 to 2017. Likewise, negative nexus between ecological footprint and technological innovation was also reported by Yang et al. (2021). However, a positive linkage between environmental quality and technological innovation has also been explored in the preceding researches (Töbelmann and Wendler 2020; Chen and Lee 2020; Yu and Du 2019). In contrast, opposed findings were also noted in other studies (Adebayo and Kirikkaleli 2021; Cheng et al. 2019).

The above literature reveals significant arguments about either positive or negative effects of the selected stimulus on environmental degradation across countries. The present research could be regarded as superior to the above studies because it applies a novel econometric model such as dynamic simulated ARDL, and frequency domain causality. Besides, In Bangladesh, no study has been performed utilizing dynamic ARDL simulations to relate variables such as technological innovation, energy usage, capital formation, trade openness, urbanization, and economic expansion to environmental deterioration. Therefore, it is imperative to assess this linkage in Bangladesh because Bangladesh has been facing the serious threat of environmental degradation and growing demands for ecological resources in recent decades.

Theoretical background

The theoretical framework of this study is based on the EKC hypothesis developed by Kuznets (1955), which was centered on income inequality. This theory explains the rising trend in income disparity and per capita income. However, some environmental economists like Panayotou (1997) and Grossman and Krueger (1991) improved this idea by looking into the relationship between economic growth and environmental quality. This hypothesis described that the effect of GDP growth on the environmental quality of any economy occurs in three stages: scale, structural, and composite effects. The first stage is termed the scale effects. Environmental degradation occurs during this phase, but after reaching a tipping point, environmental quality begins to improve due to technological advancement and increased environmental awareness. The non-renewable energy sources boost developing countries' economic and production activity; hence this phase is relevant to them. The structural and composite effects, which are the second and third stages, are considered the turning point. This is connected with developed countries, where service and technology-driven economic activities account for the majority of their economic operations. In this study, it is anticipated that Bangladesh's economic expansion would be attained to the detriment of the environment and measures will be proposed to promote the long-term sustainable environment amid economic advancement.

Data and model construction

Depending on data availability, time-series data covering the period of 1972 to 2017 was used in this study. We extracted the data on ecological footprint from the Global Footprint Network (GFN) and then the data on economic growth, capital formation, urbanization, trade openness, and use of energy from the World Bank. The data on direct patent application derived from the World Intellectual Property Organization (WIPO). The variables used in this study are described in Table 1. We transformed all the data into a natural logarithm to aside the risk of heteroscedasticity and to avoid the dynamic properties problem of the data series (Paramati et al. 2017). Natural logarithm transformation also helps us disclose growth effects (Nathan et al. 2016), and estimated coefficients in the regression can be explained as an elasticity (Paramati et al. 2017).

This study employs ecological footprint measured as a proxy of environmental degradation following the previous literature (Adedoyin et al. 2021c; Ahmed et al. 2020a, b; Baz et al. 2020; Destek and Sinha 2020; Alola et al. 2019; Danish and Wang 2019; Destek and Sarkodie 2019) denoting the dependent variable for the empirical model. The ecological footprint is an index incorporating human demands for areas

Table 1 Description of variables

Variables	Symbol	Measurement unit	Source
Ecological footprint	EF	Global hectares (gha) per capita	GFN (2021)
GDP per capita (proxy for Economic growth)	GDP	USD at constant 2010 price	WDI (2021)
Capital formation	CA	% of GDP	WDI (2021)
Urbanization	UR	Measured in terms of urban population % of total population	WDI (2021)
Trade openness	TO	(Import + Export)/GDP	WDI (2021)
Energy use	EU	Kg of oil equivalent per capita	WDI (2021)
Technological innovation	TI	Total patent applications	WIPO (2021)

required for cropland, livestock, forest, build-up land, the measure of CO_2 footprint, and the ocean area required for seafood production (Ahmed et al. 2019). In line with previous studies, GDP per capita was employed as a proxy for economic growth (Ahmed et al. 2019; Hassan et al. 2019b; Baz et al. 2020). Initially, we modeled the impact of GDP per capita on environmental degradation measured by ecological footprint.

However, allowing only one regressor in the model may produce a spurious and biased outcome. Hence, overviewing existing literature, other explanatory variables, i.e., capital formation, urbanization, and trade openness, were included in the model. Capital formation permits greater investment in various productive activities as well as higher resource consumption, which has an impact on the environment. As a result, it was also taken into account in our research. People tend to relocate from villages to cities and towns in search of a better life as economic activities increase, putting strain on the environment by transforming more land into infrastructure (Gallup et al. 1999). As a result, the model incorporates the environmental effects of urbanization. Furthermore, when an economy expands, so does its trade with the rest of the world, which may substantially influence environmental quality. Trade may also be an indicator of technological advancement, which impacts environmental quality (Destek and Sinha 2020); hence, we considered trade openness to be an explanatory variable. To that aim, unlike prior studies, two critical components of Bangladesh's economy, such as energy usage and technical innovation, were also included because Bangladesh is in an economic transition phase, and therefore energy is overexploited. Furthermore, technological advancement has become a demanding phenomenon in recent decades, with every nation aspiring to incorporate technology innovation into the development process. To evaluate the effect of these factors on environmental degradation, we encompass these factors in our empirical model. Thereafter, we employed the following function for our study.

$$lnEF = \int (lnGDP, lnGDP^2, lnCA, lnURB, lnTO, lnEU, lnTI) \tag{1}$$

where *ln*EF, *ln* CA, *ln* URB, *ln* TO, *ln* EU, and *ln* TI represent natural logarithm forms of ecological footprint, capital formation, urbanization, trade openness, use of energy, and technological innovation, respectively. *ln* GDP and *ln* GDP^2 indicate the log of real GDP per capita and log of the square of real GDP per capita, respectively. However, the estimation model is given in a quadratic form of GDP to justify the EKC hypothesis (Qiao et al. 2019). Following EKC insight, the signs of lnGDP and $lnGDP^2$ coefficients are anticipated to be positive and negative, respectively. EKC hypothesis can also be tested following Narayan and Narayan (2010), who claimed if the short-run coefficient of the lnGDP is larger than long-run coefficient, then the EKC hypothesis exists. However, the flow of the analysis employed in this study is depicted in Fig. 1.

Econometric methodology

Before employing the econometric approaches, we conducted both conventional and structural-break stationarity or unit root test. After ascertaining the stationarity properties of the variables, i.e., none of the series is stationary at the 2nd difference, we proceeded to the linear cointegration and long-run analysis. The study initially employed the conventional Augmented Dickey-Fuller (ADF) (Dickey and Fuller 1979) and the Phillips-Perron (PP) (Phillips and Perron 1988) test to check the stationarity. However, the ADF test and the PP test do not take into account the structural breaks in the data series, and, therefore, the outcome of these tests can be biased (Perron 1989). Hence, to overcome the uncertainty that emerged from any structural break in the series, in line with the previous studies (e.g., Kongbuamai et al. 2020; Nathaniel 2020; Ahmed et al. 2019), we also adopted Zivot and Andrews (ZA) (2002) structural unit root test.

ARDL bounds testing approach

After confirming the unit root result, cointegration testing is mandatory to apply an ARDL approach. To derive the long-run coefficient of the ARDL model, we need to verify the existence of the long-run relationship among variables examined using the bounds test. The null hypothesis for the

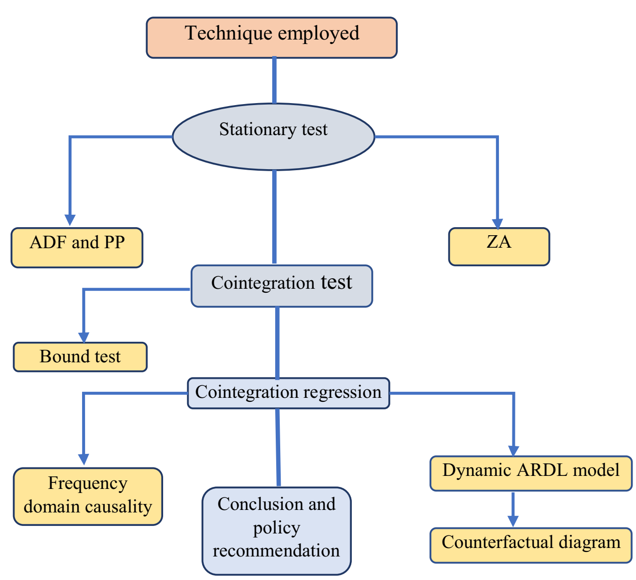

Fig. 1 Methodology flow diagram

ARDL F-bounds test (H_0: $\alpha_1 = \alpha_2 = \alpha_3 = \alpha_4 = \alpha_5 = \alpha_6 = \alpha_7 = \alpha_8 = 0$) indicates no cointegration among variables. The alternative hypothesis (H_1: $\alpha_1 \neq \alpha_2 \neq \alpha_3 \neq \alpha_4 \neq \alpha_5 \neq \alpha_6 \neq \alpha_7 \neq \alpha_8 \neq 0$) specifies the presence of cointegration. We may not accept or accept the null hypothesis based on the estimated value of F-statistic. Besides, the F-statistic value of the bound test is compared with the critical value. If the F-statistic value exceeds the critical values at the 1%, 5%, and 10% level of significance, it ensures the long-run relationship. If the lower bound value is higher than the value of F-statistics, it indicates long-run association does not prevail among the variables. The decision is inconclusive when the estimated F-statistics value remains between the value of lower and upper bound (Khan et al. 2019). Alongside the F-bounds test, a statistically significant error correction term with a negative sign consolidates the existence of a long-run association. To explore the long-run association among the selected variables, the following equation of the ARDL bounds test is formulated according to the cointegration hypotheses:

$$\begin{aligned}\Delta(lnEF)_t &= \alpha_0 + \alpha_1 lnEF_{t-1} + \alpha_2 lnGDP_{t-1} + \alpha_3 lnGDP^2_{t-1} + \alpha_4 lnCA_{t-1} + \alpha_5 lnUR_{t-1} \\ &+ \alpha_6 lnTO_{t-1} \\ &+ \alpha_7 lnEU_{t-1} + \alpha_8 lnTI_{t-1} + \sum_{i=1}^{p} \beta_1 \Delta lnEF_{t-i} + \sum_{i=1}^{p} \beta_2 \Delta lnGDP_{t-i} + \sum_{i=1}^{p} \beta_3 \Delta lnGDP^2_{t-i} + \sum_{i=1}^{p} \beta_4 \Delta lnCA_{t-i} + \sum_{i=1}^{p} \beta_5 \Delta lnUR_{t-i} + \sum_{i=1}^{p} \beta_6 \Delta lnTO_{t-i} + \sum_{i=1}^{p} \beta_7 \Delta lnEU_{t-i} + \sum_{i=1}^{p} \beta_8 \Delta lnTI_{t-i} + u_t\end{aligned} \tag{2}$$

where Δ denotes the first difference operator, t-i indicates the optimal lags selected based on the Schwarz information criterion (SIC), u t is the error term, and p indicates the lag length. Moreover, α and β s are parameters to be estimated to scrutinize the long-run linkage among variables. The short and long-run ARDL model will be employed after confirming the long-run association among the variables (Khan et al. 2019).

Autoregressive distributed lag (ARDL) model

The ARDL model is a dynamic regression model that allows variables with different lag orders to capture the best possible outcome (Pesaran et al. 2001). The model requires all the variables to be stationary at the first difference, or stationary at the level, or a mixture of both first difference and level. The advantage of the ARDL model is that it offers variables with different optimal lags, which other cointegration procedures do not provide (Ozturk et al. 2016). Moreover, the ARDL model is widely used in recent studies regarding environmental degradation and economic factors (Gülmez et al. 2020; Langnel and Amegavi 2020). Since the cointegration among the variables was found, hence, the long-run ARDL model for this study is specified as:

$$\begin{aligned}lnEF_t &= \zeta_0 + \sum_{i=1}^{q} \Phi_1 \Delta lnEF_{t-i} + \sum_{i=1}^{q} \Phi_2 \Delta lnGDP_{t-i} \\ &+ \sum_{i=1}^{q} \Phi_3 \Delta lnGDP^2_{t-i} + \sum_{i=1}^{q} \Phi_4 \Delta lnCA_{t-i} + \sum_{i=1}^{q} \Phi_5 \Delta lnUR_{t-i} \\ &+ \sum_{i=1}^{q} \Phi_6 \Delta lnTO_{t-i} + \sum_{i=1}^{q} \Phi_7 \Delta lnEU_{t-i} + \sum_{i=1}^{q} \Phi_8 \Delta lnTI_{t-i} + \xi_t\end{aligned} \tag{3}$$

In Eq. (3), Φ_1 to Φ_8 denotes the long-run variation among the study variables. The following equation reflects the error correction model for short-run coefficients:

$$\begin{aligned}lnEF_t &= \zeta_0 + \sum_{i=1}^{q} \psi_1 \Delta lnEF_{t-i} + \sum_{i=1}^{q} \psi_2 \Delta lnGDP_{t-i} + \sum_{i=1}^{q} \psi_3 \Delta lnGDP^2_{t-i} \\ &+ \sum_{i=1}^{q} \psi_4 \Delta lnCA_{t-i} + \sum_{i=1}^{q} \psi_5 \Delta lnUR_{t-i} + \sum_{i=1}^{q} \psi_6 \Delta lnTO_{t-i} \\ &+ \sum_{i=1}^{q} \psi_7 \Delta lnEU_{t-i} + \sum_{i=1}^{q} \psi_8 \Delta lnTI_{t-i} + \varphi ECT_{t-i} + \xi_t\end{aligned} \tag{4}$$

In Eq. (4), ψ implies the variability in the short-run coefficients, whereas the rate of disequilibrium adjustment is estimated by the error correction term (ECT). The possible range of ECT is from − 1 to 0 (Abbasi et al. 2021e). The estimated value of ECT should be negative and statistically significant, implying that any deviation should be back to equilibrium in the next period. This study also diagnoses the model by employing several tests such as CUSUM and CUSUMSQ to check model stability. Besides, Breusch-Godfrey Lagrange Multiplier (LM) and Breusch-Pagan-Godfrey are utilized to check the serial correlation and heteroscedasticity, respectively. Moreover, we use Durbin-Watson (DW) statistics to verify the first-order autocorrelation and the Jarque–Bera test for normality. Lastly, the Ramsey reset test is employed to investigate whether the model is correctly specified.

Dynamic ARDL simulations

The dynamic ARDL simulations model was developed by Jordan and Philips (2018) to unravel the complexities of the extant ARDL model for exploring the short and long-run association between variables. The dynamic simulated ARDL model has the capabilities to estimate, stimulate, and robotically plot the graphs to predict counterfactual variations in one independent variable and its response on the dependent variable while holding the other regressors constant (Khan et al. 2019; Sarkodie et al. 2019; Jordan and Philips 2018). In contrast, the ARDL model only can estimate the long and short-run relationship (Khan et al. 2020b). The data used for the model assessment should be integrated at I(1) and having cointegrated to perform the dynamic ARDL simulations technique, for which the study's variable conformed to the pre-requisite (Sarkodie et al. 2019). This study applied 5000 simulations in the context of the dynamic ARDL error correction term algorithm for the parameters vector from a multivariate normal distribution. Following the previous researches (Abbasi and Adedoyin 2021; Khan et al. 2020b; Sarkodie et al. 2019; Khan et al. 2019; Jordan and Philips 2018), the error correction equation of novel ARDL bounds test for this study can be specified as below:

$$\begin{aligned}\Delta(lnEF)_t &= \lambda_0 + \theta_0 lnEF_{t-1} + \beta_1 \Delta lnGDP_t + \theta_1 lnGDP_{t-1} \\ &+ \beta_2 \Delta lnGDP_t^2 + \theta_2 lnGDP_{t-1}^2 + \beta_3 \Delta lnCA_t + \theta_3 lnCA_{t-1} \\ &+ \beta_4 \Delta lnUR_t + \theta_4 lnUR_{t-1} + \beta_5 \Delta lnTO_t + \theta_5 lnTO_{t-1} \\ &+ \beta_6 \Delta lnEU_t + \theta_6 lnEU_{t-1} + \beta_7 \Delta lnTI_t + \theta_7 lnTI_{t-1} + \xi ECT_{t-1} + u_t\end{aligned} \tag{5}$$

Frequency domain causality

To scrutinize the causal relationship, we applied the spectral Granger-causality by Breitung and Candelon (2006). Although Granger causality has some drawbacks, several researchers extensively employed it to investigate the causal relationship between. Firstly, it is possible to estimate single-test statistic over time through the conventional Granger causality tests. So, it cannot be used to explore the causality at different frequencies (Gorus and Aydin 2019). Secondly, when the nexus between variables is associated with a higher than one frequency, this method does not perform effectively to capture the causal association (Masset 2008). Therefore, Granger causality in the frequency domain technique was conducted in this research to demonstrate the short-, medium-, and long-run causality, which simplifies the prophecy of the variable to be responded at specific time frequencies (Abbasi et al. 2021e). In frequency domain analyses, the spectral density function is considered to reveal the periodic fluctuation in the data series (Gorus and Aydin 2019). However, this method has a limitation to perform with a definite timescale; thus, the model holding an infinite horizon cannot be estimated (Abbasi et al. 2021e). Following the previous literature (Abbasi et al. 2021e), the equation of Breitung and Candelon (2006) is specified as follows:

$$X_t = \alpha_1 \chi_{t-1} + \; + \alpha_p \chi_{t-p} + \beta_1 Y_{t-1} + \; + \beta_p Y_{t-p} + \varepsilon_{lt} \tag{6}$$

The linear restriction of the above equation is based on $M_{y\to x}(\omega)=0$ null hypothesis. According to Abbasi et al. (2021e), we assume, $\omega_i=0.05$, $\omega_i=1.5$, and $\omega_i=2.5$ for long-, medium-, and short-term causality, respectively. However, α and β are the parameters to be estimated in lag p, time t, while ε_t is an error term.

Results and discussions

Descriptive statistics, unit root test, and lag selection

Table 2 delineates the descriptive statistics of the studied variables. The ecological footprint of Bangladesh ranged from 0.40 to 0.85, with an average value of 0.57 in the study

Table 2 Descriptive statistics and correlation matrix analysis

	EF	GDP	CA	UR	TO	EU	TI
Mean	0.572	540.769	19.706	21.793	27.306	156.936	46.153
Median	0.500	453.134	18.761	21.510	24.727	141.976	43
Maximum	0.850	1127.272	30.510	35.858	48.110	239.633	77
Minimum	0.400	322.334	4.697	8.221	10.995	104.861	16
Std. Dev	0.115	217.587	6.852	7.597	9.987	7.161	2.606
Skewness	0.056	0.180	−0.327	0.034	0.608	−0.996	−0.987
Kurtosis	2.794	2.322	2.185	2.173	2.210	0.620	0.134
Correlation matrix							
EF	1						
GDP	0.792***	1					
CA	0.632***	0.716***	1				
UR	0.714***	0.690***	0.765***	1			
TO	−0.787***	0.693***	0.702***	0.723***	1		
EU	0.775***	0.813***	0.698***	0.678***	0.776***	1	
TI	−0.419***	0.457***	0.477***	0.443***	0.436***	0.448***	1

*** and ** indicate significance at 1 and 5% level, respectively.

period. In recent years, Bangladesh experienced an upward per capita income trend, having a substantial rise in the last decades. On the other hand, capital formation, urbanization, and trade openness have registered heavy fluctuations over the years as their standard deviations are considerably higher. Significant variation of energy use and technological innovation reflects the gradual transition in sectoral changes of Bangladesh's economy. However, the estimated values of skewness and kurtosis depict that the variables are seemingly normally distributed, which is also supported by the Jarquee-Bera test in the later model diagnosis test. The correlation matrix outcome is also reported in Table 2. As the ARDL regression model includes different variables, we need to ensure that there is no multicollinearity in the variables. As none of the correlation coefficients between the independent variables exceed 0.80, we can deduce that our model is free from the multicollinearity problem (Farrar and Glauber 1967).

Table 3 illustrates the results of the ADF, PP, and ZA unit root tests. The outcome ensures that none of the underlying series is stationary at the second difference and all are stationary at the first difference. This outcome not only provides us the license to adopt the ARDL model but also allows us to employ the novel dynamic ARDL model. Following ADF and PP test, the ZA test is employed, which is more decisive as it takes into account one unknown structural break and also presents the order of integration. Similar to the ADF and PP test outcome, ZA test entails that all the series are stationary at the first difference. Appending to this, structural break dates are also visualized in the results. For instance, the ecological footprint has a break in 1993 implies that Bangladesh introduced the National Environmental Policy in 1992 to maintain the ecological balance and the country's overall development through conservation and improvement of the environment. After that, the environmental issues get considerable attention in terms of economic progress; thus, the breaks of 1993 in the dependent variable ecological footprint can be linked to this environmental policy. However, the dummy variables related to the aforementioned breaks were not significant, and without dummy variables, the model's parameters were stable. We, therefore, proceed to the dynamic simulated ARDL estimations, excluding the dummy variables from the model.

Table 4 demonstrates the results of different criteria for selecting the lag length. The recent literature extensively uses AIC, SIC, and HQ based on the VAR model to choose appropriate lag. According to the findings of AIC and SIC, lag one is appropriate, while lag two is applicable for the model based on the value of HQ. However, we adopt the SIC information criterion to choose suitable lag, SIC value implies that lag one is appropriate for our model since, among the two lag lengths, the SIC value is minimum.

Table 3 The ADF, PP, and ZA test

Variable	ADF test		PP test				ZA test	
	Level	Difference	Level	Difference	Level		Difference	
	T-Stat	T-Stat	T-Stat	T-Stat	T-Stat	Break Year	T-Stat	Break Year
LNEF	−1.179	−9.565***	−1.595	−12.025***	−4.013	2001	−14.526***	1993
	(0.902)	(0.000)	(0.669)	(0.000)	(0.363)		(0.01)	
LNGDP	1.863	−9.725***	2.084	−9.892***	−2.542	2000	−12.007***	1977
	(0.999)	(0.000)	(0.999)	(0.000)	(0.999)		(0.01)	
$LNGDP^2$	−3.029	−16.890***	−2.941	−15.778***	−2.787	1982	−20.869***	1983
	(0.137)	(0.000)	(0.193)	(0.000)	(0.793)		(0.000)	
LNCA	−2.223	−9.898***	−3.029	−16.315***	−3.710	1983	−11.165***	1978
	(0.465)	(0.000)	(0.161)	(0.000)	(0.264)		(0.01)	
LNUR	−1.644	−7.417***	−3.916	−6.158**	−4.284	1977	−18.612***	2001
	(0.290)	(0.000)	(0.106)	(0.027)	(0.185)		(0.01)	
LNTO	−3.493	−8.057***	−4.556	−8.459***	−4.428	2004	−9.678***	1978
	(0.172)	(0.000)	(0.145)	(0.000)	(0.095)		(0.000)	
LNEU	−3.085	−4.613**	−3.085	−7.452***	−2.070	1979	−11.536***	1980
	(0.122)	(0.040)	(0.122)	(0.000)	(0.9776)		(0.000)	
LNTI	−2.957	−11.026***	−2.423	−14.269***	−3.705	1984	−13.149***	1980
	(0.156)	(0.000)	(0.264)	(0.000)	(0.261)		(0.000)	

*** and ** show significance level of 1 and 5%, respectively. Parentheses contain *p* values.

Table 4 Lag selection criteria for ARDL model

Lag	LogL	LR	FPE	AIC	SIC	HQ
0	512.589	NA	1.13e−15	−14.597	−14.240	−14.440
1	856.256	474.556	2.02e−22	−16.601*	−27.677*	−29.280
2	1025.144	128.309*	1.50e−23*	−16.028	−27.305	−30.271*

LR sequential modified LR test statistic, *FPE* final prediction error, *AIC* Akaike information criterion, *SIC* Schwarz information criterion, *HQ* Hannan-Quinn information criterion. * Symbolizes lag order selected by the criterion.

Table 5 ARDL bounds test

F-statistics	Level of significance	Lower bound I(0)	Upper bound I(1)	Long-run relationship
4.08	10%	1.990	2.941	Present
	5%	2.271	3.282	
	2.5%	2.552	3.612	
	1%	2.880	3.994	

Long and short-run estimates of dynamic ARDL simulations

The F-statistics calculated from the F-bounds test are embedded above the margin of the critical value of lower bound I(0) and upper bound I(1) (Narayan 2005), even at a 1% level of significance (Table 5). This finding strongly suggests that the variables examined move together in the long run. In other words, economic growth, capital formation, urbanization, trade openness, energy use, and technological innovation have a long-run impact on the ecological footprint. Hence, we proceeded to attain the long-run coefficients, while short-run coefficients were obtained from the error correction model.

As evident from the results, GDP per capita and square of GDP per capita stimulate ecological footprint in the long run (Table 6). Other factors holding constant, ecological footprint rises 0.918% in response to 1% increase in GDP per capita in the long-run, whereas, in the short-run as GDP per capita increases by 1%, ecological footprint escalates by 0.829%, 0.786%, and 0.694% in the previous year, 2 years back, and 3 years back, respectively. However, the elasticity of both lnGDP and $\ln GDP^2$ revealed that economic growth monotonically increases the ecological footprint of Bangladesh. It indicates that the peak of ecological footprint for Bangladesh has not yet been reached following the EKC hypothesis. Reportedly, it is apparent that the long-run coefficient value is higher than that of the short-run, meaning that economic growth continues to dilapidate environmental quality more rapidly in the long-run. It also negates the EKC concept under the recent measurement procedure of Narayan and Narayan (2010). The rapid transformation of Bangladesh's economy has triggered more environmental degradation without much attention to environmental problems during economic growth. This outcome signifies the economy of Bangladesh is yet to develop in a sustainable manner that could help Bangladesh palliate the devastating impact of economic growth on environmental quality. This result is supported by the previous studies led by Adedoyin et al. (2020a) for EU countries, Ahmed et al. (2020a) for China, and Hassan et al. (2019) for the case of Pakistan. However, this outcome contradicts the previous finding revealed by Destek and Sarkodie (2019) for Pakistan.

Table 6 Findings of dynamic ARDL simulated model; Dependent variable: Ecological footprint

Variable	Coefficient	T-Stat	Prob
C	1.621***	3.605	0.001
lnGDP	0.829***	5.082	0.000
ΔlnGDP	0.451	1.054	0.251
$\ln GDP^2$	0.021*	2.002	0.071
$\Delta\ln GDP^2$	0.008	1.452	0.134
lnCA	0.557**	2.564	0.019
ΔlnCA	−0.592	−1.439	0.136
lnUR	0.433**	2.302	0.011
ΔlnUR	1.879***	3.882	0.001
lnTO	−0.231*	−2.097	0.054
ΔlnTO	0.032	0.873	0.367
lnEU	1.074***	3.486	0.000
ΔlnEU	0.761***	3.087	0.005
lnTI	−0.596**	−2.207	0.021
ΔlnTI	0.359	1.135	0.203
ECT(-1)	−0.721***	−5.245	0.000
R^2	0.942	Adjusted R^2	0.925
F statistics	592.786 [0.000]	N	45
Simulations	5000		

***, **, and * denote statistically significant at 1%, 5%, and 10% level of significance, respectively.

Although capital formation does not foster environmental degradation in the short run, it hampers the environmental quality in the long run. Precisely, the more capital enters the economy, the more investment occurs, which, in turn, leads to the development of infrastructure, expansion in economic activities, and industrialization and in this process deteriorates the environment quality (Agena 2007). This outcome also ascribes to the fact that being a rising economy, Bangladesh lacks proper environment-friendly investment and infrastructural development. However, the capital that enters the economy does not provide any deleterious feedback on the environment in the short-run period. This is because, at the initial stage of capital generating, changes in industrialization and infrastructure do not occur immediately, as it takes a longer period. As time forwards, more carbon emits, more land gets acquired, and more wastages are generated through the capital investment, which ends up decimating the environment. This finding goes congruous with the outcome of Zafar et al. (2019) for N-11 countries.

The long- and short-run coefficients of urbanization were both positive and significant, implying that urbanization promotes the expansion of the ecological footprint and, as a result, environmental degradation. Bangladesh experiences unwanted and unplanned urbanization (Uz Zaman et al. 2010), which contributes to environmental pollution to a great extent (Hasnat et al. 2018). In unplanned urbanization, the more people migrate to cities, the more land gets occupied in an unsustainable fashion (Deng et al. 2015), which eventually impedes proper management of wastages (Gills and Sharma 2021), hampers air quality (Bai et al. 2017), and destroys environment as a whole. Besides, urbanization stimulates environmental degradation by increasing the demand for food, water, energy consumption, construction, and transport (Baz et al. 2020). This finding is in line with the previous empirical studies of Langnel and Amegavi (2020) for Ghana and Ahmed et al. (2020b) for G-7 countries. However, our outcome opposes the extrapolation of Danish and Wang (2019) and Hassan et al. (2019) for Pakistan, where they found an insignificant effect of urbanization upon environmental degradation. Alongside, our findings go against the deduction of Danish et al. (2020), who suggest that urbanization reduces the ecological footprint in BRICS.

The long-run negative relationship between trade openness and ecological footprint is visualized by the coefficient of LNTO, which defines that with the expansion of trade, environmental quality improves. International trade openness facilitates the transfer of cross-border technology, allowing the country to get better access to cleaner technologies, which in turn dwindles the country's ecological footprint and promotes environmental quality (Destek and Sinha 2020). Besides, Shahbaz et al. (2018) claimed that international trade allows importing more advanced and eco-friendly technologies, which help enhance environmental quality. As a developing country, Bangladesh has immense opportunities to expand its trade and import environment-friendly technology for long-term planning in the context of environmental quality. The result fits in harmony with the study of Alola et al. (2019) and Destek et al. (2018), where they evidenced that trade openness mitigates environmental degradation and contradicts the finding of Charfeddine (2017) for Qatar and Adedoyin et al. (2021a) for EU-27 countries. Meanwhile, no evidence indicates the short-run impact of trade openness on the ecological footprint exerted in the model.

Meanwhile, energy use exerts a long-run and short-run stimulating effect on the ecological footprint. Delving deeper, energy use leads to environmental deterioration. Historically, Bangladesh's energy sector largely relies on fossil fuels, with coal and natural gas dominating power generation sources. And fossil fuel is accountable for emitting greenhouse gases and tars, which, in turn, deteriorates humankind, aquatic ecosystem, plant and forests, and air quality. As a result, fossil fuel fiercely degrades the environment as a whole. This result is in tandem with the previous finding of Abbasi and Adedoyin (2021) for China, the outcome of Adedoyin et al. (2021b) for the EU region, the inference of Adedoyin and Zakari (2020) for the UK, and the study of Khan et al. (2019) for Pakistan, where they claimed that energy consumption injures environmental quality. Furthermore, Adedoyin et al. (2020b) claimed that coal consumption deteriorates the environment in the BRICS countries.

On the other hand, despite causing short-run damage to the environment, technological innovation seems to heal the environment in the long run. Technological advancements likely improve environmental quality since improved technology might lead to more efficient production and reduced energy use, leading to lower emissions (Yang et al. 2021). Also, as Bangladesh heavily relies on fossil fuel energy, technological advancement should eliminate environmental hazards. Indeed, this finding implies that Bangladesh should eye on technological advancement to achieve a sustainable environment without hampering its production activities. Our finding echoes the previous finding of Chen and Lee (2020) and Yu and Du (2019). The error correction term of -0.721, which is statistically significant and negative, consolidates the equilibrium relationship among the variables and also shows the fast adjustment to the long-run equilibrium (Table 6). It also elucidates that at a 72% rate of adjustment, our model returns to long-run equilibrium after correcting the short-run disequilibrium.

In the dynamic ARDL model, impulse response functions automatically plot and predict the future value of a regressed variable in reaction to an independent variable while holding the other predictor variable constant. In this study, we forecasted the change in ecological footprint in response to a 10% positive or negative change in the explanatory variables. Figure 2 demonstrates the projected association between GDP per capita and ecological footprint. In the short run, each 10% increase or decrease in economic growth invariably worsens the environment. However, as

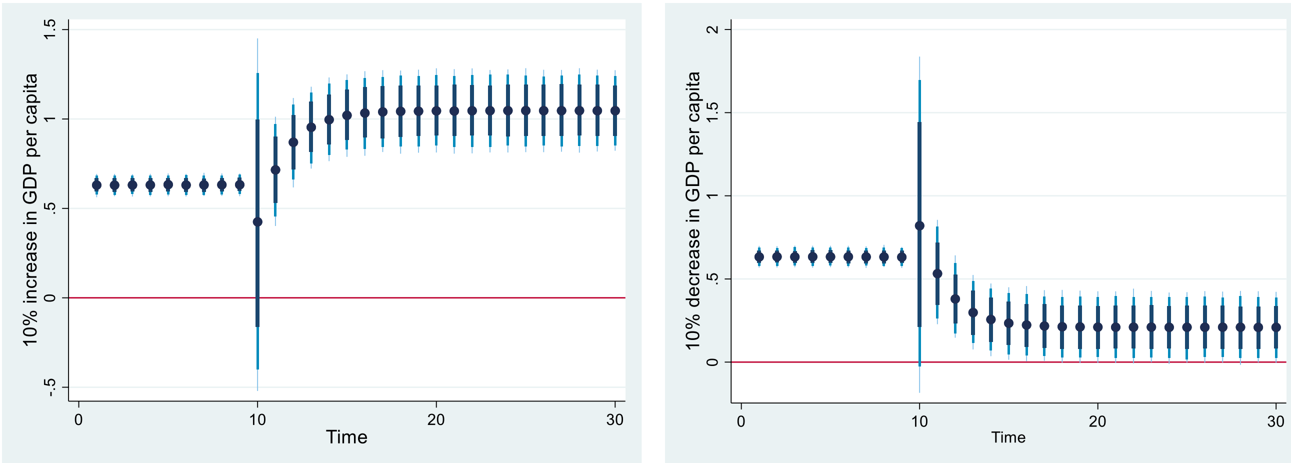

Fig. 2 Economic growth and ecological footprint. The above figure denotes ± 10% in GDP per capita and its effect on ecological footprint. The dots represent the predicted value, whereas the deep blue to light blue lines depict the 75%, 90%, and 95% confidence intervals, respectively

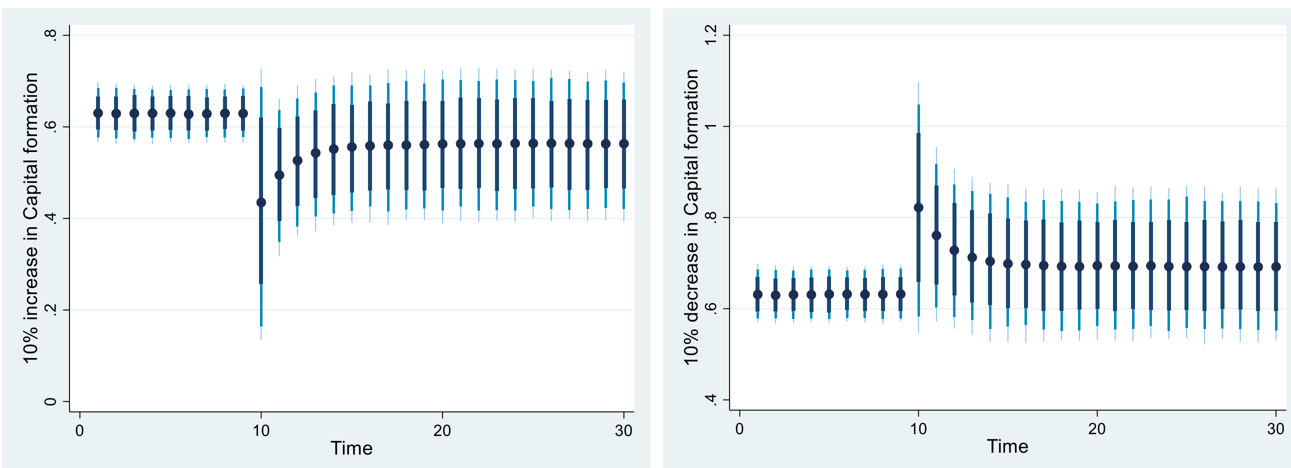

Fig. 3 Capital formation and ecological footprint. The above figure denotes ± 10% in capital formation and its effect on ecological footprint. The dots represent the predicted value, whereas the deep blue to light blue lines depict the 75%, 90%, and 95% confidence intervals, respectively

time passes, the damage precipitated to the environment by an increase in GDP per capita is intensified in the long run. On the other hand, every 10% reduction in GDP per capita reduces the ecological footprint in the long-run, and the environment naturally fixes the damage.

Figure 3 forecasts the ecological footprint's impulse response to positive or negative changes in capital formation. As shown, a 10% increase or reduction in capital formation does not lead to any notable change both in environmental quality in the short run and long run. Regardless of whether capital formation increases or decreases, the trend of ecological footprint remains positive and static though out the long-run and short-run periods.

Figure 4 shows that any positive or negative change in urbanization seems to have no significant short-term environmental impact. Furthermore, in the long run, every 10% increase in urbanization continues to degrade environmental quality. On the other end, any reduction in urbanization results in a cutback in ecological footprint in the long run.

The impulse response functions for ecological footprint to the changes in trade openness by 10% are shown in Fig. 5. Both 10% increase and decrease in trade openness cause equal short-term loss to the environment. However, as time advances, ecological footprint elevates in the long run with any expansion in trade openness, whereas any 10% plunge in trade openness leads to a steady reduction in ecological footprint. Yet, this decline in trade openness cannot heal the environment since ecological footprint persists positively in the long run.

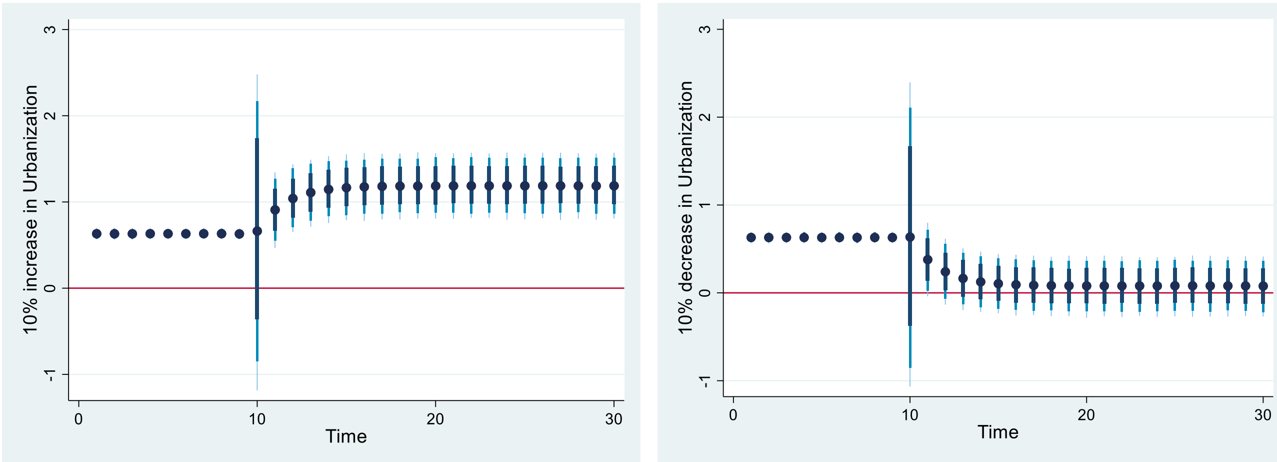

Fig. 4 Urbanization and ecological footprint. The above figure denotes ± 10% in urbanization and its effect on ecological footprint. The dots represent the predicted value, whereas the deep blue to light blue lines depict the 75%, 90%, and 95% confidence intervals, respectively

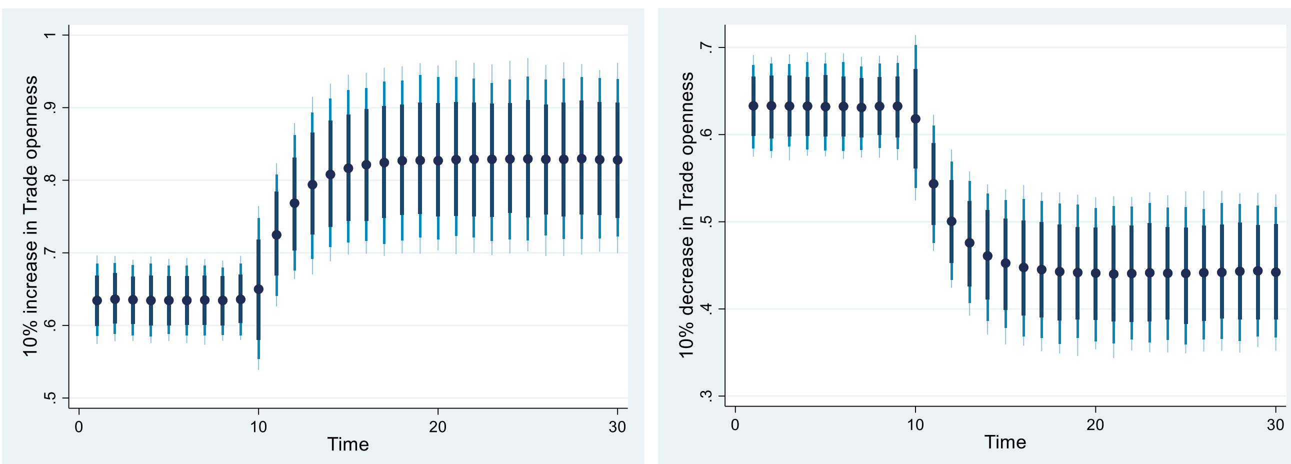

Fig. 5 Trade openness and ecological footprint. The above figure denotes ± 10% in trade openness and its effect on ecological footprint. The dots represent the predicted value, whereas the deep blue to light blue lines depict the 75%, 90%, and 95% confidence intervals, respectively

Changes in ecological footprint in response to energy use are manifested in Fig. 6. Apparently, any 10% increase or decrease in energy use causes an invariable change in the environmental quality. Further, in the long run, every 10% increase in energy use consistently deteriorates the environmental quality by raising the ecological footprint. However, environmental quality upgrades with every 10% decrease in energy use to the horizon. Hence, energy use will continue to stimulate environmental atrophy in the future.

The link between technological innovation and environmental footprint is demonstrated by the projections in Fig. 7. Any 10% increase or decrease in technological innovation results in an equal and positive short-term shift in ecological footprint. Afterward, environmental quality tends to improve in the long run with any positive change in technological innovation, whereas environment experiences more drastic deterioration to any further technological slowdown in the long run.

Coming to the model fitness, the high values of R-squared, adjusted R-squared, and F-statistic ensure the model is well fitted. The results of the Breusch-Godfrey LM test confirmed that the model is free from serial correlation (Table 7). There is no evidence of heteroscedasticity in the model verified by the Breusch-Pagan-Godfrey test. The Durbin-Watson (DW) statistic defines that the model is free from the first-order autocorrelation. To examine whether the model is correctly specified, the Ramsey RESET test is employed. The finding suggests that the model is specified properly. Besides, the residuals are

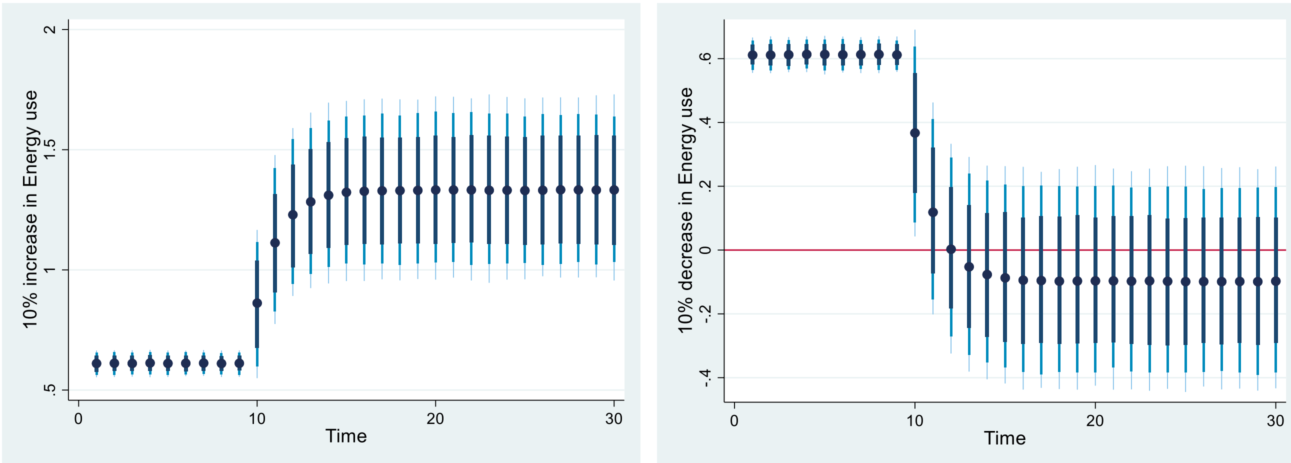

Fig. 6 Use of energy and ecological footprint. The above figure denotes ± 10% in the use of energy and its effect on ecological footprint. The dots represent the predicted value, whereas the deep blue to light blue lines depict the 75%, 90%, and 95% confidence intervals, respectively

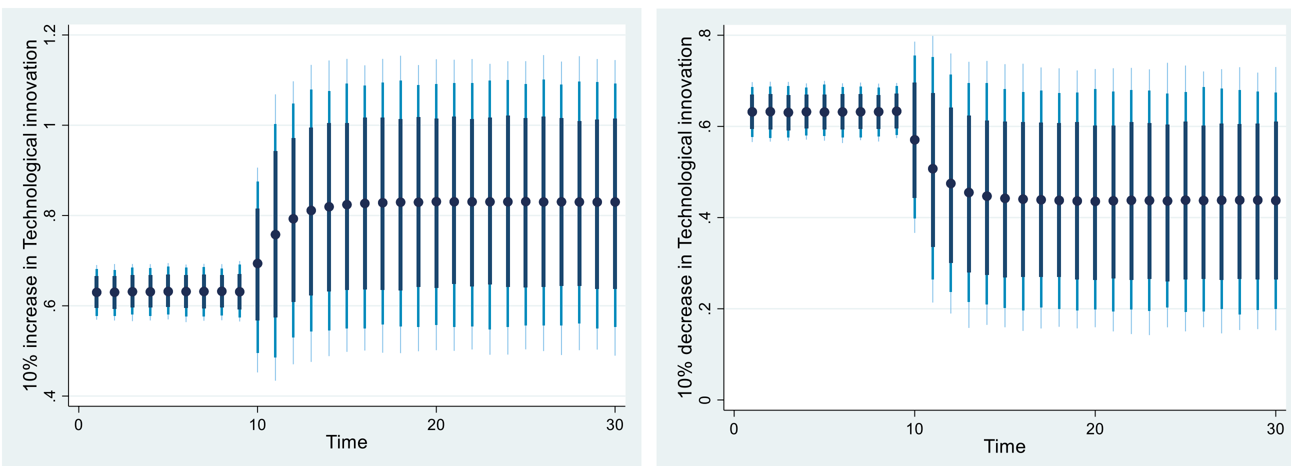

Fig. 7 Technological innovation and ecological footprint. The above figure denotes ± 10% in technological innovation and its effect on ecological footprint. The dots represent the predicted value, whereas the deep blue to light blue lines depict the 75%, 90%, and 95% confidence intervals, respectively

Table 7 Residuals diagnostics

Diagnostic test	Chi-square (P-value)	Findings
Breusch-Godfrey Serial Correlation LM	0.123	No problem of serial correlations
Breusch-Pagan-Godfrey	0.424	No evidence of heteroscedasticity
DW Stat	2.319	Free from first-order autocorrelation
Jarque–Bera test for normality	0.256	Residuals are normally distributed
Ramsey RESET test	0.583	Model specified correctly

distributed normally confirmed by the Jarque–Bera test. However, the graphical plots of CUSUM and CUSUM of squares in Fig. 8 depict that the estimates' parameters lie inside the critical margin, asserting the model stability. Lastly, to check the robustness of the model, we conducted a sensitivity analysis adding an additional variable. Results revealed that the signs of long-run coefficients remained

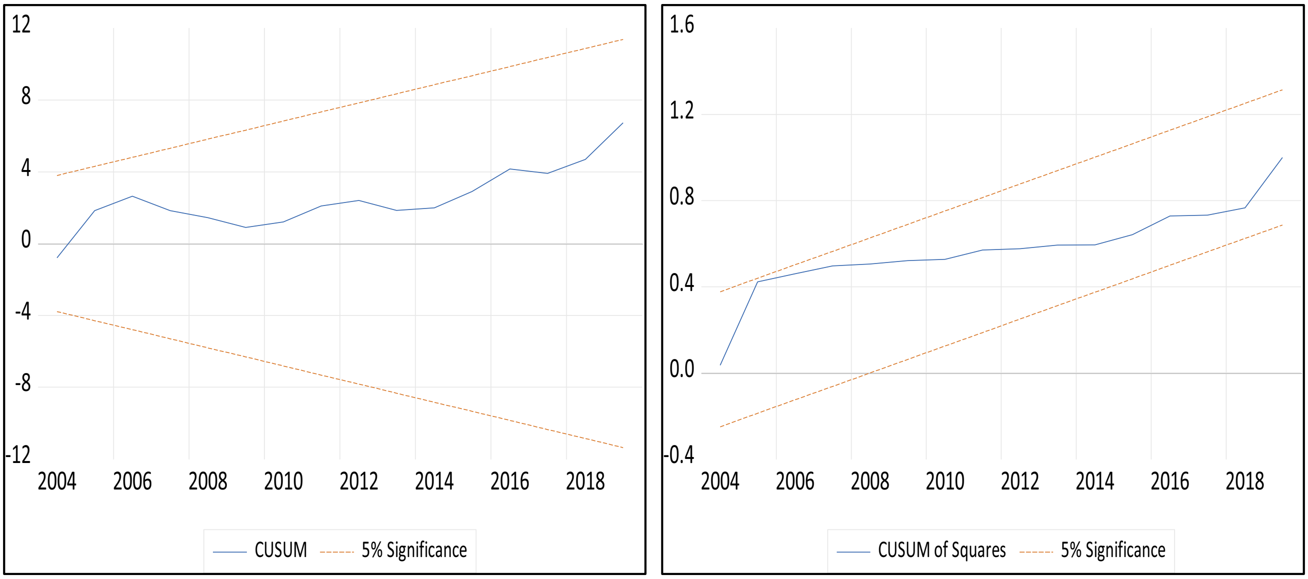

Fig. 8 CUSUM test and CUSUM of squares test

the same as we found in the studied Dynamic ARDL model, implying that our model is robust (Table A1).

Findings of frequency domain causality analysis

We have investigated the long and short-run effect of explanatory variables on the dependent variable; however, the causal relationships among variables are also influential in recommending policies. Thus, our study incorporates the frequency domain causality test to investigate the short-term, medium-term, and long-term causality for $\omega_i = 0.05$, $\omega_i = 1.50$, and $\omega_i = 2.50$ frequencies. Table 8 reports that the bidirectional long-run causal relationship exists between economic growth and ecological footprint. Hence, it ascertains that economic growth and environmental degradation are interlinked in the long run. This finding echoes the previous outcome revealed by Ahmed et al. (2019) for Malaysia and Charfeddine and Mrabet (2017) for MENA countries. This finding suggests that while giving efforts towards mitigating environmental degradation, the possible downfall in economic growth should also be taken into account, or else it may harm the economy Table A1.

Bi-directional long-run, mid-run, and short-run causality effects were also unveiled between capital formation and ecological footprint; urbanization and ecological footprint; and trade openness and ecological footprint. These outcomes suggest before regulating policies to alleviate environmental pollution, and concerns should be posted on the possible feedback impact on capital formation, trade, and urbanization. These revelations symbolize that likewise economic

Table 8 Granger causality test in the frequency domain

Causality direction	Long-term	Medium-term	Short-term
	$\omega_i = 0.05$	$\omega_i = 1.50$	$\omega_i = 2.50$
GDP = > EF	10.945***	1.774	1.367
	(0.002)	(0.325)	(0.598)
EF = > GDP	8.746**	0.896	0.674
	(0.013)	(0.532)	(0.734)
CA = > EF	7.627**	5.673*	4.571*
	(0.038)	(0.068)	(0.073)
EF = > CA	15.657***	6.674**	4.288*
	(0.000)	(0.024)	(0.056)
UR = > EF	12.354***	7.768**	7.244**
	(0.001)	(0.025)	(0.031)
EF = > UR	6.324**	7.546**	7.133**
	(0.041)	(0.029)	(0.036)
TO = > EF	7.751**	4.955*	4.379*
	(0.022)	(0.086)	(0.051)
EF = > TO	1.522**	5.497*	3.662*
	(0.048)	(0.052)	(0.099)
EU = > EF	7.734**	4.867*	4.845*
	(0.022)	(0.085)	(0.085)
EF = > EU	2.843	2.853	0.029
	(0.241)	(0.240)	(0.977)
TI = > EF	6.617**	2.324	1.875
	(0.041)	(0.297)	(0.350)
EF = > TI	1.114	1.355	2.345
	(0.612)	(532)	(0.256)

***, **, and * denote significance at 1%, 5% and 10% level, respectively. Figures in parentheses are *p* values.

growth and ecological footprint, interdependency exists between capital formation and ecological footprint, urbanization and ecological footprint, and trade openness and ecological footprint. Indeed, the regulatory authorities should maintain balances among these sectors in formulating plans towards environmental issues. Otherwise, economic activities, financial operations, trade, and urban citizens might fall victim to it. The bidirectional causality effect between urbanization and ecological footprint gains credence from the previous study of Hassan et al. (2019) for Pakistan. It is also apparent that energy use causes ecological footprint in the long-term, medium-term and, short-term without any feedback impact. Further, a one-way long-run causal relationship was revealed from technological innovation to ecological footprint. This symbolizes that environmental issues do not pose any impact on technological advancement in Bangladesh.

Concluding remarks and policy recommendations

This paper explores the relationship between ecological footprint and economic growth with consideration of capital formation, urbanization, trade openness, energy use, and technological innovation. Initially, both the conventional and the structural break stationarity tests were employed to validate the stationarity of the variables. The findings of the dynamic ARDL model suggest that the EKC hypothesis does not hold for Bangladesh, as no inverted U-shaped association is observed between economic growth and ecological footprint. Similar to economic growth, capital formation seemed to devastate the environment in the long-run. Further, urbanization proved to decimate environmental quality, both in the long run and short run. Meanwhile, the long-run coefficient of trade openness indicated that with the expansion of trade, the environment improves through the advent of technological advancement. Technological innovation seems to lessen environmental degradation in the long run, whereas energy use showed an adverse effect on the environmental quality. Lastly, long-run and short-run, medium-run, and long-run causality among the variables were inspected by adopting frequency domain causality. The long-run bidirectional causal association revealed between economic growth and environmental degradation. In addition, short-run, medium-run, and long-run feedback revealed between (i) capital formation and environmental degradation, (ii) urbanization and environmental degradation, and (iii) trade openness and environmental degradation. These bidirectional causal associations signify that environmental degradation has an interdependency association with economic growth, capital formation, urbanization, and trade openness. However, the one-way causal relationship runs from energy use to environmental degradation throughout the short-run, medium-run, and long-run periods. Technological innovation also evidenced a long-run unidirectional causal link with the environment without any feedback effect.

Critically analyzing the findings, we further recommend possible strategies to be adopted for ensuring a healthy environment with sustainable economic development:

Urbanization has a linkage with environmental degradation, and it has a bidirectional causal association with GDP. Therefore, the sustainability of urbanization should be the pivotal agenda of environmental policies since reducing urbanization will hamper economic growth. In this regard, to promote planned urbanization, more budgets should be allocated for the city corporations and municipalities. Concurrently, authorities should be stringent about environmental issues. Besides, industries should be decentralized from the city of Dhaka and Chattogram to all over the country with a proper environmental plan so that people do not migrate to these major cities but to other cities that will promote economic growth without depleting the environment.

Although economic growth is associated with environmental degradation, it cannot be ignored for the sake of people's betterment. Therefore, the government should resort to updating the environmental policies and regulations of the law in consonance with eco-friendly economic growth.

Before establishing industries and factories, advanced technologies should be equipped to mitigate the possible deleterious impact on the environment. Each industry, small or large, should be brought under the umbrella of stricture regulations, and they should continuously use of clean and renewable energy to reluctant themselves pollute the environment. For that reason, Bangladesh should aim to produce or import clean and renewable energy. Reportedly, clean energy helps improve individual well-being. Also, reducing the use of fossil fuels will help recover the damage done to the environment.

Capital formation has a positive relationship with environmental degradation. It is observed that the financial sector overlooks environmental sustainability for investments. To address this, regulations should be emerged for assessing the environmental viability of the financial sector's investment projects.

Appendix

Table A1 Sensitivity analysis to check the model robustness

Variable	Coefficient	T-Stat	Prob
C	1.295***	3.402	0.000
lnGDP	0.625***	4.234	0.000
$lnGDP^2$	0.268***	3.102	0.003
lnCA	0.852**	2.652	0.021
lnUR	0.843**	2.803	0.001
lnTO	-0.456**	-2.285	0.042
lnEU	2.302***	4.601	0.000
lnTI	− 0.069***	− 3.574	0.001
lnFDI	0.404*	2.103	0.074

***, **, and * denote statistically significant at 1%, 5% and 10% level of significance, respectively

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Declarations

Ethics approval The authors of this manuscript have agreed to authorship, approved the manuscript, given consent for submission and subsequent publication of the manuscript. The authors of this manuscript also assure that they follow the Springer publishing procedures and agree to publish it as any form of access article confirming to subscribe access standards and licensing.

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References

Abbasi KR, Abbas J, Mahmood S, Tufail M (2021a) Revisiting electricity consumption, price, and real GDP: A modified sectoral level analysis from Pakistan. Energy Policy 149:112087. https://doi.org/10.1016/j.enpol.2020.112087

Abbasi KR, Adedoyin FF (2021) Do energy use and economic policy uncertainty affect CO 2 emissions in China? Empirical evidence from the dynamic ARDL simulation approach. Environ Sci Pollut Res 28(18):23323–23335. https://doi.org/10.1007/s11356-020-12217-6

Abbasi KR, Adedoyin FF, Abbas J, Hussain K (2021b) The impact of energy depletion and renewable energy on CO2 emissions in Thailand: Fresh evidence from the novel dynamic ARDL simulation. Renew Energy 180:1439–1450. https://doi.org/10.1016/j.renene.2021.08.078

Abbasi KR, Adedoyin FF, Radulescu M, Hussain K, Salem S (2021d) The role of forest and agriculture towards environmental fortification: designing a sustainable policy framework for top forested countries. Environ Dev Sustain 1-28. https://doi.org/10.1007/s10668-021-01803-4

Abbasi KR, Lv K, Radulescu M, Shaikh PA (2021a) Economic complexity, tourism, energy prices, and environmental degradation in the top economic complexity countries: fresh panel evidence. Environ Sci Pollut Res 1-15. https://doi.org/10.1007/s11356-021-15312-4

Abbasi KR, Shahbaz M, Jiao Z, Tufail M (2021e) How energy consumption, industrial growth, urbanization, and CO2 emissions affect economic growth in Pakistan? A novel dynamic ARDL simulations approach. Energy 221:119793. https://doi.org/10.1016/j.energy.2021.119793

Adebayo TS, Kirikkaleli D (2021) Impact of renewable energy consumption, globalization, and technological innovation on environmental degradation in Japan: application of wavelet tools. Environ Dev Sustain 1-26. https://doi.org/10.1007/s10668-021-01322-2

Adedoyin FF, Agboola PO, Ozturk I, Bekun FV, Agboola MO (2021a) Environmental consequences of economic complexities in the EU amidst a booming tourism industry: Accounting for the role of brexit and other crisis events. J Clean Prod 305:127117. https://doi.org/10.1016/j.jclepro.2021.127117

Adedoyin FF, Alola AA, Bekun FV (2020a) An assessment of environmental sustainability corridor: the role of economic expansion and research and development in EU countries. Sci Total Environ 713:136726. https://doi.org/10.1016/j.scitotenv.2020.136726

Adedoyin FF, Alola AA, Bekun FV (2021b) The alternative energy utilization and common regional trade outlook in EU-27: evidence from common correlated effects. Renew Sustain Energy Rev 145:111092. https://doi.org/10.1016/j.rser.2021.111092

Adedoyin FF, Gumede MI, Bekun FV, Etokakpan MU, Balsalobre-Lorente D (2020b) Modelling coal rent, economic growth and CO2 emissions: does regulatory quality matter in BRICS economies? Sci Total Environ 710:136284. https://doi.org/10.1016/j.scitotenv.2019.136284

Adedoyin FF, Nathaniel S, Adeleye N (2021c) An investigation into the anthropogenic nexus among consumption of energy, tourism, and economic growth: do economic policy uncertainties matter? Environ Sci Pollut Res 28(3):2835–2847. https://doi.org/10.1007/s11356-020-10638-x

Adedoyin FF, Zakari A (2020) Energy consumption, economic expansion, and CO2 emission in the UK: the role of economic policy uncertainty. Sci Total Environ 738:140014. https://doi.org/10.1016/j.scitotenv.2020.140014

Agena T (2007) The relationship between economic activities and environmental degradation in Africa. Journal of the Historical Society of Nigeria 17: 28–40. http://www.jstor.org/stable/41857144. Accessed 22 Nov 2020

Ahmed Z, Asghar MM, Malik MN, Nawaz K (2020a) Moving towards a sustainable environment: the dynamic linkage between natural resources, human capital, urbanization, economic growth, and ecological footprint in China. Resour Policy 67:101677. https://doi.org/10.1016/j.resourpol.2020.101677

Ahmed Z, Wang Z (2019) Investigating the impact of human capital on the ecological footprint in India: an empirical analysis. Environ Sci Pollut Res 26(26):26782–26796. https://doi.org/10.1007/s11356-019-05911-7

Ahmed Z, Wang Z, Mahmood F, Hafeez M, Ali N (2019) Does globalization increase the ecological footprint? Empirical evidence from Malaysia. Environ Sci Pollut Res 26(18):18565–18582. https://doi.org/10.1007/s11356-019-05224-9

Ahmed Z, Zafar MW, Ali S (2020b) Linking urbanization, human capital, and the ecological footprint in G7 countries: an empirical analysis. Sustain Cities Soc 55:102064. https://doi.org/10.1016/j.scs.2020.102064

Ahmed Z, Zhang B, Cary M (2021) Linking economic globalization, economic growth, financial development, and ecological footprint: Evidence from symmetric and asymmetric ARDL. Ecol Ind 121:107060. https://doi.org/10.1016/j.ecolind.2020.107060

Al-Mulali U, Ozturk I (2015) The effect of energy consumption, urbanization, trade openness, industrial output, and the political stability on the environmental degradation in the MENA (Middle East and North African) region. Energy 84:382–389. https://doi.org/10.1016/j.energy.2015.03.004

Al-Mulali U, Ozturk I, Lean HH (2015a) The influence of economic growth, urbanization, trade openness, financial development, and renewable energy on pollution in Europe. Nat Hazards 79(1):621–644. https://doi.org/10.1007/s11069-015-1865-9

Al-Mulali U, Tang CF, Ozturk I (2015b) Does financial development reduce environmental degradation? Evidence from a panel study of 129 countries. Environ Sci Pollut Res 22(19):14891–14900. https://doi.org/10.1007/s11356-015-4726-x

Alola AA, Bekun FV, Sarkodie SA (2019) Dynamic impact of trade policy, economic growth, fertility rate, renewable and non-renewable energy consumption on ecological footprint in Europe. Sci Total Environ 685:702–709. https://doi.org/10.1016/j.scitotenv.2019.05.139

Apergis N, Payne JE, Menyah K, Wolde-Rufael Y (2010) On the causal dynamics between emissions, nuclear energy, renewable energy, and economic growth. Ecol Econ 69(11):2255–2260. https://doi.org/10.1016/j.ecolecon.2010.06.014

Bai X, McPhearson T, Cleugh H, Nagendra H, Tong X, Zhu T, Zhu YG (2017) Linking urbanization and the environment: Conceptual and empirical advances. Annu Rev Environ Resour 42:215–240. https://doi.org/10.1146/annurev-environ-102016-061128

Baz K, Xu D, Ali H, Ali I, Khan I, Khan MM, Cheng J (2020) Asymmetric impact of energy consumption and economic growth on ecological footprint: Using asymmetric and nonlinear approach. Sci Total Environ 718:137364. https://doi.org/10.1016/j.scitotenv.2020.137364

Breitung J, Candelon B (2006) Testing for short-and long-run causality: A frequency-domain approach. Journal of Econometrics 132(2):363–378. https://doi.org/10.1016/j.jeconom.2005.02.004

Charfeddine L (2017) The impact of energy consumption and economic development on ecological footprint and CO2 emissions: evidence from a Markov switching equilibrium correction model. Energy Economics 65:355–374. https://doi.org/10.1016/j.eneco.2017.05.009

Charfeddine L, Mrabet Z (2017) The impact of economic development and social-political factors on ecological footprint: A panel data analysis for 15 MENA countries. Renew Sustain Energy Rev 76:138–154. https://doi.org/10.1016/j.rser.2017.03.031

Chen Y, Lee CC (2020) Does technological innovation reduce CO2 emissions? Cross-country evidence. J Clean Prod 263:121550. https://doi.org/10.1016/j.jclepro.2020.121550

Cheng C, Ren X, Wang Z (2019) The impact of renewable energy and innovation on carbon emission: An empirical analysis for OECD countries. Energy Procedia 158:3506–3512. https://doi.org/10.1016/j.egypro.2019.01.919

Danish UR, Khan SUD (2020) Determinants of the ecological footprint: role of renewable energy, natural resources, and urbanization. Sustain Cities Soc 54:101996. https://doi.org/10.1016/j.scs.2019.101996

Danish, Wang Z (2019) Investigation of the ecological footprint's driving factors: What we learn from the experience of emerging economies. Sustain Cities and Soc 49. https://doi.org/10.1016/j.scs.2019.101626

DeFries RS, Rudel T, Uriarte M, Hansen M (2010) Deforestation driven by urban population growth and agricultural trade in the twenty-first century. Nat Geosci 3(3):178–181. https://doi.org/10.1038/ngeo756

Deng X, Huang J, Rozelle S, Zhang J, Li Z (2015) Impact of urbanization on cultivated land changes in China. Land Use Policy 45:1–7. https://doi.org/10.1016/j.landusepol.2015.01.007

Destek MA, Sarkodie SA (2019) Investigation of environmental Kuznets curve for ecological footprint: the role of energy and financial development. Sci Total Environ 650:2483–2489. https://doi.org/10.1016/j.scitotenv.2018.10.017

Destek MA, Sinha A (2020) Renewable, non-renewable energy consumption, economic growth, trade openness and ecological footprint: Evidence from organisation for economic Co-operation and development countries. J Clean Prod 242:118537. https://doi.org/10.1016/j.jclepro.2019.118537

Destek MA, Ulucak R, Dogan E (2018) Analyzing the environmental Kuznets curve for the EU countries: the role of ecological footprint. Environ Sci Pollut Res 25(29):29387–29396. https://doi.org/10.1007/s11356-018-2911-4

Dickey DA, Fuller WA (1979) Distribution of the estimators for autoregressive time series with a unit root. J Am Stat Assoc 74(366a):427–431

Dogan E, Taspinar N, Gokmenoglu KK (2019) Determinants of ecological footprint in MINT countries. Energy Environ 30(6):1065–1086. https://doi.org/10.1177/0958305X19834279

Dogan E, Turkekul B (2016) CO2 emissions, real output, energy consumption, trade, urbanization and financial development: testing the EKC hypothesis for the USA. Environ Sci Pollut Res 23(2):1203–1213. https://doi.org/10.1007/s11356-015-5323-8

Dogan E, Ulucak R, Kocak E, Isik C (2020) The use of ecological footprint in estimating the environmental Kuznets curve hypothesis for BRICST by considering cross-section dependence and heterogeneity. Sci Total Environ 723:138063. https://doi.org/10.1016/j.scitotenv.2020.138063

Eia U. (2013) Annual energy outlook 2013 (pp. 60–62). Washington, DC: US Energy Information Administration. https://www.eia.gov/outlooks/ieo/pdf/0484(2013).pdf. Accessed 27 September 2021.

Esteve V, Tamarit C (2012) Threshold cointegration and nonlinear adjustment between CO2 and income: the environmental Kuznets curve in Spain, 1857–2007. Energy Econ 34(6):2148–2156. https://doi.org/10.1016/j.eneco.2012.03.001

Farrar DE, Glauber RR (1967) Multicollinearity in regression analysis: the problem revisited. The Review of Economic and Statistics 92–107.

Gallup JL, Sachs JD, Mellinger AD (1999) Geography and economic development. Int Reg Sci Rev 22(2):179–232. https://doi.org/10.1177/016001799761012334

Gills R, Sharma JP (2021) From an Empty-Plate Lunch to Silk-Stocking Dinner: Some Futuristic Approaches in Agriculture. In Climate Change and Resilient Food Systems (pp. 35–72). Springer, Singapore. https://doi.org/10.1007/978-981-33-4538-6_2

Global Footprint Network (2021) Global Footprint Network. https://www.footprintnetwork.org/our-work/ecological-footprint/. Accessed 5 February, 2021.

Gorus MS, Aydin M (2019) The relationship between energy consumption, economic growth, and CO2 emission in MENA countries: Causality analysis in the frequency domain. Energy 168:815–822

Grossman GM, Krueger AB (1991) Environmental impacts of a North American free trade agreement (No. w3914). National Bureau of economic research

Gülmez A, Altıntaş N, Kahraman ÜO (2020) A puzzle over ecological footprint, energy consumption and economic growth: the case of Turkey. Environ Ecol Stat 27(4):753–768. https://doi.org/10.1007/s10651-020-00465-1

Hasnat GT, Kabir MA, Hossain MA (2018) Major environmental issues and problems of South Asia, particularly Bangladesh. Handbook of environmental materials management 1–40.

Hassan ST, Baloch MA, Mahmood N, Zhang J (2019) Linking economic growth and ecological footprint through human capital and biocapacity. Sustain Cities Soc 47:101516. https://doi.org/10.1016/j.scs.2019.101516

Imamoglu H (2018) Is the informal economic activity a determinant of environmental quality? Environ Sci Pollut Res 25(29):29078–29088. https://doi.org/10.1007/s11356-018-2925-y

Iqbal N, Abbasi KR, Shinwari R, Guangcai W, Ahmad M, Tang K (2021) Does exports diversification and environmental innovation achieve carbon neutrality target of OECD economies? J Environ Manage 291:112648. https://doi.org/10.1016/j.jenvman.2021.112648

Islam F, Shahbaz M, Butt MS (2013) Is there an environmental Kuznets curve for Bangladesh? Evidence from ARDL bounds testing approach. The Bangladesh Development Studies 1–23. https://www.jstor.org/stable/44730024. Accessed 22 Nov 2020

Ito K (2017) CO2 emissions, renewable and non-renewable energy consumption, and economic growth: Evidence from panel data for developing countries. Int Econ 151:1–6. https://doi.org/10.1016/j.inteco.2017.02.001

Jordan S, Philips AQ (2018) Cointegration testing and dynamic simulations of autoregressive distributed lag models. Stand Genomic Sci 18(4):902–923. https://doi.org/10.1177/1536867X1801800409

Khan MI, Teng JZ, Khan MK (2020a) The impact of macroeconomic and financial development on carbon dioxide emissions in Pakistan: evidence with a novel dynamic simulated ARDL approach. Environ Sci Pollut Res 27(31):39560–39571. https://doi.org/10.1007/s11356-020-09304-z

Khan MK, Khan MI, Rehan M (2020b) The relationship between energy consumption, economic growth and carbon dioxide emissions in Pakistan. Financial Innov 6(1):1–13. https://doi.org/10.1186/s40854-019-0162-0

Khan MK, Teng JZ, Khan MI, Khan MO (2019) Impact of globalization, economic factors and energy consumption on CO2 emissions in Pakistan. Sci Total Environ 688:424–436. https://doi.org/10.1016/j.scitotenv.2019.06.065

Kongbuamai N, Zafar MW, Zaidi SAH, Liu Y (2020) Determinants of the ecological footprint in Thailand: the influences of tourism, trade openness, and population density. Environ Sci Pollut Res 27(32):40171–40186. https://doi.org/10.1007/s11356-020-09977-6

Koondhar MA, Aziz N, Tan Z, Yang S, Abbasi KR, Kong R (2021) Green growth of cereal food production under the constraints of agricultural carbon emissions: a new insight from ARDL and VECM models. Sustain Energy Technol Assess 47:101452. https://doi.org/10.1016/j.seta.2021.101452

Kumail T, Ali W, Sadiq F, Wu D, Aburumman A (2020) Dynamic linkages between tourism, technology and CO2 emissions in Pakistan. Anatolia 31(3):436–448. https://doi.org/10.1080/13032917.2020.1742169

Kuznets S (1955) Economic growth and income inequality. Am Econ Rev 45(1):1–28

Langnel Z, Amegavi GB (2020) Globalization, electricity consumption and ecological footprint: An autoregressive distributive lag (ARDL) approach. Sustain Cities Soc 63:102482. https://doi.org/10.1016/j.scs.2020.102482

Liu X, Zhang S, Bae J (2017) The impact of renewable energy and agriculture on carbon dioxide emissions: Investigating the environmental Kuznets curve in four selected ASEAN countries. J Clean Prod 164:1239–1247. https://doi.org/10.1016/j.jclepro.2017.07.086

Masset P (2008) Analysis of financial time-series using Fourier and wavelet methods. Available at SSRN 1289420: https://ssrn.com/abstract=1289420 or https://doi.org/10.2139/ssrn.1289420

Masukujjaman M, Siwar C, Alam ASA, Bashawir A, Er A (2016) Economy-environment nexus for development: is Bangladesh on the right track? Int J Advances Appl Sci 3(2):25–29

Mohiuddin O, Asumadu-Sarkodie S, Obaidullah M (2016) The relationship between carbon dioxide emissions, energy consumption, and GDP: A recent evidence from Pakistan. Cogent Engineering 3(1):1210491. https://doi.org/10.1080/23311916.2016.1210491

Moore J, Kissinger M, Rees WE (2013) An urban metabolism and ecological footprint assessment of Metro Vancouver. J Environ Manage 124:51–61. https://doi.org/10.1016/j.jenvman.2013.03.009

Mrabet Z, AlSamara M, Jarallah SH (2017) The impact of economic development on environmental degradation in Qatar. Environ Ecol Stat 24(1):7–38. https://doi.org/10.1007/s10651-016-0359-6

Murshed M, Alam R, Ansarin A (2020) The environmental Kuznets curve hypothesis for Bangladesh: the importance of natural gas, liquefied petroleum gas, and hydropower consumption. Environ Sci Pollut Res 1-20. https://doi.org/10.1007/s11356-020-11976-6

Narayan PK (2005) The saving and investment nexus for China: evidence from cointegration tests. Appl Econ 37:1979–1990. https://doi.org/10.1080/00036840500278103

Narayan PK, Narayan S (2010) Carbon dioxide emissions and economic growth: panel data evidence from developing countries. Energy Policy 38(1):661–666. https://doi.org/10.1016/j.enpol.2009.09.005

Nathan TM, Liew VK, Wong WK (2016) Disaggregated energy consumption and sectoral outputs in Thailand: ARDL bound testing approach. J Manag Sci 3(1): 34–46. https://doi.org/10.20547/jms.2014.1603103

Nathaniel SP (2020) Ecological footprint, energy use, trade, and urbanization linkage in Indonesia. GeoJournal 1-14. https://doi.org/10.1007/s10708-020-10175-7

Nathaniel SP, Anyanwu O, Shah M (2020) Renewable energy, urbanization, and ecological footprint in the Middle East and North Africa region. Environ Sci Pollut Res 27:14601–14613. https://doi.org/10.1007/s11356-020-08017-7

Nathaniel SP, Iheonu CI (2019) Carbon dioxide abatement in Africa: the role of renewable and non-renewable energy consumption. Sci Total Environ 679:337–345. https://doi.org/10.1016/j.scitotenv.2019.05.011

Ozcan B, Tzeremes PG, Tzeremes NG (2020) Energy consumption, economic growth and environmental degradation in OECD countries. Econ Model 84:203–213. https://doi.org/10.1016/j.econmod.2019.04.010

Ozturk I, Al-Mulali U, Saboori B (2016) Investigating the environmental Kuznets curve hypothesis: The role of tourism and ecological footprint. Environ Sci Pollut Res 23:1916–1928. https://doi.org/10.1007/s11356-015-5447-x

Pan H, Zhuang M, Geng Y, Wu F, Dong H (2019) Emergy-based ecological footprint analysis for a mega-city: The dynamic changes of Shanghai. J Clean Prod 210:552–562. https://doi.org/10.1016/j.jclepro.2018.11.064

Panayotou T (1997) Demystifying the environmental Kuznets curve: turning a black box into a policy tool. Environ Dev Econ:465–484

Paramati SR, Alam MS, Chen CF (2017) The effects of tourism on economic growth and CO2 emissions: a comparison between developed and developing economies. J Travel Res 56(6):712–724. https://doi.org/10.1177/0047287516667848

Perron P (1989) The great crash, the oil price shock, and the unit root hypothesis. Econometrica: Journal of the Econometric Society 1361–1401.

Pesaran MH, Shin Z, Smith RJ (2001) Bounds testing approaches to the analysis of level relationships. J Appl Economet 16(3):289–326

Phillips PC, Perron P (1988) Testing for a unit root in time series regression. Biometrika 75(2):335–346

Qiao H, Zheng F, Jiang H, Dong K (2019) The greenhouse effect of the agriculture-economic growth-renewable energy nexus: evidence from G20 countries. Sci Total Environ 671:722–731. https://doi.org/10.1016/j.scitotenv.2019.03.336

Rashid A, Irum A, Malik IA, Ashraf A, Rongqiong L, Liu G, ... Yousaf B (2018) Ecological footprint of Rawalpindi; Pakistan's first footprint analysis from urbanization perspective. Journal of Cleaner Production 170: 362-368. https://doi.org/10.1016/j.jclepro.2017.09.186

Rehman MU, Rashid M (2017) Energy consumption to environmental degradation, the growth appetite in SAARC nations. Renewable Energy 111:284–294. https://doi.org/10.1016/j.renene.2017.03.100

Salahuddin M, Gow J, Ozturk I (2015) Is the long-run relationship between economic growth, electricity consumption, carbon dioxide emissions and financial development in Gulf Cooperation Council Countries robust? Renew Sustain Energy Rev 51:317–326. https://doi.org/10.1016/j.rser.2015.06.005

Sarkodie SA (2018) The invisible hand and EKC hypothesis: what are the drivers of environmental degradation and pollution in Africa? Environ Sci Pollut Res 25(22):21993–22022. https://doi.org/10.1007/s11356-018-2347-x

Sarkodie SA, Adams S (2018) Renewable energy, nuclear energy, and environmental pollution: accounting for political institutional quality in South Africa. Sci Total Environ 643:1590–1601. https://doi.org/10.1016/j.scitotenv.2018.06.320

Sarkodie SA, Strezov V, Weldekidan H, Asamoah EF, Owusu PA, Doyi INY (2019) Environmental sustainability assessment using dynamic autoregressive-distributed lag simulations—nexus between greenhouse gas emissions, biomass energy, food and economic growth. Sci Total Environ 668:318–332

Shahbaz M, Chaudhary AR, Ozturk I (2018) Does urbanization cause increasing energy demand in Pakistan? Empirical evidence from STIRPAT model. Energy 122:83–93. https://doi.org/10.1016/j.energy.2017.01.080

Tiwari AK, Shahbaz M, Hye QMA (2013) The environmental Kuznets curve and the role of coal consumption in India: cointegration and causality analysis in an open economy. Renew Sustain Energy Rev 18:519–527. https://doi.org/10.1016/j.rser.2012.10.031

Töbelmann D, Wendler T (2020) The impact of environmental innovation on carbon dioxide emissions. J Clean Prod 244:118787. https://doi.org/10.1016/j.jclepro.2019.118787

Ulucak R, Bilgili F (2018) A reinvestigation of EKC model by ecological footprint measurement for high, middle- and low-income countries. J Clean Prod 188:144–157. https://doi.org/10.1016/j.jclepro.2018.03.191

Uz Zaman AH, Alam KMT, Islam MJ (2010) Urbanization in Bangladesh: present status and policy implications. ASA Univ. Rev 4.

Wang C, Wang F, Zhang X, Yang Y, Su Y, Ye Y et al (2017) Examining the driving factors of energy related carbon emissions using the extended STIRPAT model based on IPAT identity in Xinjiang. Renew Sustain Energy Rev 67:51–61. https://doi.org/10.1016/j.rser.2016.09.006

Wang S, Li Q, Fang C, Zhou C (2016) The relationship between economic growth, energy consumption, and CO2 emissions: Empirical evidence from China. Sci Total Environ 542:360–371. https://doi.org/10.1016/j.scitotenv.2015.10.027

WDI (World Development Indicator) (2021). World Bank Open Data. https://data.worldbank.org/. Accessed 15 February, 2021

Wiedmann T, Barrett J (2010) A review of the ecological footprint indicator—perceptions and methods. Sustainability 2(6):1645–1693. https://doi.org/10.3390/su2061645

WIPO (World Intellectual Property Organization) (2021). WIPO IP Statistics Data Center. https://www3.wipo.int/ipstats/. Accessed 10 February, 2021

World Bank (2021). World Bank Development Indicators database. https://data.worldbank.org/. Accessed 15 Feb 2021.

WWF (World-Wide Found for Nature) International, Global Footprint Network, ZSL (Zoological Society of London), (2006). Living Planet Report 2006. WWF, Gland, Switzerland. www.panda.org/livingplanet. Accessed 10 February, 2021.

WWF, Global Footprint Network, ZSL (Zoological Society of London), (2008). Living Planet Report 2008. WWF, Gland, Switzerland. http://www.panda.org/livingplane Accessed 10 February, 2021.

Yang B, Jahanger A, Ali M (2021) Remittance inflows affect the ecological footprint in BICS countries: do technological innovation and financial development matter? Environ Sci Pollut Res 28(18):23482–23500. https://doi.org/10.1007/s11356-021-12400-3

Yasmeen H, Wang Y, Zameer H, Solangi YA (2019) Decomposing factors affecting CO_2 emissions in Pakistan: insights from LMDI decomposition approach. Environ Sci Pollut Res 27:3113–3123. https://doi.org/10.1007/s11356-019-07187-3

Yu Y, Du Y (2019) Impact of technological innovation on CO2 emissions and emissions trend prediction on 'New Normal'economy in China. Atmos Pollut Res 10(1):152–161. https://doi.org/10.1016/j.apr.2018.07.005

Zafar MW, Zaidi SAH, Sinha A, Gedikli A, Hou F (2019) The role of stock market and banking sector development, and renewable energy consumption in carbon emissions: Insights from G-7 and N-11 countries. Resour Policy 62:427–436. https://doi.org/10.1016/j.resourpol.2019.05.003

Zheng X, Wang R, Wood R, Wang C, Hertwich EG (2018) High sensitivity of metal footprint to national GDP in part explained by capital formation. Nat Geosci 11(4):269–273. https://doi.org/10.1038/s41561-018-0091-y

Zivot E, Andrews DWK (2002) Further evidence on the great crash, the oil price shock, and the unit root hypothesis. J Bus Econ Stat 10(3):251–270

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