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RESEARCH ARTICLE

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Moving towards sustainable environment development in emerging economies: The role of green finance, green tech-innovation, natural resource depletion, and forested area in assessing the load capacity factor

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Abstract

Environmental sustainability is increasingly being prioritized by governments around the world, particularly in emerging economies. This study examined the role of green finance and green technological innovation in environmental sustainability using the "load capacity factor", also takes into account natural resource depletion and forest cover. This study used annual data from 2000 to 2018 for emerging economies: Brazil, China, India, Indonesia, Turkey and Mexico. Methods of analysis included the cross-section augmented autoregressive distributed lags (CS-ARDL) model, along with validation by the common correlated mean group (CCEMG) and augmented mean group (AMG). The results show that green finance, green technological innovation and forested areas consistently have a positive impact on environmental sustainability, while resource depletion has a negative impact. The findings of CS-ARDL are consistent with those of CCEMG and AMG. The study also makes recommendations that emerging economies need to prioritize REDD+ (Reducing Emissions from Deforestation and Forest Degradation) initiatives and implement resource decoupling policies, in addition to green finance and green technology policies, to achieve environmental sustainability.

KEYWORDS
CS-ARDL, environmental sustainability, green finance, green technology innovation, load capacity factor, natural resources depletion

1 | INTRODUCTION

The beginning of the Industrial Revolution marked a period of unprecedented economic development in the preceding two and a half centuries, freeing up immense resources and raising living standards in several regions of the world. Nevertheless, this progress was not uniform, but left billions of people in abject poverty and strained ecological systems (Blampied, 2021). This is especially true for developing and emerging countries, which are struggling with the severe impacts of climate change and increasing pollution. A significant dilemma facing emerging economies is the balancing act between the need for high economic growth to alleviate poverty and the adoption of sustainable models for environmental protection. This balance has led to heated policy discussions. Most of these countries are experiencing considerable growth, so that their share of world production is increasing over time. However, they are the largest exporters of carbon emissions, even as they strive to increase their environmental sustainability initiatives. Therefore, representatives of these countries have committed to achieving environmental sustainability goals at major international environmental conferences, such as COP27 and the UN Framework Convention on Climate Change (UNFCCC). Given the different responsibilities for past emissions and the need for development, exploring further measures to achieve environmental sustainability in emerging economies is essential.

In order to achieve environmental sustainability, nations around the world have initiated activities to limit the emission of greenhouse gases (GHG) and are contributing to this by adopting various strategies. One of these strategies is to involve the financial sector to channel private capital into sustainable investments. As the efforts of the public sector alone are not sufficient to meet these financial requirements, efforts have been made to involve the private sector. The last decade has therefore seen the emergence of innovative, environmentally focused financing approaches known as "Greening Finance (GF)". This term stands for the adaptation of the financial system through the introduction of new instruments, practices and regulations aimed at channeling private investment into environmentally conscious projects. As (Zhang et al., 2023) argue, green Finance is critical to transitioning to a green economy and improving environmental standards by channeling funds into renewable energy initiatives through stable green finance frameworks. Various financial instruments, including green bonds, green investment funds, renewable energy investments and green loans, play an important role. Nevertheless, the efficiency of green finance initiatives in emerging economies is not yet satisfactory. Therefore, to achieve sustainability goals in these economies, it is essential to develop new policies to support green projects and generate capital through innovative financial instruments and approaches to ensure environmental sustainability.

Second, to achieve environmental sustainability, it is crucial to embrace significant technological innovations. "Green technologies" refer to those technological solutions that have a beneficial impact on the environment or address pollution-related challenges. The concept of green technological innovation has emerged as a response to the urgent need to diminish energy usage, mitigate emission of pollutants, enhance the environmental quality, and stimulate the development of an eco-friendly economy. Eco-technological innovation also encompasses the development of "eco-friendly products," or goods that are environmentally benign and energy-efficient. Green technological innovation includes the generation of clean energy, adoption of alternative fuels, and advancement in technologies that are more environmentally friendly compared to their fossil fuel counterparts (Khan et al., 2020). Thus, investing in such innovative technologies can lead to more sustainable production and economic activities, providing a viable pathway to achieve environmental sustainability, especially in emerging nations. Therefore, endorsing eco-technological innovations and environmental sustainability in such nations clearly demands robust policy measures. This is a crucial aspect that this study seeks to examine.

Third, the careful management of natural resources is crucial, particularly in emerging nations, as it can reduce dependence on such resources. In the current era, the availability of natural resources serves as a catalyst for economic prosperity. Nonetheless, excessive consumption can lead to elevated emission levels, leading to the exacerbated dilemma of resource depletion, thereby endangering both environmental and human health. Resource depletion occurs When resources consumption rate surpasses the replenishment rate. Hussain et al. (2020) highlighted that the rate of natural resource depletion has seen a significant upswing in recent times. The extraction of fossil fuels and biomass has significantly increased, and the exploitation of other mineral resources has seen a fivefold increase. Recent research indicates that emerging nations are intensifying resource utilization to facilitate industrialization and accommodate growing populations, consequently escalating environmental pollution. As shown in Figure 1, Indonesia has witnessed the most rapid depletion of its natural resources since 2000, closely followed by Mexico and China within the examined sample. Therefore, transitioning towards a sustainable global economy necessitates the implementation of resource management strategies that advocate for resource decoupling and emphasize limiting absolute resource consumption in emerging countries. By adopting such strategies, emerging countries can diminish their dependency on natural resources and promote economic development that is ecologically manner.

Fourth, robust policy and organizational structures are imperative for devising strategies aimed at curbing emissions from deforestation and forest degradation, also known as REDD+. The REDD+ initiative, originating from the Paris Agreement, is not merely about forest conservation but includes additional proactive forest-related actions, primarily focused on sustainable forest management, conservation and enhancement of forest carbon reserves. The objective of REDD+ is to channel funds to offset the expenses involved in implementing measures to curb emissions from deforestation and forest degradation. Within this REDD+ scheme, developing nations are eligible for outcome-based remunerations for reducing emissions when they mitigate deforestation. Deforestation leads to enduring serious ecological issues such as depletion of forests, flooding, erosion, and the loss of natural habitats. Trees play a vital role in carbon sequestration, absorbing CO_2 and storing it, which is crucial in mitigating climate change impacts. Forests are essential for absorbing greenhouse gases and are vital for building resilience against the unavoidable adverse effects of climate change, like absorbing heat and managing water flows (Raihan, Muhtasim, Farhana, et al., 2022; Raihan, Muhtasim, Pavel, et al., 2022). Recent studies have highlighted the substantial impact of forests regions in maintaining environmental health, curbing deforestation control a cost-efficient strategy to enhance environmental quality. Governments, especially in emerging nations, should strengthen efforts to mobilize public funds and allocate them through prevailing multilateral financial frameworks to reinforce REDD+, fostering demand for emissions reduction and setting the stage for enduring ecological sustainability. Hence, examining the potential contributions of forests in enhancing environmental sustainability in emerging nations is crucial.

Therefore, we used a more accurate indicator to assess environmental sustainability, called the load capacity factor (LCF). The LCF is

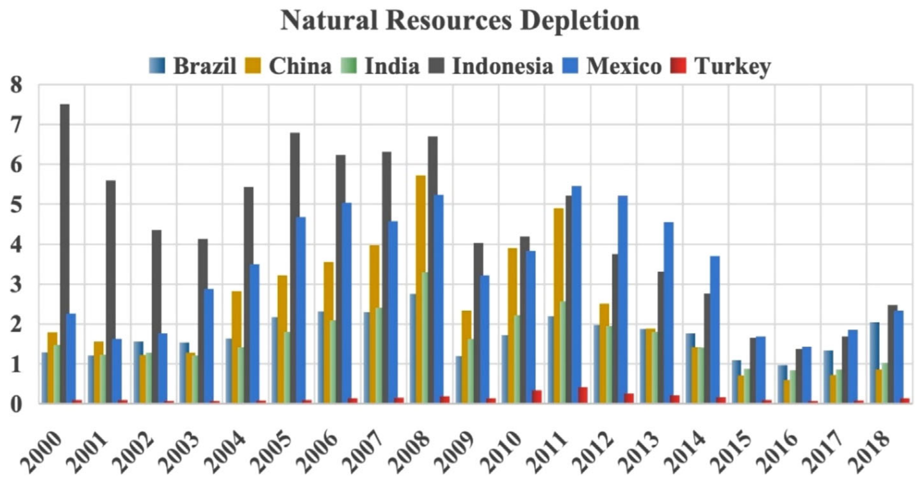

FIGURE 1 Natural resources depletion in emerging economies. *Source*: Authors own estimations.

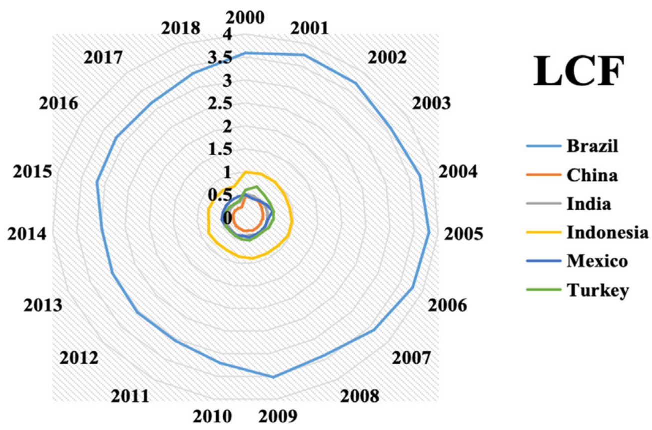

FIGURE 2 Load capacity factor for emerging economies. *Source*: Authors own estimations.

a measure of sustainability that takes into account both human pressure on the environment and the capacity of natural resources to absorb that pressure. The calculation method is the ratio between the ecological footprint and the ecological capacity. An LCF value of less than 1 means that a country's current consumption pattern has harmed the ecosystem and is therefore unsustainable, while a value of more than 1 indicates a sustainable system (Pata & Balsalobre-Lorente, 2022). In many countries, the LCF is less than 1, which means that the sustainability threshold is equal to 1. Figure 2 shows the values of the LCF by country in the sample. Among all these countries, Brazil and Indonesia have the highest LCF values in 2001, above the threshold of 1, which indicating a high bio-capacity relative to the ecological footprint and stable environmental conditions. However, LCF values in other countries are below 1, indicating that environmental conditions are unsustainable.

Emerging economies, particularly Brazil, China, India, Indonesia, Mexico and Turkey, were chosen for this study because of their impressive growth over the past 20 years. According to forecasts, they could surpass the G-7 countries by 2050. The Emerging Seven (E-7) include countries, such as Brazil, China, India, Indonesia, Mexico, Russia and Turkey. However, this study is limited to a subset of these countries, namely Brazil, China, India, Indonesia, Mexico and Turkey, collectively referred to as "emerging economies" This selection was based on the availability of green finance data, with Russia excluded due to the unavailability of data. The average annual growth rate of these countries is expected to be 3.5% over the next 34 years, compared to the G7's estimated rate of 1.6% (Wu et al., 2021). Looking more closely at individual countries, China, Brazil and India have rich reserves of bauxite and iron ore. Conversely, Turkey, Indonesia and Mexico are rich in oil and gas. Brazil, on the other hand, is known for its significant coal industry. The rapid growth of the sector has led to increased demand for resources and consequent environmental degradation. Moreover, their unique geographical and socio-economic factors make them particularly vulnerable to the effects of climate change. Consequently, emerging economies have set ambitious sustainable development goals that combine economic progress with environmental protection. Against this backdrop, this study examines the impact of green finance, green technological innovation, natural resource depletion and forest cover on environmental sustainability in emerging economies between 2000 and 2018.

Drawing from the presented evidence, it is imperative for representatives of emerging nations to engage in rigorous studies on environmental sustainability in order to effectively achieve their sustainability goals. The identified variables have a significant impact on environmental dynamics. As such, there is a compelling need to formulate a policy framework focused on sustainable development (SD) for emerging countries. This framework should also possess the flexibility to be adapted for other developing nations that aspire to align their policies towards achieving environmental sustainability. Through this research, policymakers can be better equipped to devise policies that enhance environmental sustainability by utilizing the load capacity factor as an indicator of ecosystem sustainability.

The aim of this study is to examine the relationship between green finance, green technological innovation, natural resource depletion and forested areas in achieving environmental sustainability. Although the importance of green finance and technological innovation is increasingly recognized, their impact on environmental sustainability, particularly in emerging economies, has been poorly explored. Our research fills this gap by providing insights into the complex interplay of these factors and helping policy makers develop sustainable environmental strategies. Moreover, existing literature rarely uses load capacity factors to link forest cover to environmental sustainability. By addressing both supply-side and demand-side environmental concerns, our research provides a comprehensive discussion of sustainability. Beyond academia, we emphasize the importance of green finance, technological innovation and forestlands in promoting environmental stability, and help policymakers and environmental economists develop effective green strategies. Moreover, our work not only proposes a policy framework, but also stimulates a broader discussion on how to improve existing policies to achieve environmental sustainability.

Following the introduction, Section 2 examines the prior literature on the relationship between study dependent and independent variables. The methodology, data, and framework used in the research are described in Section 3. Section 4 covers the results and their interpretations. In Section 5, the conclusion and policy recommendations are presented.

2 | LITERATURE REVIEW

The term "Environmental sustainability" refers to the essential characteristics and components of nature that enable its conservation. Recent scholarly attention underscores an increased emphasis on ecological issues. Within this realm, researchers have sought to identify the factors that positively or negatively impact environmental sustainability. This includes areas, such as green finance, advancements in environmentally-friendly technologies, the depletion of natural resources, and the significance of forests in maintaining environmental quality.

2.1 | Green finance (GF) linked with environmental sustainability (ES)

The presence of green finance and investment opportunities are strong indicators of positive climate change. Consequently, they have attracted the interest of researchers. Nevertheless, potential investors are often reluctant to invest money in renewable energy projects because of lack of information and concerns about the return on investment (Lee & Lee, 2022). These projects usually have relatively high initial costs and yield slow returns, as (Chang et al., 2022; Meo & Abd Karim, 2022) point out. To meet the needs of these projects, green finance intervenes and provides access to funds for initiatives that aim to protect the environment. Various financial instruments, including green bonds, green investment funds, renewable energy investments and green loans, play an important role (Zhang et al., 2023). As a result, a new method of financing environmental protection projects has emerged in the last decade, called "GF". In recent years, the link between environmental sustainability and green finance has attracted considerable attention in both research and policy circles. As (Balsalobre-Lorente, Shahbaz, et al., 2023; Cosma et al., 2023) points out, in order to achieve environmental sustainability, private and public capital must be diverted from polluting activities and redirected to green-oriented activities with lower environmental impacts.

Scholars have undertaken extensive research into the influence of green finance on the environment and have consistently identified its potential to foster environmental sustainability. For example, Wang et al. (2021) pointed out that green finance can prevent environmental degradation by encouraging investment in technologies such as non-fossil energy innovation, thereby improving environmental quality. While (Li, Sampene, et al., 2022) believe that rapid economic and industrial changes have significantly increased the degree of environmental degradation, and investment in green projects can promote long-term environmental sustainability. Emerging economies have increasingly recognized the pivotal role of green finance, as widely recognized by scholars like (Chin et al., 2022; Khan, Riaz, et al., 2022; Meo & Abd Karim, 2022) for its favorable impact on environmental quality. Additionally, Zhang et al. (2022) demonstrated that green finance strategies used in less developed areas have a greater impact on reducing environmental pollution. The comprehensive analysis by Meo et al. (Meo & Abd Karim, 2022) of the relationship between GF and environmental quality in nations with substantial GF investments corroborates the direct influence of GF on ES. Collectively, these findings further support the idea that green finance as a successful approach to fortify environmental sustainability. Consequently, this study aims to determine whether green finance is truly beneficial to environmental sustainability in emerging countries. The hypothesis H1 for the relationship between GF and ES is:

Hypothesis 1. Green finance (GF) encourage environmental sustainability (ES) in emerging-6 countries.

2.2 | Green technology innovations (GTI) linked with ES

Technological advancements in the field of climate have become crucial in mitigating the effects of climate change by providing opportunities to reduce greenhouse gas emissions. The escalating concerns over environmental deterioration have spurred numerous initiatives that aim to minimize the production of inorganic gases. Nonetheless, innovations in green technology emerge as the most effective strategy for reducing CO_2 emissions (Sharif et al., 2022). The ecological implications of green technology vary significantly among different economies. Notably, advanced economies have reported significant improvements in environmental conditions (Du et al., 2019). Contrarily, a study conducted in Italy by (Weina et al., 2016) indicated a limited influence of green technology on bolstering environmental conservation. A comprehensive assessment by (Shao et al., 2021) regarding the impact of eco-innovations on carbon emissions in N-11 nations from 1980 to 2018 highlighted their potential to enhance energy efficiency, reduce dependence on fossil fuels, and promote ecological sustainability. Similarly, (Sun et al., 2022) concluded that advancements in green technology transform traditional processes into environmentally friendly alternatives, optimizing energy utilization and subsequently enhancing ecological well-being.

New research consistently highlights the central role of GTI in ES, especially in economies experiencing rapid growth and rising emissions. For example, (Meirun et al., 2021) studied accelerated economic growth in Singapore and concluded that GTI serves as an effective countermeasure to the harmful environmental by-products of such growth. (Shan et al., 2021) claim that GTI helps to achieve sustainable development goals with limited environmental impacts. This is also the opinion of (Chen, Ahmad, et al., 2022), who found significant improvements in environmental quality through GTI in some of the most polluted countries in the world. (Sharif et al., 2022) conducted a comprehensive study of the G7 countries and concluded that GTI contributes to a decrease in carbon emissions. Similarly, a comprehensive study of 25 African countries by (Obobisa et al., 2022) found an inverse relationship between GTI and CO_2 emissions. The study argued for increased investment in GTI to meet sustainable development aspirations. (Gyamfi et al., 2022) confirmed the positive impact of GTI on environmental standards in BRICS countries and provided further evidence to support these findings. Overall, the empirical evidence points to a strong relationship between GTI and improved environmental outcomes. Based on these findings, the hypothesis is that GTI has a positive effect on environmental quality.

Hypothesis 2. Green technology innovations (GTI) promote environmental sustainability (ES).

2.3 | Natural resources depletion (NRD) linked with ES

In the 21st century, the depletion of Earth's natural resources has become an increasingly worrying issue. These resources are regarded as valuable assets for most nations (Sinha et al., 2022) and playing a pivotal role in ensuring economic stability and the generation of revenue. In several countries, natural resources contribute significantly to bolstering environmental sustainability through by increasing export income (Alfalih & Hadj, 2022) and funding green energy initiatives (Abid et al., 2022; Liu et al., 2022). Researchers and policymakers have recognized the significance of natural resources in achieving environmental sustainability. For example (Erdoğan et al., 2021; Majeed et al., 2021) revealed that natural resources enhance environmental sustainability, especially in resource-rich countries.

However, a number of studies have shown that natural resources have harmful effects on the environment and tend to support the resource curse hypothesis. Consequently, researchers have shown increasing interest in studying the relationship between the depletion of natural resources and environmental quality. Human economic activities, coupled with increasing natural resource utilization have generated wastes that are beyond the absorption and recovery capacity of the environment, thereby severely causing significant harm to the environment (Rafei et al., 2022). A number of studies have delved into the relationship between natural resource depletion (NRD) and its environmental consequences. For example, Hussain et al. (2020) found that an increase in NRD led to a rise in environmental pollution, with a 1% rise in NRD leading to a 0.0184% uptick in CO_2 emissions. Similarly, (Yi et al., 2023) validated that NRD adversely affects environmental sustainability in the USA, both in the short and long term. Khan, Babar, et al. (2022) also concluded that NRD contributes to environmental degradation in Canada. Furthermore, the severity of natural resource's impact on escalating CO_2 emissions is intricately linked to economic activities within these economies. All of these findings lend support to Hypothesis H3, which posits that natural resource depletion has a negative impact on environmental quality.

Hypothesis 3. Natural resource depletion (NRD) does not contribute to environmental sustainability (ES).

2.4 | Forested area (FA) linked with ES

Forests play a crucial role in both global and regional efforts to mitigate climate change. According to, (Grassi et al., 2017) forest-based climate mitigation initiatives have been effective in mitigating the level of greenhouse gas emissions. Forested areas are widely recognized internationally as a tool for mitigating climate change impacts. In this context, (Fraser et al., 2023) emphasized the significance of forest ecosystems in combating human-made climate change by absorbing substantial amounts of atmospheric carbon dioxide. In addition, (Zhu et al., 2019) pointed out that the global forest system stores a large amount of carbon and has the potential to be a source of further carbon sequestration, regarded as a "natural solution" to the challenge of climate change.

In recent years, extensive research has been conducted on the relationship between forests and environmental quality. For example, Waheed et al. (2018) analyzed data for Pakistan from 1990 to 2014 using the ARDL estimator and found that forests and renewable energy have a negative impact on CO_2 emissions. Similarly, Parajuli et al. (2019) identified a negative association between forest areas and carbon dioxide emissions. Raihan and Tuspekova (2022c) employed the DOLS method and analyzed a time series dataset spanning from 1990 to 2019. Their findings revealed a significant negative correlation between forested area and CO_2 emissions in Malaysia, indicating that a 1% increase in forested areas corresponds to a 3.86% reduction in CO_2 emissions. In a parallel study by Raihan and Tuspekova (2022b) observed that forests have a positive impact on environmental conditions in Brazil. while Raihan et al. (Raihan, Muhtasim, Farhana, et al., 2022) also identified evidence that that forests play an important role in promoting environmental sustainability in Bangladesh. Furthermore, the research conducted by (Raihan & Tuspekova, 2022a) highlighted that in Kazakhstan, a 1% increase in forested areas may lead to a 2.59% increase in long-term environmental. Consequently, Hypothesis H4 posits that an increase in forested areas leads to better environmental outcomes. Thus, Hypothesis H4 proposed as follows.

Hypothesis 4. Forest area (FA) promote environmental sustainability (ES) in emerging-6 countries from 2000 to 2018.

The existing literature highlights the importance of various factors, namely GF, GTI, NRD, and FA, in shaping ES outcomes. However, it is noteworthy that the majority of environmental research tends to focus predominantly on conventional metrics, such as CO_2 emissions, ecological health, and carbon footprint, which often serve as surrogates for assessing environmental degradation. This myopic focus often neglects a broader measure of environmental degradation, the so-called "load capacity factor." Remarkably, the literature on load capacity factor is still relatively sparse, particularly with regard to its study in the context of emerging economies. Furthermore, there is a striking lack of information on the influence of green finance, innovative green technology, resource depletion and forested land on load capacity factors concerning environmental sustainability stressors in emerging economies. This study seeks to fill this gap by undertaking a ground-breaking analysis and examining how green finance, innovative green technology, resource depletion and forested land are related to environmental sustainability, using the load capacity factor as the central metric. In this way, this study aims to make a distinctive and valuable contribution to the prevailing academic work in this field.

3 | DATA AND METHODOLOGY

The aim of this study was to analyze the factors influencing sustainable environmental development in six emerging economies, including Brazil, India, Indonesia, Turkey, China and Mexico. Annual panel data from 2000 to 2018 were used. To achieve this objective, six variables were selected in the study. The dependent variable in this scenario is the LCF, which stands for sustainable environmental development (ES). The focus variables are GF and GTI. In addition, the study also included NRD, FA, and economic growth (GDP) as control variables. The time frame chosen for this study is based on the availability of data for these variables. Table 1 lists the symbols, their meanings, measurements and sources for these variables.

Table 2 provides a comprehensive statistical analysis of the data series for ES, GF, GTI, NRD, FA, and GDP. The table illustrates that when looking at the mean values, GDP and GF have the highest values, followed by FA, GTI, NRD, and ES. At the same time, GDP and GF also have a higher standard deviation, indicating greater variability within these particular series. Moreover, all of the above economic variables show a significant discrepancy between their maximum and minimum values, indicating remarkable fluctuations within the series. Such pronounced fluctuations within the individual data series indicate that these economic variables are not normally distributed.

3.1 | Theoretical underpinning and model specification

The present investigation aims to explore the potential impact of several key factors, including GF, GTI, NRD, FA, and EG, on ES. The study aims to evaluate how these factors influence the LCF and subsequently develop a policy framework that promotes environmental sustainability. A comprehensive analysis of theoretical foundations has been conducted to determine the suitable selection of variables for this investigation.

A sustainable, low-carbon economy depends heavily on green finance in order to regulate and advance the development of renewable energy sources. By promoting the use of renewable energy resources, it contributes to the establishment of a green economy and improves environmental quality. Nonetheless, it is imperative that green finance initiatives are meticulously designed and aligned with broader environmental objectives in order to achieve a truly sustainable environment. Consequently, we have formulated the following functional representation:

$$ES_{it} = f(GF_{it}) \tag{3.1}$$

Green technological innovation exerts a significant and positive impact on the environment by reducing pollution and limiting the consumption of non-renewable resources. It is important to emphasize that the use of green technological innovation is an indispensable strategy in concerted efforts to address pressing environmental problems. Consequently, it is fair to say that innovation plays a central role in advancing the twin goals of environmental sustainability and climate change mitigation. With the inclusion of GTI in equation (1), the model extended formulation can be stated as follows:

$$ES_{it} = f(GF_{it}, GTI_{it}) \tag{3.2}$$

Unsustainable consumption and production practices have a twofold negative impact on the environment. On the one hand, they deplete finite natural resources through their relentless use of material inputs. On the other hand, these practices trigger a range of environmental impacts throughout the life cycle of a product or service, from resource extraction and processing to manufacturing, consumption and waste disposal. The research conducted in this study covers the crucial aspect of natural resource depletion in the context of environmental pollution. Natural resource depletion is becoming an important demand-side issue that significantly influences the level of pollution. The extraction and use of natural resources, for example, leads to the emission of hazardous gases into the atmosphere. This includes the release of powerful greenhouse gases such as carbon dioxide (CO_2) and methane (CH_4). Given this explanation, it is therefore possible that the depletion of natural resources has a negative impact on ES. This insight leads to an extension of equation (3.2) as follows:

TABLE 1 Description of variables and data sources.

Variables/ symbols	Meanings	Measurements	Sources
ES	Environmental sustainability	The load capacity factor serves as a measure of each country's environmental sustainability, calculated as the ratio of biocapacity to ecological footprint, expressed in global hectares per capita.	Global Footprint Network (https://data.footprintnetwork.org)
GF	Green finance	Public Investments on Renewable Energy (2019 million USD)	The international Renewable Energy Agency (IRENA) Public Finance Database (https://www.irena.org/Energy-Transition/Finance-and-investment/Investment)
GTI	Green technological innovation	Environment-related technologies as a % of all technologies	OECD statistics (https://stats.oecd.org)
NRD	Natural resource depletion	adjusted savings % of GNI	WDI (https://databank.worldbank.org)
FA	Forest area	Forest area (% of land area)	WDI (https://databank.worldbank.org)
GDP	Economic growth	GDP per capita (constant 2015 US$)	WDI (https://databank.worldbank.org)

Source: Authors own compleation.

TABLE 2 Descriptive statistics.

Variables	*ES*	*GF*	*GTI*	*NRD*	*FA*	*GDP*
Mean	0.997285	659.8472	9.247544	2.286251	36.80599	5889.851
Median	0.477431	205.9842	9.155000	1.795464	31.19532	6842.357
Maximum	3.808770	11758.38	15.26000	7.502890	65.93436	12006.82
Minimum	0.243208	0.007035	2.610000	0.069682	18.78050	757.6687
Std. Dev.	1.101206	1571.629	2.750910	1.784640	15.49271	3346.304
Observations	114	114	114	114	114	114

Note: Authors own compleation.

$$ES_{it} = f(GF_{it}, GTI_{it}, NRD_{it}) \tag{3.3}$$

Forests are a significant natural resource that provide a variety of ecosystem services and support environmental stability. Often referred to as the 'lungs of the planet', forests help stabilize the global climate and produce about 40% of the Earth's oxygen. The ability of forested regions to sequester carbon from the atmosphere is becoming increasingly important. It is therefore imperative to explore the potential of forests in promoting ecosystem services, especially in emerging economies. This leads us to an extension of equation (3.3) as follows:

$$ES_{it} = f(GF_{it}, GTI_{it}, NRD_{it}, FA_{it}) \tag{3.4}$$

In developing countries, there is a potential tension between environmental sustainability and economic growth. During the initial stages of industrialization, most of these countries tend to prioritize robust economic development over environmental protection. Economic growth inevitably requires energy. However, if this energy consumption is not based on sustainable practices, it can lead to significant environmental degradation. In particular, the reliance on energy derived from fossil fuels is critically examined for its negative impact on the ecological balance, primarily due to the associated increase in carbon emissions. Based on established theoretical foundations, this study establishes the following empirical framework:

$$ES_{it} = f(GF_{it}, GTI_{it}, NRD_{it}, FA_{it}, GDP_{it}) \tag{3.5}$$

The Equation 3.5 shows that a combination of *GF*, *GTI*, *NRD*, *FA* and *GDP* play a role in determining environmental sustainability. For the purpose of putting the original model to the test, it can be written as follows in regression form in Equation 3.6:

$$ES_{it} = \theta_1 + \vartheta_1 GF_{it} + \vartheta_2 GTI_{it} + \vartheta_3 NRD_{it} + \vartheta_4 FA_{it} + \vartheta_5 GDP_{it} + \varepsilon_{it} \tag{3.6}$$

The slope and intercept to be estimated are represented in Equation 3.6 by θ and ϑ, while "i" and "t" in the subscript denote cross-sections and time series respectively, and "ε" represents a random error term.

3.2 | Estimation strategy

The strategy for estimation is outlined in Figure 3 of the analysis framework and further explicated in the following sections.

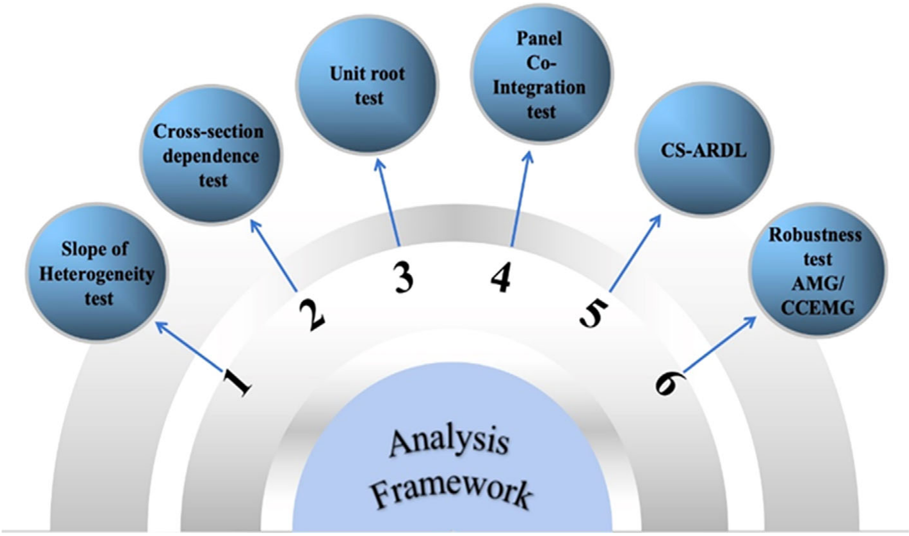

FIGURE 3 Analysis framework. *Source*: authors own completion.

3.2.1 | Slope heterogeneity and cross-section dependence

We started our analysis of the panel data by looking at the slope heterogeneity and cross-sectional dependence. These are important parts of panel data models that must be taken into account to avoid giving wrong or misleading results (Wei et al., 2022). The Industrial Revolution brought about the growth of globalization and trade, which caused some countries to specialize in specific goods and services while others adopted a more general approach. Because of this, some regions needed help from others to reach their goals. This made the economies of different parts of the world dependent on each other, which led to the idea of slope homogeneity in economics (Breitung, 2005). Hence, we use the Pesaran and Yamagata (2008) slope heterogeneity test.

$$\check{\Delta}_{,HT} = (N)^{1/2} 2k^{-1/2}\left(\frac{1}{N}\tilde{S} - k\right) \quad (3.7)$$

$$\check{\Delta}_{,AHS} = (N)^{1/2}\left(\frac{2k(T-k-1)}{T+1}\right)^{\frac{1}{2}}\left(\frac{1}{N}\tilde{S} - 2k\right) \quad (3.8)$$

Equation (3.7) represents the homogeneity of the slope coefficient with $\check{\Delta}_{,HT}$, while equation (3.8) signifies the adjusted homogeneity of the slope coefficient through $\check{\Delta}_{,AHS}$. The test in question confirms the similarity of the slope coefficients up to the significance level established by the null hypothesis.

Cross-sectional dependency within panel data is a significant concern that needs to be addressed before conducting empirical estimations of the data. This type of dependency arises from the increased interconnections within socio-economic networks and the frequently disregarded global consequences, making traditional panel estimators unreliable. Neglecting the issue of cross-sectional dependency may lead to inaccurate findings, especially in initial research efforts (Campello et al., 2019; Sarafidis & Wansbeek, 2012). To evaluate the existence of cross-sectional dependencies among countries, we utilize the Cross-Sectional Dependence (CD) test developed by Breitung et al. (Breitung & Pesaran, 2008). Mathematically, cross-sectional dependence can be represented in standard equation format, as shown in Equation.3.9:

$$CD_{Adjusted} = \sqrt{\frac{2T}{N(N-1)}\left(\sum_{i=1}^{N-1}\sum_{k=i+1}^{N}\check{T}_{ik}\right)}\frac{(T-j)\check{T}_{ik}^{2} - E(T-j)\check{T}_{ik}^{2}}{V(T-j)\check{T}_{ik}^{2}} \quad (3.9)$$

3.2.2 | Unit root test

In this study, the CIPS, a second generation unit root test introduced by Pesaran (2007), is used instead of conventional tests. Conventional tests assume independence of cross-sections and homogeneity of slopes in the models, which can lead to erroneous results. This formula is used in the CIPS test:

$$\Delta V_{i,t} = \alpha_i + \alpha_i X_{i,t-1} + \alpha_i V_{t-1} + \sum_{1=0}^{p} \alpha il \Delta \overline{V}_{t-1} + \sum\nolimits_{1=1}^{p} \alpha_{il} \Delta V_{l,t-1} \quad (3.10)$$

where in Equation (3.10), $\overline{V}_{t-1}$ represents the average of cross-sections. The average of cross-sections can be found, and the CADF (Cross-section Augmented Dickey Fuller test) can be calculated using the equation mentioned above. This CADF value can then be used to determine the CIPS using equation 3.11:

$$\widehat{CSAIPS} = \frac{1}{2}\sum_{i=1}^{n} CADF_i \quad (3.11)$$

3.2.3 | Co-integration tests

The long-run relationship between variables is examined by the co-integration test of (Westerlund, 2007) and co-integration test of

Banerjee and Carrion-i-Silvestre (2017). Despite challenges such as the dependence and variability of the slope in panel data, this test provides reliable results by combining group means and panel statistics. This method, which is similar to the one described here, is often used in studies of group means and panel statistics. The importance of the Westerlund co-integration test lies in its ability to incorporate slope heterogeneity into the models and in its consideration of cross-sectional interdependence.

$$G_\tau = \frac{1}{N}\sum_{i=1}^{N}\frac{\widehat{a}_i}{S.E\widehat{a}_i} \tag{3.12}$$

$$G_a = \frac{1}{N}\sum_{i=1}^{N}\frac{T\widehat{a}_i}{\widehat{a}_i(1)} \tag{3.13}$$

where Equations 3.12 and 3.13 provide the group mean.

$$p_\tau = \frac{\widehat{a}}{S.E(\widehat{a})} \tag{3.14}$$

$$p_a = T.\widehat{a} \tag{3.15}$$

The equations 3.14 and 3.15 are estimation panel.

For robustness, we employed a co-integration test (Banerjee & Carrion-i-Silvestre, 2017) to further validate our co-integration analysis. The significance of this test lies in its ability to handle variables that are cross-sectionally dependent. This test assesses the common causes of CSD by calculating the average for each variable in the cross-sections. This approach offers robustness as it accommodates a diverse array of cross-sectional and temporal structures. Notably, the test allows for potential structural breaks within panel data. This test offers greater predictive potential by being able to accommodate a wide range of combinations of time periods and cross-sections. Moreover, the assessment ensures meticulous detection of structural deviations in the dataset.

3.2.4 | Cross-section augmented autoregressive distributed lags

The CS-ARDL approach examines the relationship between environmental sustainability, green finance and green technology innovation in the context of other control variables. This approach is superior because it takes into account problems, such as slope heterogeneity, cross-sectional dependency, and endogeneity. Despite the small sample size, the econometric method CS-ARDL provides accurate results for a short panel. The method CS-ARDL is a suitable solution to eliminate the potential biases caused by the strong correlation between the explanatory variables and unobserved factors. The use of the CS-ARDL approach is based on its important assumptions. The equation CS-ARDL is formulated as follows:

$$\Delta ES_{i,t} = \theta_i + \sum_{i=1}^{p}\theta_{il}\Delta ES_{i,t-1} + \sum_{i=1}^{p}\acute{\theta}_{il}X_{i,t-1} + \sum_{i=1}^{p}\acute{\theta}_{il}\overline{Z}_{i,t-1} + \alpha_i + \mu_{i,t} \tag{3.16}$$

where in Equation 3.16 X is the set of explanatory variables such GF, GTI, NRD, FA, and GDP.

$$W_{i,t} = \sum_{i=0}^{pw}\varphi_{i,l}W_{i,t-1} + \sum_{i=0}^{pz}\gamma_{i,l}Z_{i,t-1} + \varepsilon_{i,t} \tag{3.17}$$

Equation (3.17) presents the autoregressive distributed lag (ARDL) model, in which cross-sectional means are used for each respective regressor. This equation is further elaborated upon in Equation (3.18):

$$W_{i,t} = \sum_{i=0}^{pw}\varphi_{i,l}W_{i,t-1} + \sum_{i=0}^{pz}\gamma_{i,l}Z_{i,t-1} + \sum_{i=0}^{px}\alpha_i\overline{X}_{t-1} + \varepsilon_{i,t} \tag{3.18}$$

In the proposed model, the variable W_{it} signifies environmental sustainability and is designated as the principal dependent variable. The term $Z_{i,t-1}$ indicates all the explanatory variables, encompassing aspects such as green finance, green technological innovation, natural resource depletion, and forested area. Additionally, $\overline{X}_{t-1}$ illustrates the mean of the variables under consideration, both dependent and independent. This inclusion is strategic, aiming to offset CSD that might arise from potential spillover effects. Notations like Pw, Pz, and Px depict the lagged values associated with each respective variable. To offer clarity on the model's estimation techniques, both the mean group estimator and the long-run coefficients can be deciphered from the following equation:

$$\widehat{\pi}CS-ARDL,i = \frac{\sum_{l=0}^{pz}\widehat{\gamma}_{li}}{1-\sum_{i=0}}\widehat{\varphi}_{l,t} \tag{3.19}$$

$$\widehat{\pi}_{MG} = \frac{1}{N}\sum_{i=1}^{N}\widehat{\pi}_i \tag{3.20}$$

$$\triangle W_{it} = \vartheta_i[W_{i,t} - \pi_i Z_{i,t-1}] - \sum_{i=0}^{pw-1}\varphi_{i,t}\Delta_i W_{i,t-1} + \sum_{i=0}^{pz}\gamma_{i,l}\Delta_i Z_{i,t-1} + \sum_{i=0}^{px}\alpha_i\overline{X}_t + \varepsilon_{i,t} \tag{3.21}$$

While in the aforementioned equation:

$$\Delta_i = t-(t-1)$$

$$\widehat{t}_i = -\left(1-\sum_{i=0}^{pw}\widehat{\varphi}_{i,t}\right) \tag{3.22}$$

$$\widehat{\pi}_i = \frac{\sum_{l=0}^{pz}\widehat{\gamma}_{li}}{\widehat{\tau}_i} \tag{3.23}$$

TABLE 3 Slope coefficients homogeneity/heterogeneity test.

Delta (*P*-values)	Adjusted Delta (*P*-values)
Model-1	
$ES_{it} = f(GF_{it}, NRD_{it}, FA_{it}, GDP_{it})$	
6.168	8.038
0.000	0.000
Model-2	
$ES_{it} = f(GTI_{it}, NRD_{it}, FA_{it}, GDP_{it})$	
7.765	9.552
0.000	0.000

Source: Authors estimations.

TABLE 4 Cross sectional dependency test.

Variable	CD-test	*p*-value
ES	12.660***	.000
GF	8.290***	.000
GTI	3.660***	.000
FA	2.830***	.000
NRD	13.850***	.000
GDP	17.380***	.000

Note: ***, **, and * denoted a significance level 1%, 5%, 10%.

$$\widehat{\pi}_{MG} = \frac{1}{N}\sum_{i=1}^{N}\widehat{\pi}_i \tag{3.24}$$

3.2.5 | Robustness analysis- AMG-CCEMG

The Augmented Mean Group (AMG) technique is used to verify the study's robustness. The AMG method's usefulness stems from the fact that it may be used to remedy the problem of slope heterogeneity in models. Even with CSD, non-stationarity, and endogeneity issues, the test yields reliable findings (Eberhardt, 2012). The empirical analysis in this study was conducted using two statistical software packages, namely Stata 17 and EViews 10. These software tools were used to conduct a rigorous examination of the data set and to enable comprehensive statistical modeling and data analysis.

4 | RESULTS AND DISCUSSIONS

In panel data analysis, it is essential to thoroughly assess issues like cross-sectional dependency and slope heterogeneity before establishing the connections between variables. Testing for slope heterogeneity in Table 3 reveal that both models face this issue, as evidenced by the significant delta and adjusted delta figures. As presented in Table 4, the outcomes from the cross-sectional dependency test confirm the mutual dependence among all the examined variables. This denotes that shifts or alterations in the variable group from emerging nations will influence other emerging nations, highlighting the interconnected nature of the emerging economies in the sample.

In this study, the 2nd generation CIPS unit root test is used to solve the problems of panel data caused by cross-sectional dependence and slope heterogeneity. The results in Table 5 show the result of the CIPS unit root test, which indicates that all variables have become stationary at the level of first difference I (1). This indicates that the mean and variance of the variables in both models change over time.

The Westerlund test statistic in Table 6 confirms that there is a stable long-term relationship between the variables under consideration in both models. The results of the Westerlund test, including the significant group and panel statistics, support this claim. The co-integration test conducted by (Banerjee & Carrion-i-Silvestre, 2017) allows for the identification of structural breaks in the panel data, as can be seen in Table 7.

4.1 | Benchmark estimation

Based on the results presented in Table 8, several key determinants of ES in emerging economies have a significant impact, namely GF, GTI, NRD, FA, and GDP. The results suggest that apart from NRD and GDP, the remaining factors have the potential to improve environmental sustainability in these countries by increasing the LCF. Furthermore, the study has revealed the stability of the relationships between these variables over time, as shown by the consistently negative and statistically significant ECM coefficient. Moreover, the results indicate a positive relationship between GF and GTI with long-term environmental improvements, suggesting their potential role in reducing human-made pressures on the natural environment.

In this study, we focused on GF and GTI as independent variables in both Model 1 and Model 2, while controlling for other factors, such as NRD, FA and GDP. Our analysis within Model 1 finds a statistically significant relationship between GF and ES, suggesting that an increase in GF leads to an improvement in environmental quality. Our results suggest that a 1% increase in green finance could have a short-term reduction in human-induced environmental impact of 0.067% and a long-term impact of 0.139%. This suggests that the use of green finance can help maintain the quality of the environment by increasing the load factor in emerging economies. The results of the CS-ARDL estimation support our first hypothesis, which is that green finance promotes environmental sustainability in emerging countries. Furthermore, our findings are consistent with previous research conducted by Khan et al. (Khan, Riaz, et al., 2022); Li et al. (Li, Sampene, et al., 2022), Zakari et al. (Zakari & Khan, 2022) and Meo et al. (Meo & Abd Karim, 2022), all of which have consistently demonstrated that green finance serves as an effective instrument for enhancing environmental quality.

Using the metric for public investment in renewable energy for green financing established by the International Renewable Energy Agency (IRENA) and used by (Afshan et al., 2023; Chin et al., 2022;

TABLE 5 Pesaran (2007) panel unit root test in the presence of cross-section dependence.

	I (0)		I (I)		
Variables	Intercept	Intercept & trend	Intercept	Intercept & trend	Order
ES	−1.471	−2.186	−4.281***	−4.608***	I (1)
GF	−1.156	−2.592	−5.988***	−6.046***	I (1)
GTI	−1.249	−1.320	−5.340***	−5.402***	I (1)
NRD	−1.984	−2.74	−3.695***	−3.933***	I (1)
FA	−0.756	−2.785	−3.250***	−3.697***	I (1)
GDP	−1.423	−2.131	−2.720***	−3.483***	I (1)

Note: Asterisks *, **, and *** is for 10%, 5%, and 1% level of significance, respectively.

TABLE 6 Westerlund (2007) ECM based Co-integration test.

Model-1	Gt	Ga	Pt	Pa
Value	−4.30***	−24.90***	−14.73***	−16.18***
P-value	.002	.000	.000	.001
Model-2	**Gt**	**Ga**	**Pt**	**Pa**
Value	−3.84***	−19.02***	−11.25***	−18.48***
P-value	.005	.000	.000	.000

Note: ***, **, and * denoted a significance level 1%, 5%, 10%.

TABLE 7 Banerjee & Carrion-i-Silvestre, 2017 co-integration test.

	Model-1		Model-2	
Countries	Constant	Trend	Constant	Trend
Full-sample	−3.623**	−4.901**	−2.912**	−3.112**
Brazil	−4.118**	−5.671**	−2.811**	−3.113**
China	−5.812**	−4.981**	−2.372*	−3.001*
India	−6.173**	−6.802**	−2.172*	−3.139*
Indonesia	−6.294**	−6.013**	−2.457**	−2.819*
Mexico	−4.700**	−4.903**	−2.851**	−2.962*
Turkey	−5.173**	−5.001**	−2.011**	−2.299**

Note: ***, **, and * denoted a significance level 1%, 5%, 10%.

TABLE 8 CS-ARDL.

Model.1				
$ES_{it} = f(GF_{it}, NRD_{it}, FA_{it}, GDP_{it})$				
Variables	Short-run analysis		Long-run analysis	
	Coefficients	*p*-value	Coefficients	*P*-value
GF	.067**	.011	.139***	.003
NRD	−.124***	.000	−.317***	.009
FA	.073**	.011	.141***	.000
GDP	−.512**	.019	−.919***	.006
Constant	−.1337***	.000	−.1562***	.003
Model.2				
$ES_{it} = f(GTI_{it}, NRD_{it}, FA_{it}, GDP_{it})$				
Variables	Short-run analysis		Long-run analysis	
	Coefficients	*p*-value	Coefficients	*P*-value
GTI	.103**	.011	.191**	.019
NRD	−.094**	.032	−.296***	.003
FA	.048***	.009	.094***	.007
GDP	−.603***	.000	−.781***	.000
Constant	−.1282***	.000	−.1711***	.000

Note: ***, **, and * denoted a significance level 1%, 5%, 10%.

Du, 2023; Li et al., 2023). This research presents empirical evidence from emerging economies to support the policy advocated by (IRENA, 2020). Our research confirms the intuitive idea that green finance plays a central role in promoting the adoption of green energy resources in emerging economies, paving the way for long-term environmental sustainability. In the context of the relationship between ES and GF, GF can provide funding for green initiatives that include green energy projects, sustainable transport and energy-efficient infrastructure. These initiatives can effectively replace high-carbon counterparts, such as fossil-fuel-based electricity generation and gasoline-powered vehicles, ultimately enhancing ecological efficiency, as recently emphasized by (Du, 2023; Li et al., 2023; Yang et al., 2023). Thus, strategies that attract private investment in green projects and green financing initiatives are key for emerging economies to achieve their environmental sustainability goals.

In addition, Model 2 assumes that green technological innovations play a central role in achieving ES. The control variables used in Model 2 are consistent with those in Model 1. The results show that a 1% increase in green technological innovation leads to a 0.103% decrease in human-induced environmental degradation in the short term and 0.191% in the long term. This means that green technological innovation has the potential to support environmental sustainability, mainly by reducing pollution and mitigating other environmental risks, while increasing the load capacity factor in the sampled countries. The use of green technological innovations helps minimize environmental waste disposal and can have a direct positive impact on environmental quality, as shown by the second hypothesis.

Regarding the positive link between GTI and ES, green tech-innovations pave the way for environmentally friendly products and services, thus reducing the negative impact of human activities on the environment. Moreover, green innovations play a crucial role in curbing greenhouse gas emissions (Balsalobre-Lorente, dos Santos Parente, et al., 2023; Esmaeili et al., 2023). As suggested by (Balsalobre-Lorente, Driha, et al., 2022; Balsalobre-Lorente, Ibáñez-Luzón, et al., 2022; Balsalobre-Lorente, Nur, et al., 2023), in order to promote ES, it is essential to provide greater incentives to companies that adopt green technologies, thereby improving environmental quality. GTI has a significant impact on environmental sustainability in emerging economies. These findings are consistent with previous research (Chen, Wang, et al., 2022; Li, Li, et al., 2022; Shan et al., 2021; Udeagha & Ngepah, 2022). In conclusion, emerging economies should increase their commitment to environmental projects to foster further green technological innovation and advance their path to a sustainable future.

The results of our study show that the findings regarding most of the control variables are consistent with the prevailing assumptions. With respect to the factors influencing environmental sustainability, the CS-ARDL has significant positive coefficients, especially for FA. This suggests that an extensive forest area is inversely correlated with environmental degradation over time. Forests act as carbon sinks by removing CO_2 from the atmosphere, which helps to reduce greenhouse gas emissions. Our findings therefore highlight the central role of forest ecosystems in improving environmental quality by sequestering anthropogenic CO_2 emissions and thus increasing the load capacity factor. This observation is confirmed by recent scientific papers, including Waheed et al. (2018), Begum et al. (2020), Raihan and Tuspekova (2022a), Raihan and Tuspekova (2022b), and Raihan, Muhtasim, Pavel, et al. (2022); Raihan, Muhtasim, Farhana, et al. (2022), that forested areas contribute to environmental sustainability. Nonetheless, the reduction of forest cover through deforestation exacerbates ecological damage and raises concerns about global warming. Deforestation as one of the main causes of environmental degradation, calling it the second largest anthropogenic source of emissions (Raihan & Tuspekova, 2022c). The initiative REDD + underlines the urgency of curbing emissions from deforestation and forest degradation and highlights it as an important climate change mitigation strategy for developing countries. Therefore, it is of utmost importance for these countries to invest in REDD+ and sustainable forest management to combat deforestation and achieve ecological balance.

Our research has determined that in emerging countries, both NRD and economic growth (GDP) hinder environmental sustainability. The data reveals a negative correlation between NRD and GDP with regards to environmental enhancement. Such patterns suggest that increased economic activity and resource utilization exacerbate environmental strains, thereby diminishing the LCF. The consequences of resource depletion and environmental disruptions are universal concerns that manifest differently in various regions around the world. The processes of resource extraction, their subsequent transformation into marketable goods, and their eventual consumption often occur across different nations. Each phase in this life cycle has its own set of environmental consequences and associated benefits.

Our findings repeat the conclusions of numerous studies, including those by Hussain et al. (2020); Yi et al. (2023); Ahmed et al. (2020); Umar et al. (2020); Pata and Isik (2021); Abbasi et al. (2021); Khan, Babar, et al. (2022); Du et al. (2022); Ni et al. (2022); (Jiang et al., 2022); (Doğan et al., 2022) All of these studies have determined the adverse environmental consequences of NRD and GDP. It is becoming increasingly evident that uncontrolled depletion of natural resources, combined with economic growth, can endanger ES. Consequently, a shift towards decoupling requires consideration of both the volume of resource consumption associated with economic activities and the environmental consequences of resource utilization throughout its life cycle. For a transition towards a globally sustainable economy, it is imperative to devise resource management strategies that promote resource decoupling, with a particular emphasis on reducing absolute resource consumption in rapidly growing economies.

In emerging nations, there is a significant correlation between economic activities and environmental degradation, primarily due to the consumption of natural resources and energy. Byaro et al. (2022) postulate that as economies grow, there is a marked increase in the exploitation of natural resources, which is essential for their sustainability and economic development. This growth often results in the excessive extraction of resources. Sensitive economic progress in these regions is often associated with excessive resource consumption, which leads to systemic inefficiencies and a dependence on non-renewable energy sources. Notably, many developing economies prioritize rapid economic expansion over the preservation of the environment. While according to Abban et al. (2022); (Balsalobre-Lorente, Driha, et al., 2022; Balsalobre-Lorente, Ibáñez-Luzón, et al., 2022) highlight that while energy is crucial for economic progress, its unsustainable consumption can increase greenhouse gas emissions and exacerbate environmental damage. Therefore, it is imperative for the governance and policymakers in these emerging economies to fervently implement policies that promote sustainable economic growth and decouple it from negative environmental impacts.

In addition, research demonstrates that environmental sustainability within emerging nations is positively influenced by factors, such as green finance, advancements in sustainable technology, and the presence of forested regions in the short term. On the other hand, economic growth and excessive resource use negatively affect environmental conservation.

4.2 | Sensitivity analysis

The study found that the short-term results were consistent with the long-term results. The study used the Augmented Mean Group and Common Correlated Effects Mean Group methods to verify the robustness of the CS-ARDL method in Table 9. The research indicated that the long-term estimates by AMG-CCEMG, and CS-ARDL approaches were similar. The AMG and CCEMG methods showed that GF, GTI, NRD, FA, and GDP are important factors in affecting environmental sustainability in emerging countries. The findings of the AMG and CCEMG methods were consistent with those of the CS-ARDL method, which also indicated that, with the exception of NRD and GDP, all the other variables have a positive impact on

TABLE 9 AMG-CCEMG.

Augmented mean group (AMG)					
Model.1			**Model.2**		
Variables	**Coefficients**	***P*- value**	**Variables**	**Coefficients**	***P*-value**
GF	.072***	.000	**GTI**	.225***	.000
NRD	−.267**	.019	**NRD**	−.208***	.008
FA	.093***	.003	**FR**	.112**	.019
GDP	−.757***	.000	**GDP**	−.868***	.001
Common correlated effects mean group (CCEMG)					
Model.1			**Model.2**		
Variables	**Coefficients**	***P*- value**	**Variables**	**Coefficients**	***P*-value**
GF	.098**	.011	**GTI**	.189***	.000
NRD	−.176**	.014	**NRD**	−.254***	.006
FA	.061***	.007	**FR**	.083***	.000
GDP	−.641***	.000	**GDP**	−.993***	.000

Note: ***, **, and * denoted a significance level 1%, 5%, 10%.

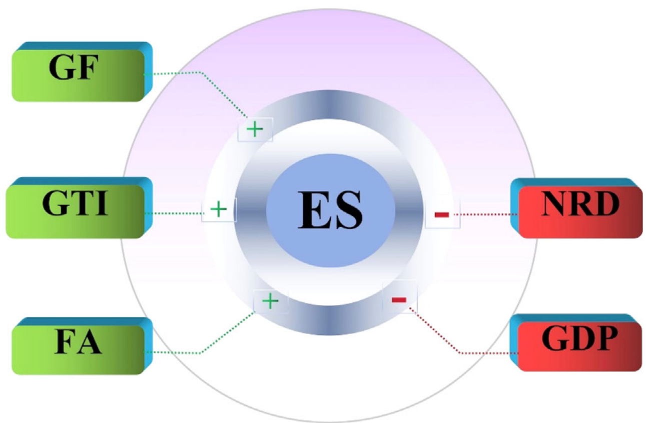

FIGURE 4 Summary of the results. GF and GTI represent green finance and green technological innovation, while FA and NRD refer to forested area and natural resource depletion, respectively. In addition, GDP represents economic growth, and ES represents environmental sustainability. The expected impact of the variables on ES is indicated by positive (+) and negative (−) sign.

environmental sustainability. See Figure 4 for a graphical interpretation that provides a summary of the results from CS-ARDL, CCEMG and AMG.

5 | CONCLUSION AND POLICY RECOMMENDATION

Environmental sustainability is a global priority aimed at mitigating the adverse effects of human activities on the environment. This issue has attracted the attention of environmental scientists, as well as governments, policymakers, and researchers. Overall, this research adds to the existing body of literature on sustainability by assessing the intersection of green finance green technological innovation with environmental sustainability in emerging economies. Natural resource depletion, forested area, and GDP serve as control variables in this analysis. This comprehensive study, covering the time frame between 2000 to 2018. Advanced estimation techniques like CS-ARDL, CCEMG, and AMG were employed to analyze the data. Findings reveal the pivotal role of green finance and green technology in enhancing environmental sustainability by reducing human-induced environmental pressure, emphasizing their capability to augment the LCF in both short and long terms in the observed emerging nations. The study also discloses the positive influence of forested areas and the detrimental effects of natural resource depletion and GDP on environmental sustainability. Consequently, any policy strategies focusing on green finance, green technological innovation, natural resource depletion, forest cover and economic growth will have a significant effect on environmental sustainability and vice versa.

To advance environmental sustainability, governments must take practical steps to reduce human-made pollution and ensure a sustainable future for generations to come. First, given the positive impact of GF on ES, it is critical for leaders in developing countries to create regulations that encourage both public and private investment in renewable energy and move energy systems towards sustainability. As public funding alone is not enough, it is essential to implement national policies by encouraging private investment in renewable energy to ensure that green finance is accessible and affordable in emerging economies. Furthermore, a comprehensive assessment of the impact of green finance is crucial to determine how effectively it contributes to achieving environmental sustainability goals in these countries. In this way, investors and policymakers can together contribute to the realization of a greener and more sustainable future.

Secondly, Green tech-innovations have shown positive effects on environmental conservation in emerging nations. Thus, it is vital for policymakers to prioritize and attract investments into these sustainable innovations. This will not only mitigate the adverse effects of human activities on nature but also strengthens environmental resilience. Moreover, leaders in these nations should actively seek private investments in green tech initiatives. By doing so, they can accelerate the adoption of these technologies, ensuring not only environmental preservation but also enhancing the nations' ability to withstand climate-induced challenges.

Thirdly, regarding the positive implications of FA on the ES, our study recommends that policymakers in emerging nations should integrate their national their national REDD+ initiatives with their SDG responses. This is because REDD+ promotes investment in sustainable forestry practices and should integrate their national deforestation and forest degradation, all of which are pivotal for environmental conservation. Furthermore, these countries can make ideal policies to local needs that maximize the benefits from REDD+ efforts and efficiently meet SDG targets. It is imperative for governments in these countries to formulate a Forest and Climate Change strategy within the framework of REDD+. Such a strategy could greatly augment efforts aimed at bolstering green developmental agenda. Additionally, the role of governmental regulation and funding for REDD+ are crucial. This will not only foster reduced emissions but will also set the stage for consistent private sector investments in the long run.

Fourth, considering NRD diminishing effects on the ES, it is imperative for governments in emerging countries to impose limits on the overconsumption and misuse of natural resources. This helps in mitigating the prolonged aftereffects of resource exhaustion and adverse environmental consequences. They can achieve this by implementing policies that that emphasize resource decoupling. With regard to resource consumption, there are two main approaches to lessen adverse environmental effects in emerging countries: (1) altering the combination of resources consumed by replacing more detrimental resources with those that are less harmful, and (2) utilizing resources in an environmentally friendly manner throughout their entire life cycle. In conclusion, emerging economies should adopt impact decoupling strategies to minimize the environmental consequences of economic growth. Such strategies aim at bolstering economic performance while simultaneously lessening environmental degradation.

This study introduces an innovative approach termed the "load capacity factor" to assess environmental conditions, laying the foundation for deeper inquiries into environmental sustainability. This factor is regarded as one of the most comprehensive tools for environmental evaluation. Subsequent research might explore regions like MINT, BRICST, the Next Eleven Economies (N-11), and countries with a range of resource utilization. By doing so, determine the influence of aspects such as digital financial inclusion, institutional quality, and financial development on sustainability using the load capacity factor. Such insights will guide us towards effective strategies to enhance environmental health.

AUTHOR CONTRIBUTIONS

Muhammad Anas: Writing—original draft, conceptualization, methodology, visualization, software and formal analysis. **Wei Zhang:** Supervision, reviewing, final version – approval. **Satar Bakhsh:** Formal analysis and writing – review & editing. **Dr. Liaqat Ali:** Reviewing, editing & grammar. **Cem Işık:** Reviewing, final version – approval. **Jie han:** Review & editing. **Xuemeng Liu:** Reviewing, final version – approval. **Hamad Ur Rehman:** Review & editing. **Amjad Ali:** Review & editing. **Min Huang:** Review & editing.

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