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ARTICLE

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Assessing the roles of green innovations and renewables in environmental sustainability of resource-rich Sub-Saharan African states: A financial development perspective

Mohammed Musah[1] | Bright Akwasi Gyamfi[2] | Stephen Taiwo Onifade[3] | Frank Gyimah Sackey[4]

[1]Department of Accounting, Banking and Finance, Business School, Ghana Communication Technology University, Accra, Ghana

[2]School of Management, Sir Padampat Singhania University, Bhatewar, Udaipur, India

[3]School of Finance and Accounting, Department of Economics, University of Vaasa, Vaasa, Finland

[4]Department of Economics, Business School, Ghana Communication Technology University, Accra, Ghana

Correspondence
Stephen Taiwo Onifade, School of Finance and Accounting, University of Vaasa, FI-65200, Vaasa, Finland.
Email: stephentaiwo.onifade@gmail.com

Abstract

Environmental literature keeps expanding on the natural resources-environmental sustainability conundrum. However, most studies examine this conundrum in different geographical locations other than resource-rich Sub-Saharan African (SSA) countries while also neglecting the criticality of issues like green innovations, financial development, and renewable energy. Besides, the likelihood of a nonlinear relationship has often been jettisoned in the framework. Thus, the resources-sustainability nexus was examined in the SSA using robust econometric techniques, while underscoring the roles of green innovations, renewable energy, and financial development. Using the cross-sectional augmented auto-regressive distributed lag (CS-ARDL), cross-sectional augmented distributed lag (CS-DL), and the common correlated effect mean group (CCEMG) approaches that conciliate with residual cross-sectional dependence and heterogeneity amongst others, we discovered that (i) the natural resources-sustainability nexus is nonlinear in SSA. (ii) unlike the environmental gains from green innovations and renewables in the SSA, natural resource harms their environmental sustainability (iii) the interaction between financial development and natural resources worsened the ecosystem of the countries (iv) the interaction between natural resources and the duo of green innovations and renewable energy enhances SSA's ecological quality (v) urbanization damage environmental sustainability by spurring ecological footprints. Furthermore, one-way causality paths were observed from the trio of natural resources, financial development, and green innovations to ecological footprints. But renewable energy and urbanization had a feedback causal relationship with ecological footprints. The findings are robust to CO_2 emissions as an alternative environmental quality measure. Policy implications to foster SDGs-related pollution mitigation agenda were thereafter extensively discussed for the SSA.

KEYWORDS
environmental sustainability, financial development, green innovations, natural resources, renewable energy, sub-Saharan Africa

1 | INTRODUCTION

Ecological deterioration is a global issue and a key component of the United Nations' sustainable development agenda. Series of report from the Intergovernmental Panel on Climate Change have shown that the pollution from anthropogenic human activities is causing serious hazards on the environment and the lives of mankind, even as the chaos of climate change intensifies in the 21st century (IPCC, 2018). Hence, various attempts to curb this menace has culminated into the existence of diverse treaties like the Brazil's 1992 Earth Summit, Japan's 1997 Kyoto Protocol, Mexico's 2010 Cancun Agreement, and recently, the 2015 Paris Accord in France. Despite the enactment and implementation of these agreements, the increasing concentration of greenhouse gases continue to cause global warming and other climate trends to persist. Statistically, the world's average temperature in 2021 was 1.11°C and the global average temperature from 2015 to 2021 have persistently surpassed 1°C relative to the pre-industrial levels (WMO, 2022). Addressing this matter has remained a major global challenge. Among the identified factors causing environmental degradation in the literature is natural resource. Resources play a vital role in the development of nations. Especially, the less developed ones, heavily rely on their resources to promote the growth of their national income (Onifade et al., 2023a). Therefore, the treadmill conjuncture of production, which postulates that rapid economic progress frequently leads to a great desire for natural resources and technologies stands valid (Aladejare, 2022). Resources in their natural state may not be harmful, but the processes used in extracting them might be detrimental to the environment. For example, the extraction of oil, minerals, and gases among others was reported as a major cause of ecological damage (Balsalobre-Lorente et al., 2018; Onifade, 2023).

Besides, financial development (FD) stimulates the growth of industry and infrastructure, which could also result in ecological deterioration (Baloch et al., 2019). Robust financial systems also help households to access low-cost facilities to buy energy-consuming and pollution-intensive items, which end up damaging the ecology. Contrastingly, well-developed financial sectors promote environmental safety by funding energy efficiency, research and development initiatives, and green energy generation (Pata et al., 2022). Moreover, renewable energy (RE) is an economical and a technically viable instrument that could aid in mitigating ecological pollution (Gyamfi et al., 2018). Energies from renewable sources also help to reduce pollution and ensure energy security by mitigating the dependency on dirty fuels. According to Appiah et al. (2023), RE help to mitigate pollution, environmental and climate effects, energy costs, and ecological footprints (EF). Additionally, RE promotes ecological sustainability, by abating wealth inequality (Pata et al., 2022). Furthermore, green innovations (GI) have been identified as a critical factor that promote the quality of ecosystems (Abid et al., 2022). As documented by Castellacci and Lie (2017), GI help to mitigate pollution and promote ecological safety in economies. Green innovations foster green environment by lowering the amount of energy derived from fossil fuels, and increasing the share of ecologically harmless resources, consumption, and waste reutilization (Ganda, 2020). To Albort-Morant et al. (2016), these elements improve the ecosystem while also contributing to firms' overall growth.

Irrespective of these countless studies, the connection between NR and environmental sustainability (ES) in resource rich Sub-Saharan African (SSA) economies (Chad, Congo DR, Guinea, Liberia, Mauritania, Niger, Nigeria, Sierra Leone, South Sudan, Zambia) has often been ignored. Also, accounting for the roles of FD, RE, and GI has mainly been overlooked in studies hitherto. This study is therefore undertaken to help fill-in that void. Specifically, the study sought to (1) examine the effect of NR on ES in resource-rich SSA countries; (2) determine the interactive effect of FD and NR on ES in the countries; (3) explore the interactive effects of RE and NR on ES in the countries; (4) examine the interactive effect of GI and NR on the nations' ES; and (5) determine the non-linear relationship between NR and ES in the nations. According to the Emissions Gap Report of the United Nations Environment Programme (UNEP), a significant amount of the world's mineral reserves is found in the nations' natural resource sector, in addition to their enormous agrarian wealth. The aforestated nations also account for a larger portion of Africa's 40% of global gold deposits and nearly 90% of the world's chromium and platinum reserves (Aladejare, 2020). Similarly, some of the countries contribute significantly to Africa's oil and natural gas reserves of roughly 12% and 8% of the global figure correspondingly (UN Environmental Programme [UNEP], 2022). Despite all these favorable statistics, the nations have unsustainable ecological conditions. Specifically, the EF of almost all the countries far exceeds their biocapacity. This indicates that the countries are experiencing ecological deficits. According to Pata et al. (2022), ecological deficit is the excess of EF over biocapacity, meaning, the nations' natural resources are under intense pressure as a result of anthropogenic human activities. Besides, the investigated states are all developing and industrial economies, and also possess a significant percentage of global resources. Hence, any notable shock in their economies would have a material impact on all other economies in the globe. Nonetheless, the nations are not exempted from - environmental pollution issues, as they are significant contributors of pollutions on the environment. Though the countries make the smallest contributions to greenhouse gas emissions, they are the hardest hit by the effects of climate change.

According to the World Meteorological Organization, 91% of the nearly 2 million fatalities brought on by the about 11,000 natural disasters between 1970 and 2019, occurred in developing countries, of which resource-rich economies in SSA are no exception. The studied countries' commitment to the net-zero emission targets, clearly underscores the need for them to switch from pollution-based activities to more ecologically friendly options. Hence, studying how natural resources, FD, RE, and GI affect their drive towards sustainable environment was deemed appropriate. Moreover, given the persistent policy challenges in Africa, it was crucial to figure out how the ecological policies of the nations could be realigned to accomplish their pollution mitigation targets. This study was therefore conducted to offer a policy framework that is SDG-focused for achieving the objectives of SDG 13, 11, 12 and 7 amongst others. Thus, the study contributed to the body of knowledge at the policy level via this route.

This study makes innovative contributions to literature in various ways. First, as much as we are aware, this is the first study to examine the linkage between natural resources and ES in resource-rich Sub-Saharan economies, while accounting for the roles of FD, RE, and GI. The only related study conducted on these countries was Sibanda et al. (2023). But in their study, the authors investigated the connection between NR, institutional quality and ecological deterioration, which differs from ours to a large extent. Secondly, FD, RE, and GI have material influence on natural resources. If the series have substantial effects on natural resources, then they can play a major role in the NR-ES connection. However, no study has attempted to test this relationship in resource-rich economies in SSA. Our study accounted for this research gap by examining how FD, RE, and GI moderate the association between NR and ES in the nations. Unlike prior explorations that focused on only the linear association between NR and ES, our study fills this gap by exploring the nonlinear association amidst the series. This will provide us the chance to accurately capture the various facets of ecological pollution in the nations. Fourthly, most preceding explorations used CO_2 emissions as a surrogate of ES. However, environmental deterioration goes beyond CO_2 emissions. Therefore, it was pertinent to use an indicator that captures all aspects of pollution in the ecosystem. Hence the adoption of EF. Ecological footprint is a comprehensive measure of environmental degradation, because it accounts for gas emissions and other aspects of ecological pollution. As far as we are aware, the linkage between NR and ES in resource rich SSA economies is unexplored, and the critical roles of FD, RE, and GI have not been checked using EF as a measure of the environment. Methodologically, we applied the CS-ARDL, CS-DL, and the CCEMG techniques that to the best of our knowledge, have not been applied to examine the association between the variables in resource-rich SSA economies. Unlike other conventional econometric techniques, these approaches allow for CD and heterogeneity among others, that can cause the parameter estimates to be biased if neglected. Because the above techniques do not comment on causalities, we engaged the D-H test that is efficient to heterogeneous slopes, to explore the causal paths amidst the series.

2 | LITERATURE REVIEW

This section presents the literature review of the study. The reviews are presented under sub-headings, natural resource rents and environmental sustainability nexus; financial development and environmental sustainability nexus; renewable energy and environmental sustainability nexus; and green innovations and environmental sustainability nexus. Gaps in literature forms the concluding part of this section.

2.1 | Natural resource (NR) and environmental sustainability (ES) link

Many studies on the association between NR and ES have been conducted. The findings are however contrasting. For example, in the study of Alvarado et al. (2021), NR hinders ES in blocs like the BRICS economies. Shittu et al. (2021) studied 45 Asian economies and affirmed NR as beneficial to ES thus, aligning with study of Zafar et al. (2019) for the United States. On 56 Belt and Road Initiative nations, Hussain et al. (2020) documented NR depletion as consequential to ES. These conflicts the studies of Danish and Khan (2020) for BRICS economies and Demir et al. (2023) and Çetin and Saygın (2019) both for Turkey. Also, on BRICS nations, Adedoyin et al. (2020) validated NR as harmless to ES. This varies from the exploration of Mahmood and Saqib (2022) who confirmed NR as ecologically harmful. In the studies of Sun, Addae, et al. (2021) and Miao et al. (2022), NR harmed ecological safety in Chinese cities and industrialized economies respectively. Usman, Jahanger, et al. (2022) researched on Artic economies and also confirmed NR as damaging to ES. While Gyamfi et al. (2022) found an inverted U-shaped association amidst NR and pollution in the Mediterranean region, Awosusi et al. (2022) only confirmed a trivial connection between these factors in Colombia. Thus, most studies are contrasting in their submissions.

2.2 | Financial development (FD) and environmental sustainability (ES) link

The association between FD and ES has also been expansively explored but with mostly ambiguous discoveries. For instance, Abid et al. (2022) conducted a study on leading economies and found FD as friendly to ES. This finding contrasts the studies of Çetin and Yüksel (2018), and Weili et al.'s (2022). Hafeez et al. (2022) examined the predictors of ES in top polluting Asian economies and discloses that FD is a trivial determinant of ES. This varies from the study of Usman, Ozturk, et al. (2022) for Artic nations. Hongqiao et al. (2022) examined the US case and noted that FD worsened America's ES. Habiba et al. (2022) also observed that FD harmed ecological quality in 12 top emitting nations. This finding supports that of Ozturk et al. (2022) for Turkey, but contrasts that of Çetin et al. (2022) for 18 upper middle-income economies. Opula et al. (2022) studied the FD-ES connection in West Africa and argued that FD did not materially predict ES in the region. This finding deviates from the study of Çetin and Ecevit (2017) who affirmed FD as a positive determinant of emissions in Turkey. Ehigiamusoe et al. (2022) investigated 31 African nations and confirmed FD as harmful to ES. This finding supports the study of Adebayo et al. (2022) and Pata et al. (2022) for Turkey and South Asia accordingly. The latter noted that FD deteriorated ES by escalating ecological footprints. Çetin et al. (2023) investigated the role of FD in the link between globalization and ecological pollution in selected emerging economies. Based on the discoveries, development in the financial sector escalated pollution in the nations. Also, a causality from FD to environmental degradation was disclosed.

2.3 | Renewable energy (RE) and environmental sustainability (ES) link

Renewable energy has been persistently argued as one of the variables that promotes ES. As such, countless studies in different settings have been conducted to examine its association with ES. For instance, Batool et al. (2022) researched on South Asia and confirmed RE as beneficial to ES. Huang et al. (2022) investigated emerging seven (E-7) and group of seven (G-7) economies reporting that it advances ecological sustainability in these economies. In Alola et al. (2021)'s exploration on China, RE surprisingly promotes pollution in the lower and upper quantiles while observing a causality from RE to ecological pollution. On the other hand, Gierałtowska et al. (2022) adopted the generalized method of moments (GMM) approach to investigate the RE and ES in 163 economies and noted RE improved the countries' ES. Çetin et al. (2021) studied the role of RE in the tourism-environmental pollution connection in Turkey. From the findings, energy from renewable sources enhanced ecological safety in the nation. Also, a bidirectional causality between RE and environmental degradation was unfolded. In the study of Pata et al. (2022), RE escalated ecological quality in four South Asian economies. Adebayo et al. (2022) also noted that RE advanced ES in the middle quantile for Turkey while predicting ES at different quantiles in mean and variance. Seker et al. (2015) adopted the autoregressive distributed lag (ARDL) technique to study the determinants of ecological quality in Turkey from 1974 to 2010. From the results, energy utilization considerably predicted carbon emissions in the country. Also, a causality from energy consumption to emissions of carbon was uncovered. Habiba et al. (2022) adopted the system-GMM approach to study the RE-ES connection in 46 SSA economies and disclosed that RE substantially improved ES. This finding conflicts the study of Çetin et al. (2020) for Turkey. Kirikkaleli et al. (2022) scrutinized the Chinese economy from Q1 of 1990 to Q4 (2018) and reported that energies from renewable sources enhanced ES via low pollutant emissions. This finding is in tandem with Sarigül and Topcu (2021) who affirmed clean energy as friendly to the environment of Turkey. Ertugrul et al. (2016) analyzed the predictors of pollutant emissions in the top ten carbon emission emitters among developing economies. From the discoveries, energy consumption was a major determinant of emissions in the long-run.

2.4 | Green innovations (GI)and environmental sustainability (ES) link

Green innovation (GI) refers to any innovation that helps to develop goods, services, or procedures that minimize the damage and deterioration of the environment while making the wise use of natural resources (Leal-Millán et al., 2017). It also refers to novel methods or programs intended to lower ecological harm (Kemp et al., 2001). According to Leal-Millán et al. (2017), the inclusion of GI and new technologies in manufacturing processes help to promote sustainable environment and development. One of the key elements that predict ecological sustainability is GI. As a such, recently, some studies have been conducted on the GI-ES connection in different geographical locations. For example, Sharif et al. (2023) researched on Nordic countries from 1995 to 2020 and reported that GI improve ES. An et al. (2023) studied the top eight advanced economies over the period 1990–2018 and also noted that green technologies advanced ES and the well-being of humans. Yasmeen et al. (2023) investigated OECD countries and discovered that green technologies were major drivers of energy efficiency and productivity, thereby lowering energy intensity and ecological pollution. Habiba et al. (2022) have also reported that GI can improve ES. In Hongqiao et al.'s (2022) investigation on the US, GI promoted the nation's ES. Besides, environmental innovations caused pollutant emissions in the economy. It was suggested that the US should promote innovations in eco-technologies to help advance its ES. In the exploration of Ali et al. (2022) GI promoted ES in BRICS economies while noting a causality between GI and ecological pollution.

2.5 | Literature gaps

It is evidenced from the reviews that the connection between NR, FD, RE, GI and ES has been expansively explored, but none of the studies examined the affiliation between NR and ES in resource-rich SSA economies, while accounting for the interactive roles of FD, RE and GI at the same time. Also, aside, Gyamfi et al. (2022) all the studies examined the direct associations amidst the variables of concern. Besides, most of the explorations failed to account for structural breaks, endogeneity, heterogeneity, and residual cross-sectional correlations amongst others. To help fill these gaps, a study on the nexus between NR and ES in resource-rich SSA economies, while accounting for the moderating roles of FD, RE and GI was deemed fitting. To accomplish the goals of this research and significantly advance literature and policy, the following hypothesis were developed for testing;

Hypothesis 1. Natural resources worsen environmental sustainability in resource-rich SSA countries.

Hypothesis 2. The interaction between financial development and natural resources deteriorates environmental sustainability in the countries.

Hypothesis 3. The interaction between renewable energy and natural resources improves environmental sustainability in the countries.

Hypothesis 4. The interaction between green innovations and natural resources promotes environmental sustainability in the nations.

Hypothesis 5. Natural resources have a non-linear relationship with environmental sustainability in the nations.

3 | METHODOLOGY

3.1 | Data source

In this exploration, a panel data on seven resource-rich economies in Sub-Saharan Africa (SSA) was used for the analysis. According to the World Bank, the resource-rich SSA countries are Chad, Congo DR, Guinea, Niger, Nigeria, Sierra Leone, Zambia, Liberia, Mauritania, and South Sudan. Because data on ecological footprint (EF) for Liberia and Mauritania were not available, and that of South Sudan was only available from 2012 to 2018, those countries could not form part of the sample. Data covering the period 1990 to 2018 was used for the analysis. The time frame adopted for the analysis was dictated by data availability. As of the time this analysis was conducted, data on ecological footprint (EF) for the countries was available from 1961 to 2018 while that on renewable energy (RE) was available from 1990 to 2021. Also, data on natural resources (NR) was available from 1970 to 2021 while that on financial development (FD) was available from 1980 onwards. Moreover, data on green innovations (GI) was available from 1961 to 2019 while that on urbanization was available from 1960 to 2022. Therefore, using data on RE as the start period and that on EF as the end period, 1990 to 2018 was deemed fitting for the analysis, because all the series could contribute significant data over that period. The data on NR, RE and urbanization was directly extracted from the World Bank database (WDI, 2022). Following Habiba et al. (2022), FD was proxied by an index computed by the International Monetary Fund (IMF), while development of environmentally-related technologies sourced from the OECD database was used to measure GI in line with Onifade et al. (2023b). Because the widely used indicator of environmental degradation (CO_2 emissions) is constrained with regards to its measurement of pollution, many scholars have of late, relied mostly on ecological footprint, because it takes into consideration all aspects of pollution in the ecosystem (Udemba, 2021). Aside carbon footprint, this indicator also takes into account pollution from forest areas, croplands, built-up lands, fishing grounds, and grazing lands. This multidimensional nature of the variable makes it a better measure of ecological performance than others. Therefore, in line with some studies (Hussain et al., 2022; Usman, Ozturk, et al., 2022), ES follows EF in this exploration. The series were selected for the sample countries as shown in Table 1 after taken into consideration the sustainable development goals (SDGs) of the United Nations (UN).

3.2 | Theoretical underpinning and model specification

Natural resource rents have been proven to be a key determinant of environmental sustainability. However, few studies have examined how the variable explains sustainable environment in Africa. To help fill this gap, a study on the nexus between natural resource rents (NR) and environmental sustainability in Africa was deemed appropriate. In attaining this goal, the first baseline econometric model was established in Equation (1) while accounting for the moderating roles of green innovations (GI), financial development (FD), and renewable energy (RE) consumption.

TABLE 1 Sample Countries & Full Information About the Variables.

Sample: Chad, Congo DR, Guinea, Niger, Nigeria, Sierra Leone, Zambia.

Indicators	Symbol	Definition(s)	Sourced from
Ecological footprint	EF	Global hectare of land	GFN
Total natural resource rents	NR	Percentage of GDP	WDI
Financial development	FD	Financial development index	IMF
Renewable energy consumption	REC	Percentage of total energy consumption	WDI
Green innovations	GI	Development of environment-related technologies (percentage of all technologies)	OECD
Urbanization	URB	Percentage of total population	WDI

Abbreviations: EF, ecological footprint; FD, financial development; GI, green innovations; IMF, International Monetary Fund; NR, natural resources; OECD, Organization for Economic Cooperation and Development; URB, urbanization; WBD, World Bank database.

$$\ln EF_{it} = a_o + \beta_1 \ln NR_{it} + \beta_2 \ln FD_{it} + \beta_3 \ln RE_{it} + \beta_4 \ln GI_{it} + \beta_5 \ln URB_{it} + \mu_t \quad (1)$$

where ecological footprint (EF) is the environmental quality criterion; and urbanization (URB) is a control variable to help minimize model specification bias. Besides, $\beta_1,...\beta_5$ are the coefficients of lnNR, lnFD, lnRE, lnGI, and lnURB respectively; *i* denotes the studied nations; *t* is the time dimension; and *a* and μ are the constant and residual terms correspondingly. All the series were in their natural logarithm to help minimize heteroscedasticity and data fluctuations in line with (Chen, Tackie, et al., 2022). Theoretically, natural resources are major sources of income to economies. However, over exploitation of natural resources could be consequential to the ecosystem of nations (Dingru et al., 2023; Du et al., 2022). According to Alvarado et al. (2021), expansion in agricultural production, logging, and illegal mining are among the key agents of ecological pollution. In Chinese cities, Sun, Li, et al. (2021) has also reported resource extraction as detrimental to both environmental and economic progress. In contrast, natural resources may promote ecological quality if they could reduce the utilization of polluting energies. For instance, natural resources could be converted to green energies with the aid of modern technologies (Balsalobre-Lorente et al., 2018). Resources may also generate technique effects, if they are channeled into energy-efficient technologies. Consequently, these technologies could help to promote sustainable environment. The beneficial effects of NR on ES have been reported by others (Shittu et al., 2021; Zafar et al., 2019). From the above, natural resources have varying effects on the ecosystem of nations. We therefore predicted the coefficient of the variable to be either positive $(\beta_1 = \partial \ln EF_{it} / \partial \ln NR_{it} > 0)$ or negative $(\beta_1 = \partial \ln EF_{it} / \partial \ln NR_{it} < 0)$. Besides, improved financial systems give individuals and businesses access to finance, which raises living standards and encourages economic expansion. This ultimately leads to increased energy utilization and therefore, more ecological pollution (Saud et al., 2019). Also, growth in stock markets assists publicly traded companies to strengthen their funding sources, lower operational risk and finance costs, initiate new projects, and ultimately maximize energy utilization and environmental deterioration. Moreover, financial sector growth raises ecological pollution through foreign investment inflows (Farouq et al., 2021). Sound financial systems attract foreign investors to developing economies. However, the influxes of these investors are usually accompanied by rising productions that are tied to the consumption of polluting energies. These investors prefer to invest in emerging economies because of their lax environmental regulations (Raza & Shah, 2018). In contrast, healthy financial systems encourage the adoption of innovative manufacturing techniques and the procurement of cutting-edge technology that are more environmentally and energy efficient (Ulucak et al., 2020). Domestic credit helps to reduce potential ecological degradation since it increases financial access for companies that embrace environmentally friendly technologies or produce eco-friendly products (Farouq et al., 2021). With reference to the above assertions, we projected the coefficient of FD to be either positive $(\beta_3 = \partial \ln EF_{it} / \partial \ln FD_{it} > 0)$ or negative $(\beta_3 = \partial \ln EF_{it} / \partial \ln FD_{it} < 0)$ aligning the studies of Weili et al. (2022) and Çetin et al. (2022) respectively. Besides, renewable energy can be a vital tool for abating pollution in the ecology while safeguarding energy security (Bozkaya et al., 2022). According to Pata (2021), energies from renewable sources help to enhance air quality and human health; lower EF, climate effects, and energy prices; and generate employment opportunities. Therefore, since renewable energy is a resource for environmental sustainability, it was expected to have a negative effect on EF $(\beta_2 = \partial \ln EF_{it} / \partial \ln RE_{it} < 0)$. Further, the promotion of energy efficiency, environmental optimization, and economic growth are the three tenets of GI. This is primarily seen in technological advancement, which helps in energy conservation and pollution reduction (Long et al., 2017). Green innovations effectively reduce pollution by improving energy consumption efficiency. They also support the shift to ecologically sustainable lifestyles and are thus essential means of achieving green growth (Shao & Zhong, 2021). GI enhance ecological quality by reducing the negative effects of industrial production processes (Li et al., 2019). Innovative technologies reduce pollution and maintain a clean environment in host economies, because the production systems employed by foreign entities are often better than those in developing nations (Zhu et al., 2016). Due to their positive benefits, host countries embrace them to improve their industrial methods. In research by Suki et al. (2022), technology reduced pollution in the ecosystem via efficiency improvements. Using a data of 27 European Union economies, Tobelmann and Wendler (2020) confirmed

GI as friendly to ES. Thus, we predicted the elasticity of GI to be negative ($\beta_4 = \partial \text{lnEF}_{it}/\partial \text{lnGI}_{it} < 0$) supporting the works of Zeng et al. (2022). Finally, URB is a historically inescapable tendency that has had a significant impact on economies. Urban population in both wealthy and emerging nations puts a tremendous amount of strain on natural resources (Nathaniel & Khan, 2020). URB can be beneficial for knowledge, innovation, and economic growth, but also accelerates deforestation and environmental damage (Danish & Wang, 2019). To Ahmad et al (2021), unplanned URB is harmful to the environment, but sustainable URB could improve the ecosystem. Therefore, it is thought that URB could increase ecological safety if it is managed effectively but could cause environmental deterioration if not handled properly. In the studies of Sahoo et al. (2022), urban population contributed to pollution, however, others confirmed URB as friendly to ecological quality (Danish & Khan, 2020; Nathaniel et al., 2019). We therefore projected the coefficient of URB to be either positive ($\beta_5 = \partial \text{lnEF}_{it}/\partial \text{lnURB}_{it} > 0$) or negative ($\beta_5 = \partial \text{lnEF}_{it}/\partial \text{lnURB}_{it} < 0$). To examine the moderating roles of RE, FD, and GI in the link between NR and environmental sustainability (ES), the baseline model was augmented with the interactive terms between FD and NR ($\text{FD} \times \text{NR}$), between RE and NR ($\text{RE} \times \text{NR}$), and between GI and NR ($\text{GI} \times \text{NR}$). The augmented model therefore became;

$$\ln \text{EF}_{it} = a_o + \beta_1 \text{lnNR}_{it} + \beta_2 \ln \text{FD}_{it} + \beta_3 \ln \text{RE}_{it} + \beta_4 \text{lnGI}_{it} + \beta_5 \ln \text{URB}_{it} + \pi_1 (\ln \text{FD}_{it} \times \ln \text{NR}_{it}) + \pi_2 (\ln \text{RE}_{it} \times \ln \text{NR}_{it}) + \pi_3 (\ln \text{GI}_{it} \times \ln \text{NR}_{it}) + \mu_t \tag{2}$$

where $\text{FD} \times \text{NR}$=interactive term between FD and NR; $\text{RE} \times \text{NR}$=interactive term between RE and NR; and $\text{GI} \times \text{NR}$=interactive term between GI and NR. Moreover, π_1, π_2, and π_3 are the coefficients of the interactive terms correspondingly. Based on the interactions, the marginal effects of FD, RE and GI on ES at different levels of NR were computed as;

$$\frac{\partial \text{lnEF}_{it}}{\partial \text{lnFD}_{it}} = \beta_2 + \pi_1 \text{lnNR}_{it} \tag{2a}$$

$$\frac{\partial \text{lnEF}_{it}}{\partial \text{lnRE}_{it}} = \beta_3 + \pi_2 \text{lnNR}_{it} \tag{2b}$$

$$\frac{\partial \text{lnEF}_{it}}{\partial \text{lnGI}_{it}} = \beta_4 + \pi_3 \text{lnNR}_{it} \tag{2c}$$

here, the main focus was on the sign and significance of the coefficients (for example β_1 and π_1). A positive marginal effect ($\beta_2 + \pi_1 \text{lnNR}_{it}$) means, as NR increased, the impact of FD on the environment also increased, while a negative sign means higher NR reduced FD roles in the environment. To test for the nonlinear relationship between NR and ES, Equation (1) was augmented with the square of NR (NR^2) resulting in the Equation (3);

$$\ln \text{EF}_{it} = a_o + \beta_1 \text{lnNR}_{it} + \beta_2 \text{lnFD}_{it} + \beta_3 \text{lnRE}_{it} + \beta_4 \text{lnGI}_{it} + \beta_5 \text{lnURB}_{it} + \varphi_1 \ln \text{NR}^2{}_{it} + \mu_t \tag{3}$$

where NR^2 is the square of NR and φ_1 is its parameter to be estimated. Essentially, NR was nonlinearly related to ES, if the signs of β_1 and φ_1 were different and significant. The relationship amidst the series was to be U-shaped if β_1 was negative ($\beta_1 = \partial \text{lnEF}_{it}/\partial \text{lnNR}_{it} < 0$) and φ_1 was positive ($\varphi_1 = \partial \text{lnEF}_{it}/\partial \text{lnNR}_{it} > 0$). Contrastingly, the association was to be inverted U-shaped if β_1 was positive ($\varphi_1 = \partial \text{lnEF}_{it}/\partial \text{lnNR}_{it} > 0$) and φ_1 was negative ($\varphi_1 = \partial \text{lnEF}_{it}/\partial \text{lnNR}_{it} < 0$). Taken partial derivatives of Equation (3), the threshold level could be computed as in (3a);

$$\frac{\partial \text{lnEF}_{it}}{\partial \text{lnNR}_{it}} = \beta_1 + 2\varphi_1 \text{lnNR}_{it} \tag{3a}$$

Provided that '0' values are assumed for the partial derivative(s), the turning point of the variable could be computed as Equation (3b);

$$\ln NR_{it} = \frac{-\beta_1}{2\varphi_1} \tag{3b}$$

3.3 | Estimation strategy

Cross-sectional dependence (CD) has become a major issue due to the growing convergence of the global economy (Gyamfi et al., 2022; Onifade, Gyamfi, Haouas, & Asongu, 2023). Many nations have diverse economies and political systems, and because they are linked to others by trade and other economic issues, they are more susceptible to related shocks. Therefore, failure to account for CD in panel data analysis could lead to erroneous estimates and conclusions (Musah et al., 2022). Hence, the CD test of Pesaran (2015) was engaged since it yields reliable results in large N and small T (N > T) panel datasets. The utilized Pesaran (2015) CD test in Equation (4) assumes weak CD in residual terms and the violation of this assumption implies CD limitations.

$$CD = \left[\frac{2T}{N(N-1)}\right]^{\frac{1}{2}\sum_{i=1}^{N-1}\sum_{j=i+1}^{N}\widehat{\rho}_{ij}} \tag{4}$$

where $\widehat{\rho}_{ij}$ is the pairwise correlation coefficients, N denotes the cross-sections and T is the time dimension. For robustness purpose, other tests were performed and reported later. Moreover, the studied nations are diverse with regards to macroeconomic indicators like financial globalization, natural resource rents, green innovations, and financial development among others. These differences might cause heterogeneity in the slope parameters. Therefore, assuming homogeneity in the slope coefficients could result in misleading estimates and inferences. Hence, the Pesaran and Yamaga (2008) test was used to check whether the parameters were homogeneous or heterogeneous. The test predicts the delta tilde ($\tilde{\Delta}$) and the adjusted delta tilde $\left(\tilde{\Delta}_{adj}\right)$ statistics are expressed in Equations (5) and (6);

$$\tilde{\Delta} = \sqrt{N}\left(\frac{N^{-1}\tilde{S}-k}{\sqrt{2k}}\right) \tag{5}$$

$$\tilde{\Delta}_{adj} = \sqrt{N}\left(\frac{N^{-1}S-E(\tilde{z}_{iT})}{\sqrt{Var(\tilde{z}_{iT})}}\right) \tag{6}$$

The above tests assume homogeneity in slope coefficients. Therefore, failure to validate this hypothesis implies, the slope parameters are heterogeneous. Besides, the integration order of variables is essential for approach selection. Hence, following Chen, Wang, et al. (2022), the cross-sectionally augmented ADF (CADF) and the cross-sectionally augmented Im, Pesaran and Shin (CIPS) unit root tests were employed to assess the variables features of integration. These tests were used because they control for CD in panel data analysis. The test is expressed in Equation (7) in line with Pesaran (2007).

$$\Delta y_{it} = a_i + b_i y_{i,t-1} + c_i \overline{y}_{t-1} + \sum_{j=0}^{p} d_{ij}\Delta\overline{y}_{t-j} + \sum_{j=1}^{p}\delta_{ij}\Delta y_{i,t-j} + e_{it} \tag{7}$$

where $\overline{y}_{t-j}$ and $\Delta\overline{y}_{t-j}$ are the means of the cross-sections and the CIPS test can be obtained by taking a simple average of Equation (7) to obtain Equation (8).

$$\text{CIPS} = N^{-1}\sum_{l=1}^{N}\text{CADF}_l \tag{8}$$

These tests assume that variables under investigation are nonstationary. Hence, failure to accept this hypothesis suggests the series are stationary. The setback of the CIPS and the CADF tests is that they do not cover structural breaks. Therefore, following Jian and Afshan (2022), the Bai and Carrion-i-Silvestre (2009) test that accounts for structural breaks were engaged in Equation (9) in addition to the CD.

$$y_{it} = \alpha_i + F_t'\pi_i + \sum_{j=1}^{li}\theta_{ik}\text{DU}_{\text{ikt}} + \beta_i t + \sum_{k=1}^{mi}\gamma_{ik}\text{DT}_{\text{ikt}} + \varepsilon_{it} \tag{9}$$

where DU and DT are the dummy variables, j and k are the dates of the breaks at levels and trend correspondingly, F_t and π_i are respectively the common factors and the factor loadings, and l_i and mi are the structural breaks affecting the mean and the trend correspondingly. Before proceeding to estimate the parameters of determinants, it is worthwhile to establish whether the investigated series are flanked by a cointegration association or not. Therefore, following Onifade and Alola (2022), the Westerlund (2007) test was adopted in Equation (10) to examine the cointegration attributes of the series. This test is beneficial because it accounts for CD unlike conventional techniques like the Kao and Chiang (2000) test that assume cross-sectional independence.

$$\Delta z_{it} = \delta_i' d_i + \theta_i\left(z_{i(t-1)} + \pi_i'\right) + \sum_{j=1}^{m}\theta_i\Delta z_{i(t-1)} + \sum_{j=1}^{m}\varphi_i\Delta y_{i(1-j)} + \omega_{it} \tag{10}$$

where θ_i measures how previous periods departs from long-run equilibrium and impacts its short-run facets. This test predicts group (G_τ, G_α) and panel (P_τ, P_α) statistics specified in Equations (10a)–(10d) respectively.

$$\text{G}_\tau = \frac{1}{\text{N}}\sum_{i=1}^{N}\frac{\theta_i}{\text{SE}\left(\widehat{\theta}_i\right)} \tag{10a}$$

$$\text{G}_\alpha = \frac{1}{\text{N}}\sum_{i=1}^{N}\frac{T\theta_i}{\theta_i'(1)} \tag{10b}$$

$$\text{P}_\tau = \frac{\widehat{\theta}_i}{\text{SE}\left(\widehat{\theta}_i\right)} \tag{10c}$$

$$\text{P}_\alpha = T\widehat{\theta}_i \tag{10d}$$

The test assumes no cointegration amidst series. If this is rejected, it implies the series are bonded by a cointegration affiliation in the long-run (Westerlund, 2007). For robustness purpose, we also engaged the Banerjee and Carrion-i-silvestre (2017) test in Equation (11) to put structural breaks under adequate check.

$$Y_{it} = \partial_i + G_t'\emptyset_i + \omega_i D_{it} + \delta_{it} + X_{it}' u_i + (D_{it} X_{iT})' \vartheta_i + \varepsilon_{it} \tag{11}$$

From the above, Y_{it} and X_{it} denote the criterion and input variables respectively, and T_i denotes the break year. Also, $D_{it} = 1(t > T_i)$, while ε_{it} and ∂_i are the error and constant terms correspondingly. After the cointegration tests, in order to simultaneously take advantage of obtaining both long and short-run coefficients, the CS-ARDL was applied, and we also use the CS-DL technique since both methods produce this advantage. Therefore, these two methods were used as the principal estimators. Additionally, the former technique is beneficial because it is efficient to CD and heterogeneous slopes (Chudik et al., 2017) and it is stated as seen in Equation (12).

$$y_{it} = \mu_i + \sum_{q=1}^{p_y} \lambda_{iq} y_{i,t-q} + \sum_{q=0}^{p_x} \beta_{i,q}' x_{i,t-q} + \sum_{q=0}^{p} \overline{v}_t + \mu_{i,q} \tag{12}$$

where $\overline{v}_{t-q} = (\overline{y}_{it-q,}\, \overline{x}_{it-q})$. The CS-DL estimator in Equation (13) on other hand, is not sensitive to lag selection, and directly estimates long-run elasticities. The technique also controls for CD and heterogeneity in slope parameters (Chudik et al., 2017). In an ARDL (p_y, p_x) model with added averages of the cross-sections to deal with CD, the estimated CS-DL equation becomes;

$$y_{it} = w_i + \theta_i x_{it} + \sum_{q=1}^{p_{x-1}} \delta_{it}' \Delta x_{it-q} + \sum_{q=1}^{p_{\overline{y}}} \gamma_{yi,q} \overline{y}_{it-q} + \sum_{q=1}^{p_{\overline{x}}} \gamma_{x,it}' \overline{x}_{it-q} + u_{it} \tag{13}$$

where $(\overline{y}_{it-1,}\, \overline{x}_{it-1})$ are the cross-sectional mean of the regressand and the regressors accordingly, $p_{\overline{y}} = 0$, and $= p_{\overline{x}} = \left[T^{1/3}\right]$. Later on, the CCEMG estimator was engaged. This technique is efficient to models with stationary and nonstationary variables (Işik et al., 2020), and controls for endogeneity (Ahmad & Zhao, 2018), CD and slope heterogeneity (Eberhardt, 2012). Under this method, CD is handled by adding cross-sectional means to the base of the variables, but not further lags to help prevent multi-collinearity issues (Pesaran, 2006). So both methods help to check robustness of primary estimators' findings. At the final stage of the analysis, the causal connections amidst the series were explored in Equation (14) via the Dumitrescu and Hurlin (2012) panel causality test. According to El Menyari (2021), this test accounts for heterogeneity in slope coefficients. The test is officially expressed as;

$$Y_{it} = w_i + \sum_{m=1}^{M} \alpha_i^{(m)} Y_{it-m} + \sum_{m=1}^{M} \delta_i^{(m)} X_{it-m} + \varepsilon_{it} \tag{14}$$

where the regressand and the regressors are respectively denoted by Y_{it} and X_{it}, w_i is the constant term, $\alpha_i^{(m)}$ is the autoregressive coefficient; t is for the study period, i is for the cross-sections, and M epitomizes the lags. The DH causality test is made up of two statistics as seen in Equations (15) and (16);

$$W_{N,T}^{HNC} = N^{-1} \sum_{i=1}^{N} W_{i,t} \tag{15}$$

$$Z_{N,T}^{HNC} = \frac{\frac{1}{\sqrt{N}} \left[\sum_{i=1}^{N} W_{i,t} - \sum_{i=1}^{N} E(W_{i,t}) \right]}{\sqrt{\frac{1}{N} \sum_{i=1}^{N} Var(W_{i,t})}} \tag{16}$$

where $Z_{N,T}^{HNC}$ is the Z-bar statistic, $W_{N,T}^{HNC}$ is the W-statistic with its variance and expectations being $\mathrm{Var}(W_{i,t})$ and $\mathrm{E}(W_{i,t})$ correspondingly. This technique test's the hypothesis that one variable does not heterogeneously cause the other. If this assumption is rejected, it implies, there is causation amidst the series. The estimation procedure is depicted in Figure 1.

4 | DISCUSSIONS OF THE EMPIRICAL FINDINGS

The Table 2 contains the general descriptive statistics of the series. From the table EF had the highest mean value while FD had the lowest average. Also, EF ranged from 19.18 to 15.28, NR from 0.45 to 4.14, FD from −0.71 to 3.19, RE from 0.32 to 4.58, GI from 1.21 to 3.95, and URB from 2.59 to 4.06. Besides, NR, FD, RE and URB were negatively skewed, while EF and the skewness for GI is positively inclined. Moreover, apart from EF, FD, and URB that were platykurtic in shape in term of their distribution pattern, NR, RE, and GI's distributions were leptokurtic. Based on the skewness and kurtosis estimates, the hypothesis of the variables possessing a normally distributed distribution could not be validated. This is validated by the Jarque-Bera test outcomes exhibited in the table. Additionally, there aren't collinearity challenges in the series as affirmed by the VIF results. Finally, NR, FD, and URB were positively associated with EF, while RE and GI had a moderately positive association with EF.

4.1 | Evaluation of CD and heterogeneity

Economic connections amidst nations may give rise to issues of cross-sectional dependence (CD). According to Onifade (2022), failure to account for CD in residual terms may lead to biased estimates and conclusions. Therefore, as an initial step, we performed the CD tests displayed in Table 3 to confirm whether the residual terms were cross-sectionally correlated or not. In the results, the hypothesis of no cross-sectional reliance in the error terms was rejected. This implies, there was CD in the panel understudy. The finding also suggests that a shock on one country may spillover to the other nations due to the connections amidst them. Since the studied countries are different in terms of economic performances like financial development, natural resources, urbanization, renewable energy, and green innovations amongst others, there could be heterogeneity in the slope parameters. The negligence of this issue could also give rise to erroneous estimates and inferences (Pata et al., 2022). Therefore, moving further, the Peseran-Yamagata test depicted in Table 3 was conducted to deduce either homogeneity or heterogeneity in the corresponding slope parameter estimates and it was clearly deduced that the slope coefficients were heterogeneous in nature. After these findings, econometric methods that control for CD and heterogeneity amongst others, were subsequently selected for the latter analysis.

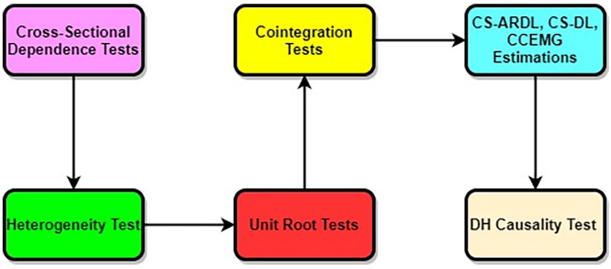

FIGURE 1 Analytical process.

TABLE 2 The Overall descriptive statistic(s).

Statistics	EF	NR	FD	RE	GI	URB
Mean	16.94	2.31	1.28	3.79	2.24	3.41
Median	16.81	2.57	1.40	4.43	2.58	3.55
Maximum	19.18	4.14	3.19	4.58	3.95	4.06
Minimum	15.28	0.45	−0.71	0.32	1.21	2.59
Std. Dev.	1.03	1.03	1.06	1.46	1.29	0.40
Skewness	0.61	−1.11	−0.04	−2.11	1.58	−0.48
Kurtosis	2.69	3.47	1.65	5.74	3.72	1.84
Jarque-Bera	13.53	56.11	10.79	25.82	12.74	24.89
Probability	0.00***	0.00***	0.03**	0.00***	0.02**	0.00***
The VIF	–	1.21	1.04	1.14	1.56	1.67
Tolerance	–	0.83	0.96	0.88	0.64	0.60
Outcome of Correlational Checks						
Variables	**EF**	**NR**	**FD**	**RE**	**GI**	**URB**
EF	1.000					
NR	0.64 (0.00)***	1.000				
FD	0.68 (0.00)***	0.22 (0.07)*	1.000			
RE	−0.47 (0.00)***	0.04 (0.85)	0.47 (0.02)**	1.000		
GI	−0.52 (0.00)***	0.17 (0.21)	0.61 (0.00)***	0.34 (0.05)*	1.000	
URB	0.61 (0.03)**	0.57 (0.00)***	0.01 (0.78)	0.48 (0.02)**	0.58 (0.00)***	1.000

Note: Values in the brackets denote probabilities, ***, ** indicate significance at the 1% and the 5% levels respectively.

TABLE 3 CD and heterogeneity tests results.

Panel A: CD test	Model 1	Model 2	Model 3
Breusch-Pagan LM	196.84 (0.00)***	124.17 (0.00)***	161.08 (0.00)***
Pesaran scaled LM	25.53 (0.00)***	10.82 (0.02)**	39.88 (0.00)***
Pesaran CD	14.36 (0.00)***	17.54 (0.00)***	21.56 (0.00)***
Panel B: Heterogeneity test			
$\tilde{\Delta}$-tilde stat.	13.78 (0.00)***	15.85 (0.00)***	18.49 (0.00)***
$\tilde{\Delta}_{adj}$-tilde stat.	15.75 (0.00)***	17.720 (0.00)***	20.26 (0.00)***

Note: Values in the brackets () denote probabilities, ***, ** indicate statistical relevance at the 1% and the 5% levels respectively.

4.2 | Unit root assessments and cointegration checks

In the presence of CD, the application of conventional unit root tests is invalid because those tests assume no CD in residual terms. Since our data structure had CD issues, there was the need to adopt tests that accounted for that in our unit root analysis. Therefore, the unit root tests were done, and the estimates outlined in Table 4 attest that the samples are characterized by unit root at levels but not after first difference. This implies, the samples reflect an I(1) pattern of integration. However, since these approaches do not cover structural breaks problems, the Bai and Carrion-i-Silvestre test displayed in Table 4 was also performed. Findings from the test further confirmed the series to be integrated of order one (1). The series possessing a first-differed integration order suggests they might be cointegrated in the long-run. Therefore, at the fourth phase, the Westerlund's test depicted in Table 5 was performed to examine the variables' attributes of cointegration. From the results, the hypothesis of no cointegration amidst the series was not approved. This means, the investigated series possessed a long-term cointegration association aligning that of Phale et al. (2021). Since the Westerlund's test do not control for structural breaks, we also run the Banerjee and Carrion-i-Silvestre test again and following the findings in Table 5, cointegration amidst the studied series was further confirmed. The affirmation of cointegration between the variables paved way for elasticities of the regressors to be estimated.

TABLE 4 Unit root tests results.

Variable(s)	With CIPS Levels	With CIPS 1st Difference	With CADF Levels	With CADF 1st Difference
Panel A: Unit root tests (CIPS & CADF)				
lnEF	−2.12	−5.65***	−2.42	−5.72***
lnNR	−1.45	−3.31**	−1.87	−4.68***
lnFD	−1.86	−4.21***	−1.93	−4.85***
lnRE	−2.05	−5.47***	−2.55	−5.78***
lnGI	−1.57	−3.42**	−1.64	−3.45***
lnURB	−2.11	−5.51***	−1.43	−3.28**
lnFD × lnNR	−1.76	−4.58***	−1.91	−4.81***
lnRE × lnNR	−2.28	−5.72***	−2.57	−5.82***
lnGI × lnNR	−2.32	−5.85***	−2.74	−5.97***
$lnNR^2$	−1.87	−4.67***	−1.98	−4.93***

Variable	Levels Z statistic	Levels Pm statistic	Levels P statistic	1st difference Z statistic	1st difference Pm statistic	1st difference P statistic
Panel B: Bai and Carrion-i-Silvestre (2009) unit root test						
lnEF	0.54	−0.87	39.41	−2.85***	4.92***	64.14***
lnNR	0.37	−0.64	34.62	−2.58***	3.94***	57.67***
lnFD	0.65	−0.93	43.74	−3.31***	5.81***	83.94***
lnRE	0.31	−0.59	31.25	−1.95**	2.31**	55.87**
lnGI	0.82	−0.97	44.85	−3.48***	5.87***	87.72***
lnURB	0.44	−0.77	37.67	−2.77***	4.65***	61.72***
lnFD × lnNR	0.38	−0.66	35.64	−2.65***	3.97***	58.61***
lnRE × lnNR	0.52	−0.84	38.74	−2.83***	4.75***	62.37***
lnGI × lnNR	0.34	−0.62	33.86	−2.55***	3.88***	56.28***
$lnNR^2$	0.67	−0.95	43.82	−3.37***	5.84***	85.41***

Note: For Bai and Carrion-I-Silvestre (2009) test, 1%, 5% and 10% critical values (CV) for Z and Pm statistics are 2.326, 1.645 and 1.282 respectively while the critical values (CV) for P at the 1%, 5% and 10% are 56.06, 48.60 and 44.90 correspondingly. Also, ***, **, * denote significance at the 1%, 5% and the 10% levels respectively.

TABLE 5 Cointegration tests results.

Statistic	Model 1	Model 2	Model 3
Panel A: Westerlund (2007) test			
Gt	−6.45 (0.00)***	−4.64 (0.00)***	−5.87 (0.00)***
Ga	−7.98 (0.00)***	−6.17 (0.00)***	−6.94 (0.00)***
Pt	−3.56 (0.02)***	−3.97 (0.00)***	−4.72 (0.00)***
Pa	−5.45 (0.00)***	−4.01 (0.00)***	−5.55 (0.00)***
Panel B: Banerjee and Carrion-i-Silvestre (2017) test			
Panel			
Chad	−4.67***	−5.44***	−4.56***
Guinea	−3.88***	−4.07***	−5.70***
Nigeria	−2.85**	−3.58***	−3.14***
Zambia	−5.31***	−2.64**	−5.50***
Congo, DR	−4.42***	−4.15***	−2.95***
Liberia	−3.64***	−5.54***	−3.41***
Sierra Leone	−2.71**	−3.72***	−4.48***
Congo	−6.68***	−4.65***	−2.64**
Mauritania	−5.05***	−3.41***	−3.95***
Niger	−4.42***	−2.84**	−4.12***
South Sudan	−5.11***	−3.45***	−4.45***

Note: For the Banerjee and Carrion-i-Silvestre (2017) test, critical values (CV) at 1% and 5% are −2.94 and −2.82 respectively. Also, ***, ** denote significance at the 1% and 5% levels respectively.

4.3 | Panel regression analysis

After detecting cointegration affiliation amidst sample observations, the elasticities of the explanatory components were then estimated with the CS-ARDL technique. Based on the results displayed in Table 6, natural resources played an essential role in increasing EF in the nations. Specifically, a percentage rise in natural resources respectively raised the nations' EF by 0.97%, 0.81%, and 0.75% in the three models correspondingly. This implies dependency on natural resources was damaging to the ecosystems of the countries. The discovery is justifiable because natural resources drive most consumption and production activities in the nations. As economies expand, the lifestyles of citizens' change. This may lead to the over usage of natural resources causing pollution on the environment. Also, the increase in manufacturing activities may lead to the consumption of raw materials sourced from natural resources. This may exert unnecessary pressure on the environment resulting in pollution. For instance, the demand for timber for production purposes requires the cutting down of trees (deforestation). This depletes forest lands causing ecological pollution. Similarly, the demand for steel, aluminum and other ferrous metals increases the rate of mining activities damaging the ecology in the process. For most economies to meet their demand for energy and other materials, they put much pressure on natural resources deteriorating the environment in the processes. According to Usman, Ozturk, et al. (2022), natural resource abundance is not enough to promote the green energy requirements of economies. This may increase the demand for dirty energies resulting in ecological pollution. In contrast, Ahmad, Jiang, et al. (2021) observed that natural resource abundance stimulates the utilization of clean energies like natural gas that help to minimize adversities on the ecosystem. The harmful effect of natural resources on ecological quality stands with some works like Miao et al., 2022, but conflicts others like Shittu et al. (2021) and Danish and Khan (2020). Also, FD had a significantly positive influence on EF, indicating the variable's harmful effect on

TABLE 6 CS-ARDL estimation results.

Dependent variable = Ecological footprint (EF)			
Regressors	Model 1	Model 2	Model 3
lnNR	0.97 (0.00)***	0.81 (0.00)***	0.75 (0.00)***
lnFD	0.65 (0.00)***	0.58 (0.00)***	0.61 (0.00)***
lnRE	−0.82 (0.00)***	−0.74 (0.00)***	−1.55 (0.00)***
lnGI	−1.84 (0.00)***	−0.94 (0.00)***	−0.72 (0.00)***
lnURB	0.77 (0.00)***	1.03 (0.00)***	0.85 (0.00)***
lnFD × lnNR	–	0.26 (0.02)**	–
lnRE × lnNR	–	−0.62 (0.00)***	–
lnGI × lnNR	–	−0.72 (0.00)***	–
$lnNR^2$	–	–	−0.59 (0.00)***
ECT	−0.64 (0.00)***	−0.73 (0.00)***	−0.68 (0.00)***
F-statistic	84.75 (0.00)***	96.42 (0.00)***	77.85 (0.00)***
R-squared	0.76	0.84	0.78
RMSE	0.05	0.02	0.03
CD-statistic	−5.12 (0.46)	−3.44 (0.31)	−4.12 (0.42)
Marginal effects			
Levels	**FD**	**RE**	**GI**
Maximum	1.66	−3.31	−3.92
Mean	1.18	−2.17	−2.60
Minimum	0.98	−1.69	−2.04

Note: Where Values in the brackets () denote probabilities, ***, ** indicate statistical relevance at the 1% and the 5% levels respectively.

ecological quality. More precisely, a percentage surge in FD triggered EF by 0.65%, 0.58%, and 0.61% in model 1 to 3 respectively. Development in the financial sector had a detrimental effect on the environment because it created a conducive environment for consumers to obtain loans or credits to purchase pollution-intensive items that end up degrading the ecology. Thus, by giving people's access to affordable facilities, FD enhanced their ability to buy luxurious products including automobiles, air-conditioning systems, and domestic washing engines among others, that consequently increased the rate of pollutant emissions due to intensified energy demand thereby polluting the ecosystem the more. Robust financial systems also provide funding to businesses to purchase machines, tools and equipment to expand their operations, resulting in excessive energy utilization, and subsequently, more pollutant emissions. This implies, FD may not be able to promote ecological quality, if businesses are unable to implement advanced, energy-efficient, and environmentally-friendly technologies. Using the wealth effect to support their claim, Sadorsky (2010) and Acheampong (2019) indicated that surging wealth dampens environmental quality as it promotes industrial activities and energy utilization. The harmful effect of FD on ecological quality disclosed this study supports the studies of Ehigiamusoe et al. (2022), Adebayo et al. (2022) and Ozturk et al. (2022), but contrasts that of Usman, Ozturk, et al. (2022).

Besides, a 1% change in RE mitigated EF by 0.82%, 0.74%, and 1.55% in the models respectively, thus, indicating that clean energy helps to improve the nations' ecological quality. Increasing dependence on clean energies did not only help to abate ecological pollution, but also helped to address energy security issues in the nations. The adverse connection amidst the series further implies, the countries were in the path of attaining the SDGs of the United

Nations (specifically, SDGs 13, 7 and 12) due to the inclusion of green energy technologies in their energy mix. These outcomes are upheld if we look at the study of Batool et al. (2022) and Huang et al. (2022) unlike the revelation from Alola and Onifade (2022). Moreover, GI entered with a negative sign, suggesting that the variable was friendly to ecological quality in the nation. Specifically, a 1% increase in GI improved environmental quality by 1.84%, 0.94%, and 0.72% in the three models correspondingly. A plausible justification of this finding is that making use of green technologies help to stimulate the production and consumption of this same form of energy. This minimizes the utilization of polluting energies thereby boosting ecological quality. Also, ecological innovations reduce energy costs and hastens the shift to a pollution free economy (Hodson et al., 2018). According to Abid et al. (2022), governments are able to promote green projects when they factor GI in their sustainable environment decisions. The integration of ecologically friendly technologies into industrial production, minimizes environmental adversities, eventually reducing pollution in the ecosystem. Qin et al. (2021) and Alola & Onifade (2022) have also advocated for the incorporation of GI in the core plans of economies to help abate the detrimental effects of extensive economic activities. The beneficial impacts of GI on environmental sustainability are in line with the studies of Tariq et al. (2022) for South Asia and Zeng et al. (2022) for China.

Furthermore, URB had a significantly positive influence on EF in all the three models. This implies, the variable destroys ecological sustainability. If all things are kept normal, a 1% rise in URB promoted EF by 0.77%, 1.03%, and 0.85% respectively. Urbanization escalated pollution in the nations because variations in urban population impact on economic activities and energy utilization. Urban areas are the hubs of economic activities, which requires significant energy consumption and motor traffic patterns that worsen the rate of pollution (Ehigiamusoe et al., 2022; Onifade et al., 2022). Jobs are mostly concentrated in urban and semi-urban areas because that is where industrial expansion is primarily centered. As the number of job opportunities rise, so is the expectation of good living conditions. This assumption draws people from rural to urban areas, resulting in excessive energy utilization and other polluting activities that end up degrading the environment. Also, urban population are likely to be segregated into skilled and unskilled labor, because employment opportunities are now decided by skill level. This separation may widen social and economic differences resulting in the creation of shadow cities and slum regions. People in these areas may lack clean sources of energy leading to the utilization of ones that are ecologically damaging (Adebayo et al., 2022). The detrimental effect of URB on EF validates a couple of works in the literature like Pata et al. (2022), Cetin et al. (2018) and Çetin and Ecevit (2015), but works like Yu, Soh, et al. (2022) do not corroborate this stance.

In model 2 (moderating effect model), the coefficient of the interactive term between FD and NR (FD $\times$ NR) was significantly positive. This implies, FD worsened the detrimental effect of natural resources on the environment. The discovery is justifiable because, FD stimulate activities that advance economic growth of which natural resource extraction is no exception. However, the execution of these activities involves the utilization of polluting energies that leads to ecological pollution. According to Amin et al. (2022) and Sheraz et al. (2021), nations promote activities that advance economic progress at the expense of the environment. Weak financial systems harm the natural environment because they provide funding for non-green businesses to support ecologically damaging activities. However, effective and robust financial systems support industries by funding innovations in technological and other R&D (research and development) ideas that are beneficial to the natural ecosystem. To determine the impact of a simultaneous change in FD and natural resources on EF, we computed the marginal effect of FD on EF at various levels of NR utilization. The marginal effects of FD at the maximum, mean and minimum levels of NR consumption were 1.66, 1.18, and 0.98 respectively. Thus, the increase in FD and resource utilization further creates more ecological quality damages by promoting pollution across the states. Ganda (2022) reported that the interaction between natural resources and FD can better help the ecosystem. This conflicts the outcome of our exploration. Also, the parameter of the interactive term between RE and NR (RE $\times$ NR) was significantly negative. This means, RE reduced the damaging impacts of NR on the ecosystem. Thus, the inclusion of clean energy technologies in natural resource activities helped to advance ecological quality in the nations. To discover the contemporaneous change in RE and natural resources on EF, we computed the marginal effect of RE on EF at various levels of NR consumption. The marginal effects of RE at the maximum, mean and minimum levels of NR utilization were -3.31, -2.17, and -1.69

correspondingly. This implies, the rise in RE and natural resource utilization promoted ecological quality by minimizing the overall pollution trends among the states. Nevertheless, our discovery varies from observation from China and Columbia as seen in He et al. (2022) and Awosusi et al. (2022) respectively.

Similarly, the interaction between GI and NR (GI × NR) was significantly negative in effect thereby indicating that GI mitigated the negative environmental consequences associated with natural resource utilization. According to Zuo et al. (2022), innovative technologies increase natural resource use and improve ecological sustainability. To capture the contemporaneous change in GI and natural resources on EF, we calculated the marginal effect of GI on EF at various levels of NR consumption. The marginal effects of GI at the maximum, mean and minimum levels of NR utilization were −3.92, −2.60, and −2.04 respectively. This means, the rise in GI and natural resource consumption improved the ecosystem of the nations by reducing the rate of pollution. According to Jahanger et al. (2022), innovative technologies negatively moderated the resources-pollution connection in 73 developing economies.

In model 3 (nonlinear model), NR entered with a positive sign while the square of NR was significantly negative. Since one % rise in NR results in around 0.75% rise in EF while a percentage increase in the square of NR leads to 0.59% reduction in EF, it implies, NR had an inverted U-shaped association with ecological pollution. Thus, at the initial stage, natural resource consumption degraded ecological quality, but after a certain threshold level, further increases in natural resource utilization improved the ecosystem of the nations. This is so because most natural resource activities are driven by polluting energies at the early stage. But with the inclusion of green innovations and renewable energy resources, natural resource utilization improved ecological quality at the later stage. The computed turning point was about 0.64. Gyamfi et al.'s (2022) investigation on the Mediterranean region supports this finding, contrary to Chen, Wang, et al. (2022) assessment of the Chinese case. Besides, the coefficient of the error correction terms (ECTs) signify that the deviations from long-run equilibrium for last period respectively influenced the short-run dynamics by 64%, 73%, and 68%. On the diagnostics, the R-squared (R^2) values signify that the predictors accounted for 84.75%, 96.42%, and 77.85% of the variabilities in the response variable while the significant F-values demonstrate that the observed R^2 values are reliable and not spurious. Thus, entire evaluated connections in the series were statistically reliable. Finally, the root mean square error (RMSE) values indicate that the model accurately predicted the criterion variable, while the insignificant CD test statistics means, the issue of CD initially detected had been resolved after using the CS-ARDL technique.

4.4 | Sensitivity analysis

We conducted two different sensitivity tests to check the robustness of the study's outcomes. First, we used different proxies to measure the response and the explanatory variables to determine whether the choice of model will alter the CS-ARDL findings. Specifically, we proxied the criterion variable by CO_2 emissions, NR by forest rents (% of GDP), FD by domestic credit to the private sector (% of GDP), RE by hydro power electricity (% of total), GI by research and development expenditure related to environmental protection (% of GDP) and URB by urban population growth (annual %). Based on the results displayed in Table 7, NR, FD and URB had significantly positive signs in all the three models inferring that, natural resource utilization, financial sector growth, and urban population damaged ecological quality in the nations by spurring EF. However, RE and GI entered with negative and significant coefficients signposting that the green technologies utilization helped in advancing ecological sustainability in the economies. Besides, GI and RE negatively moderated the resources-environmental pollution channel as depicted in model 2. This indicates that RE and GI mitigated the harmful effects of NR on ecological quality. Finally, in model 3, there was a nonlinear affiliation between natural resources and EF. Specifically, the coefficient of NR was positive while that of NR square was negative. This infers NR's inverted U-shaped link with the EF. Thus, at the early stages, ecological deterioration increased when natural resource consumption increased, but at the later stage, the rise in natural resource utilization helped to advance ecological sustainability.

TABLE 7 CS-ARDL estimation using alternative proxies.

Dependent variable = CO_2 emissions			
Regressors	**Model 1**	**Model 2**	**Model 3**
lnNR	0.69 (0.00)***	0.53 (0.00)***	0.42 (0.00)***
lnFD	0.45 (0.00)***	0.33 (0.04)**	0.58 (0.00)***
lnRE	−0.58 (0.00)***	−0.65 (0.00)***	−0.35 (0.03)**
lnGI	−0.94 (0.00)***	−0.54 (0.00)***	−0.44 (0.00)***
lnURB	0.37 (0.00)**	0.42 (0.00)***	0.68 (0.00)***
lnFD × lnNR	–	0.18 (0.06)*	–
lnRE × lnNR	–	−0.47 (0.00)***	–
lnGI × lnNR	–	−0.51 (0.00)***	–
$lnNR^2$	–	–	−0.41 (0.00)***
ECT	−0.56 (0.00)***	−0.68 (0.00)***	−0.57 (0.00)***
F-statistic	72.61 (0.00)***	84.05 (0.00)***	75.47 (0.00)***
R-squared	0.72	0.81	0.75
RMSE	0.06	0.04	0.05
CD-statistic	−7.88 (0.54)	−4.74 (0.37)	−5.81 (0.48)
Marginal effects			
Levels	**FD**	**RE**	**GI**
Maximum	1.08	−2.60	−2.65
Mean	0.74	−1.74	−1.72
Minimum	0.61	−1.37	−1.32

Note: Where Values in the brackets () denote probabilities, ***, ** indicate statistical relevance at the 1% and the 5% levels respectively.

Secondly, we employed the CS-DL and the CCEMG estimators to estimate the EF model to determine whether the results will be the same across methodologies. From the estimates shown in Tables 8 and 9, the coefficients of NR, FD and URB were positive and statistically significant across the models. This indicates that, the variables escalated pollution in the ecosystem. However, the parameters of RE and GI were substantially negative, inferring that they improved ecological sustainability in the nations. In model 2, the interaction between RE and EF, and between GI and EF were significantly negative. This suggests that, RE and GI helped to minimize the worsening influence of natural resources on ecological quality. Finally, NR and EF exhibited an inverted U-shaped relationship based on the estimates in model 3. This signposts that, natural resources had a nonlinear association with ecological sustainability in the nations. Summarily, the estimates varied in terms of weight of the coefficients, but similar in the nature of their impacts. The differences in parameters might be as a result of the new variables and methodologies adopted. However, since the signs of the coefficients were consistent throughout, we conclude that the overall assessments are robust for policy formulations considerations.

4.5 | Causality analysis

To further examine the association between the variables in a bivariate framework, we employed the DH causality test which accounts for CD and heterogeneity. Based on the outcomes portrayed in Table 10, unidirectional

TABLE 8 CS-DL estimation results.

Dependent variable = Ecological footprint (EF)			
Regressors	Model 1	Model 2	Model 3
lnNR	0.74 (0.00)***	0.65 (0.00)***	0.58 (0.00)***
lnFD	0.57 (0.00)***	0.44 (0.00)***	0.56 (0.00)***
lnRE	−0.82 (0.00)***	−0.72 (0.00)***	−0.95 (0.00)***
lnGI	−0.96 (0.00)***	−0.85 (0.00)***	−0.67 (0.00)***
lnURB	0.65 (0.00)***	0.93 (0.00)***	0.71 (0.00)***
lnFD × lnNR	–	0.14 (0.04)**	–
lnRE × lnNR	–	−0.57 (0.00)***	–
lnGI × lnNR	–	−0.61 (0.00)***	–
$lnNR^2$	–	–	−0.42 (0.00)***
F-statistic	81.06 (0.00)***	85.42 (0.00)***	73.17 (0.00)***
R-squared	0.71	0.81	0.74
RMSE	0.06	0.03	0.04
CD-statistic	−6.45 (0.51)	−4.18 (0.38)	−5.46 (0.47)

Note: Where Values in the brackets () denote probabilities, ***, ** indicate statistical relevance at the 1% and the 5% levels respectively.

TABLE 9 CCEMG estimation results.

Dependent variable = Ecological footprint (EF)			
Regressors	Model 1	Model 2	Model 3
lnNR	0.52 (0.00)***	0.41 (0.00)***	0.34 (0.00)***
lnFD	0.37 (0.00)***	0.28 (0.00)***	0.23 (0.00)***
lnRE	−0.45 (0.00)***	−0.38 (0.00)***	−0.57 (0.00)***
lnGI	−0.48 (0.00)***	−0.27 (0.00)***	−0.31 (0.00)***
lnURB	0.25 (0.00)***	0.39 (0.00)***	0.27 (0.00)***
lnFD × lnNR	–	0.11 (0.04)**	–
lnRE × lnNR	–	−0.34 (0.00)***	–
lnGI × lnNR	–	−0.28 (0.00)***	–
$lnNR^2$	–	–	−0.36 (0.00)***
Wald-stat.	73.06 (0.00)***	81.18 (0.00)***	78.77 (0.00)***
RMSE	0.05	0.03	0.04
CD-statistic	−4.02 (0.37)	−5.44 (0.43)	−4.85 (0.39)

Note: Where Values in the brackets () denote probabilities, ***, ** indicate statistical relevance at the 1% and the 5% levels respectively.

causalities from NR and FD to EF were observed. This suggests that changes in NR and FD caused changes in EF. Studies by Aladejare (2022) for the five richest African economies and Yu, Chukwuma Onwe, et al. (2022) for Nigeria support the study's finding correspondingly. Also, bidirectional causalities between RE and EF, and between URB and EF were observed. This implies, the variables reinforced each other. Thus, policies on RE and URB had a material influence on environmental degradation, while ecological policies also had significant impacts on RE and

TABLE 10 Dumitrescu hurlin panel causality tests results.

Null hypothesis	W-stat.	Zbar-stat.	Prob.	Causality flow
lnNR⇏lnEF	9.48	6.71	0.00***	Unidirectional
lnEF⇏lnNR	1.56	0.45	0.67	
lnFD⇏lnEF	7.75	3.65	0.00***	Unidirectional
lnEF⇏lnFD	2.23	−0.68	0.78	
lnRE⇏lnEF	10.44	7.16	0.00***	Bidirectional
lnEF⇏lnRE	6.27	3.51	0.00***	
lnGI⇏lnEF	8.46	6.54	0.00***	Unidirectional
lnEF⇏lnGI	1.81	−0.15	0.81	
lnURB⇏lnEF	11.25	8.41	0.00***	Bidirectional
lnEF⇏lnURB	4.14	2.18	0.03**	
lnFD × lnNR⇏lnEF	8.27	5.31	0.00***	Unidirectional
lnEF⇏lnFD × lnNR	2.44	−0.58	0.72	
lnRE × lnNR⇏lnEF	6.85	5.41	0.00***	Unidirectional
lnEF⇏lnRE × lnNR	1.54	−0.27	0.84	
lnGI × lnNR⇏lnEF	7.65	4.61	0.00***	Unidirectional
lnEF⇏lnGI × lnNR	1.12	−0.74	0.92	
$lnNR^2$⇏lnEF	2.94	−0.61	0.78	No causality
lnEF⇏$lnNR^2$	0.21	−0.38	0.95	

Note: Where the explained factor is lnEF; ***, ** indicate statistical relevance at the 1% and the 5% levels respectively.

URB in the nations. Mentel et al.'s (2022) exploration of twenty-six (26) different states holds similar stance on these outcomes. Additionally, EF was linked to GI on causality ground thus signifying that GI was responsible for the variations in ecological quality. Moreover, a one-way causality from FD × NR, RE × NR, and GI × NR to EF was disclosed. This indicates that changes in the interactive terms caused changes in environmental pollution. Finally, there was no causality between the square of NR and EF. This means, the variables were independent of each other.

5 | FINAL CONCLUSIONS AND POLICY DIRECTIONS

Green innovations (GI), Natural resource (NR), financial development (FD), and renewable energy (RE), are key factors that explain the environmental quality (EQ) of economies. For that purpose, we examined the nexus between NR and EQ in resource-rich SSA countries, while accounting for the roles of FD, RE, and GI over the period 1990 to 2018. With the probable occurrence of heterogeneity, CD, endogeneity and structural breaks, the study engaged robust econometric techniques in its empirical assessments. Heterogeneity and cross-sectional correlation pitfalls were deduced in the sample observations and the observations possessed an I(1) integration order and cointegrated in the long-run. The CS-ARDL technique was engaged to estimate the elasticities of the regressors and from the findings, natural resources damaged ecological quality in the countries. Also, FD worsened environmental sustainability, but RE and GI promoted the nations' ecological quality. Moreover, urbanization (URB) was not friendly to EQ in these resource-rich states. Besides, the interaction between GI & NR, and the one between RE & NR improved EQ by mitigating EF, but the interaction between FD and NR harmed EQ by spurring EF. Finally, NR had a nonlinear association with ecological sustainability in the nations. Sensitivity analysis via an alternative model and the CS-DL and CCEMG approaches validated the above findings. On the causal connections amidst the variables, unidirectional causalities from NR, FD and GI to EF was observed. But RE and URB were bidirectionally related to EF in the economies.

Relying on the study's discoveries, the following policy implications are deduced. First, NR positively explained EF. This implies, the variable was not friendly to EQ in these resource-rich states. As such, strict regulations have to be formulated to control natural resource activities in the nations. This point aligns the proposition of Miao et al. (2022) that, the need for green innovation involves the implementation and improvement of rules governing mineral, soil, and water pollution. According to the authors, this approach will not only curb pollution, but will guarantee the long-term viability of the ecosystem. Moreover, forests and other natural resources should be protected by enforcing heavy penalties against offenders. To boost biocapacity, promote resource regeneration, and lessen ecological effects, other minimal-polluting resources like hydro energy and natural gas should be utilized in the economies. Besides, firms and individuals whose activities promote sustainable environment should be encouraged in the natural resource sector, but those whose actions pollute the ecology, should be completely phased out. Also, RE and GI negatively explained EF. This implies, the variables advanced EQ in the nations. Therefore, significant investments in RE and green technological innovations could help to improve the ecology of the nations. It is also crucial to encourage the utilization of RE and green technologies at the commercial and household levels by providing subsidies and other incentives to their sources. Moreover, most individuals are unaware about the benefits associated with the adoption of RE and GI. Therefore, organizing programmes at the community level to educate the populace on the advantages of embracing RE and GI will be worthwhile.

Besides, developments at the financial sector positively predicted EF. This suggests that FD was detrimental to EQ in the nations. Therefore, the financial sector should desist from offering support to businesses and individuals whose activities are not friendly to the ecology. Also, authorities should support the operations of financial institutions that promote green energy generation, innovative technologies, energy efficiency, and other activities that enhance ecological quality. Formulation of stringent regulations to monitor activities of the financial sector will also help to enhance EQ in the nations. Additionally, the interaction between FD and NR worsened the nations' EQ. Hence, improving the policies on FD and natural resources could help to promote EQ by mitigating the rate of pollution. Also, the interaction between GI and NR, and between RE and NR mitigated pollution in the ecosystem. The governments should base on these discoveries to develop appropriate policies to promote the adoption of green energy and innovative technologies to help advance the nations' ecological quality. Furthermore, NR had a nonlinear affiliation with EQ. This implies, initially NR escalated pollution in the economies, but with the adoption of RE and green technologies, NR improved EQ at the highest level. Therefore, the governments should advocate for more investments in RE and innovative technologies to help promote the pollution mitigation agenda of the nations.

Finally, urbanization was a significantly positive determinant of EF. This means urbanization escalated pollution in the nations. Therefore, tighter energy conservation measures need to be implemented, especially in urban areas where majority of energy-intensive activities take place. Moreover, it is crucial to advance rural development by establishing robust, independent local regulatory agencies with effective governance frameworks, because when economic activities are governed by a single regulatory body, it frequently results in ecological pollution and local exclusion. Also, no matter where economic activities take place, be it rural or urban, ecological restrictions must be in place. Environmental laws intended to make the formal economy more environmentally friendly frequently encourage pollution in rural areas by stimulating the growth of the informal economy. To therefore mitigate pollution in both rural and urban areas, policy interventions need to be fair, long-lasting and inclusive. Additionally, awareness creation on economic practices that pollute both urban and rural areas can help to boost the green environment agenda of the nations. The current study is not different from most empirical investigations in that it has inherent limitations. Data accessibility, which constrained the study's sample size, was a key drawback. In future when data is readily available, we recommend that additional research should be conducted on a larger sample and over a longer period so that more useful conclusions could be drawn. Because the study used a panel technique, the nations were pooled together. Future studies could examine the nexus amidst the series at the country-level for more fruitful deductions to be made.

AUTHOR CONTRIBUTIONS

All authors have jointly contributed to the manuscript.

CONFLICT OF INTEREST STATEMENT

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

The data for this present study are sourced from the Global Footprint Network-GFN, (http://www.footprintnetwork.org/), the Organization for Economic Co-operation and Development—OECD, (https://www.oecd.org/), the International Monetary Fund-IMF, (https://www.imf.org/en/Data), and the database of the World Development Indicators (https://data.worldbank.org).

ORCID

Stephen Taiwo Onifade https://orcid.org/0000-0003-1497-7835

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