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Testing the income-finance-trade-environment nexus based on the ecological load capacity factor: Frequency-domain causality evidence from Nigeria

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ABSTRACT

To ensure sustainable development, it is crucial that the consumption of ecological resources remains within their productive capacity. This study aims to support policy formulation by examining the nexus between income, financial development, trade openness, and the ecological load capacity factor in Nigeria from 1970 to 2021. The results of the Bayer-Hanck and autoregressive distributed lag (ARDL) bounds cointegration tests indicate a long-run equilibrium relationship among the variables. Parameter estimations were conducted using the dynamic ordinary least squares (DOLS) and ARDL model estimators. Both the long-run and short-run results indicate that the ecological load capacity factor has a U-shaped curve with income, thereby validating the load capacity curve hypothesis in Nigeria. The estimated threshold turning points of the curve fall within Nigeria's current range of per capita GDP, which indicates that further increases in income will enhance ecological sustainability. Additionally, the ecological load capacity factor exhibits a negative relationship with financial development and trade openness in the long run. The Breitung-Candelon spectral Granger causality tests reveal that, in the long run, unidirectional causality runs from income and trade openness to the ecological load capacity factor, and bidirectional causality exists in the case of financial development. Furthermore, the tests indicate that none of the causal paths are significant for wavelength periods below four years. Therefore, the study recommends implementing medium-to long-term policy strategies to strengthen the ecological resilience base of the economy.

1. Introduction

In recent decades, the relationship between drivers of economic activity and indicators of environmental sustainability has garnered significant attention from researchers and policymakers. The goal of economic progress is to improve living standards, reduce poverty, and achieve higher per capita income, but it can also impose substantial strain on ecological resources and ecosystems. These ecological productive resources (EPRs) include cropland, grazing land, fishing grounds, built-up land, forest area, and nature's carbon-absorbing capacity [1]. These resources are essential for meeting basic human needs, such as food production, livestock and fish

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resources, clothing, timber, and urban infrastructure. Remarkably, the availability of these EPRs is limited [2,3]. Therefore, imprudent use of these resources leads to depletion, carbon emissions, deforestation, overgrazing, fisheries collapse, food insecurity, species extinction, and an overall increase in human pressure on ecosystems [4]. Consequently, striking a balance between economic growth and environmental sustainability is crucial. The challenge lies in understanding the key factors that either exacerbate or mitigate the environmental impacts of economic activity. Within the economic literature, the role of financial systems and international trade is well recognized [5–7]. Hence, it is essential to grasp the interconnections among per capita income, financial development, trade openness, and ecological degradation to formulate effective policies that reconcile economic progress with environmental sustainability.

According to Grossman and Krueger [8,9], an increase in income can have three distinct effects on environmental degradation: scale, composition, and technique effects. While the scale effect suggests that increased economic activity can lead to environmental degradation, the composition and technique effects suggest that it can also drive changes in the production patterns and technology that may mitigate environmental impacts [10]. However, specific outcomes depend on various factors, including economic liberalization measures such as financial development and trade openness, which shape economic activity [11]. When countries open up their economies, engage in international trade, and develop their financial systems, there is usually an increase in economic activity, resulting in greater production and consumption [11,12]. This increased scale of economic activity can put additional strain on the environment, leading to increased pollution, resource depletion, and other forms of environmental degradation [11,13]. The composition effect focuses on the changes in the structure of an economy that occur as a result of liberalization [11]. When trade barriers and credit constraints are reduced, industries may undergo shifts in their production patterns. Some sectors may expand while others may contract. The composition effect suggests that certain industries, particularly those that are less resource-intensive or polluting, may experience growth due to liberalization [14]. Consequently, this can lead to a change in the overall environmental impact of the economy [15]. The technique effect relates to changes in production processes and technologies that occur due to liberalization. As countries engage in international trade and develop their financial systems, they face increased competition. As a result, they may strive to improve their production efficiency and adopt cleaner technologies [11,12]. The technique effect suggests that economic liberalization can drive technological innovation and the adoption of cleaner and more environmentally friendly production methods, thereby reducing the environmental impact of economic activities [11–13].

The relevance of the income-finance-trade-environment nexus in shaping environmental policies cannot be overlooked, as demonstrated by the findings of Grossman and Krueger [8]. It highlights the importance of comprehending the relationship between income and environmental impact indicators and the specific contributions of financial development and trade openness. Not surprisingly, there has been growing interest in this topic in the literature [12,13,16–18]. However, there is no conclusive consensus on the precise shape of the environmental impact curve with respect to income in these and other related studies [19]. Various results have been reported, with some studies indicating a monotonically increasing relationship [20], a monotonically decreasing relationship [21], an inverted U-shaped curve [18,22,23], or a U-shaped curve [10,24,25]. These discrepancies can be attributed to variations in measures of environmental quality and contextual factors among the countries studied [10,26]. Similarly, empirical studies on the impact of financial development and trade openness on environmental degradation have produced conflicting findings. Some studies, for instance, Dada et al. [12], suggest that financial development and trade openness contribute to the intensification of environmental degradation. Conversely, studies by Dada et al. [17] and Acar et al. [18] propose that financial development and trade openness actually help mitigate environmental degradation. Therefore, it is evident that there is no definitive consensus regarding the effects of financial development and trade openness on environmental quality indicators across different countries. Further empirical research is necessary to shed more light on the complex income-finance-trade-environment nexus and reach more definitive conclusions.

Apart from the conflicting evidence on the income-finance-trade-environment nexus in the literature, most existing studies have relied solely on the ecological footprint metric to assess ecological sustainability [12],[16],[17],[22]. However, this measure has limitations and falls short in capturing ecological sustainability comprehensively, as it only focuses on demands placed on ecological productive resources while neglecting the supply side of ecological sustainability [26–29]. To further enhance ecological sustainability accounting, it is beneficial to incorporate the concepts of both demand and supply. Specifically, the ecological footprint can be utilized to track demands on ecologically productive resources, while biocapacity can be used to monitor the supply of these resources [1]. In this context, the load capacity on ecological productive resources can be determined by dividing the biocapacity by the ecological footprint [27–29]. The load capacity represents an ecological threshold value equal to or greater than 1 if the biocapacity is sufficient to meet the demands for ecologically productive resources. According to Siche et al. [30] and Pata and Samour [27], a load capacity factor of less than 1 indicates that the biocapacity is inadequate to meet the demands for ecological productive resources. This implies that current consumption patterns are unsustainable and pose limitations on conserving ecologically productive resources for future needs. Therefore, the load capacity can be considered a more comprehensive measure of ecological sustainability [27–29].

Taking into account the literature gap, this study aims to examine the relationship between per capita income, financial development, trade openness, and the ecological load capacity factor (ELCF) in Nigeria. The specific objectives are as follows: (i) to identify the shape of the curve between per capita income and ELCF in Nigeria; (ii) to examine the impact of bank-based financial development and trade openness on ELCF in Nigeria; and (iii) to test the direction of causality between the variables across different time periods to define mitigation policy pathways. The literature on the drivers of the ecological load capacity factor is still in its emerging stage. Despite the growing interest in this topic [26–29,31–33], the Nigerian economy has received limited empirical attention. To the best of our knowledge, no study in the literature has explored the relationship between per capita income, financial development, trade openness, and the ecological load capacity factor in Nigeria. Therefore, Nigeria presents a unique opportunity to extend the literature on this topic.

Over the past 30 years, the Nigerian economy has witnessed remarkable economic growth, with per capita gross domestic product (GDP) (in constant 2015 US$) rising from 1451.37 in 1985–2429.58 in 2021 [34]. However, these higher figures may come with a caveat, as depicted in Fig. 1: the ecological load capacity of the economy, which serves as the foundation of this success, is now significantly below the threshold path and has steadily declined in recent years. This suggests that the current consumption patterns are unsustainable, and the biocapacity is currently insufficient to meet the demands on EPRs. Sustainability concerns are further exacerbated by the substantial contribution of mineral and fossil fuel extraction and processing to GDP growth [35]. In theory, the increasing per capita GDP will result in higher demands on EPRs unless accompanied by significant investments in environmentally friendly technologies and improvements in technical efficiency [36]. Therefore, it is not surprising that financial development and trade openness have become areas of policy interest. This is particularly relevant considering the crucial role that financial systems and global trade play in promoting investment and facilitating the diffusion of green technologies.

This study contributes significantly to the literature in several ways. First, it employs the load capacity metric to model ecological sustainability in Nigeria. This metric has a key advantage, as it integrates both the supply and demand dimensions of ecological accounting, enabling a comprehensive assessment of the ecological balance. By considering both supply and demand aspects, it helps to avoid conflicting policy directions and ensures a more coherent and efficient approach towards achieving ecological sustainability. Second, unlike most previous studies that use linear models to analyse the relationship between income and the ecological load capacity factor, this study employs a nonlinear model to capture the shape of the curve. This approach provides an empirical test of the load capacity curve hypothesis proposed by Pata and Kartal [26]. Third, this study utilizes the novel spectral Granger causality test proposed by Breitung and Candelon [37] to examine the quadripartite relationship between per capita income, financial development, trade openness, and the ecological load capacity factor in Nigeria. This technique allows for the analysis of changes in the load capacity factor across different frequency segments, enabling the identification of significant frequencies where the impact variables explain variations in the load capacity factor. This step assists in determining short-term, medium-term, and long-term ecological sustainability pathways. Fourth, this study contributes to the literature by utilizing the most up-to-date dataset. While previous studies have primarily relied on the depth of credit supply to economic sectors as the sole indicator of financial development, this study recognizes the multidimensional nature of financial development. It constructs an index by incorporating indicators that assess the extent of credit supply, deposit mobilization, size of bank assets, and liquid liabilities. Overall, this study aims to provide valuable insights into the relationship between economic factors and the ecological load capacity factor by utilizing advanced econometric techniques. By employing the load capacity metric, employing a nonlinear model and utilizing the spectral Granger causality test, this study contributes to a deeper understanding of the complex dynamics between economic factors and ecological sustainability in Nigeria.

The subsequent sections of this study will address the following areas. First, Section 2 critically examines the literature concerning the environmental implications of income, bank credit, and trade openness. Subsequently, Section 3 delves into the empirical model, data, and necessary econometric steps. Following this, Section 4 presents and critically discusses the outcomes derived from the regression and Granger causality analyses. Finally, in the concluding portion (Section 5), the study provides a summary, draws a conclusion based on the results, and offers pertinent policy recommendations.

2. Theoretical foundation and literature review

2.1. Theoretical underpinnings

The relationship between income and environmental degradation is often studied within the framework of the environmental Kuznets curve (EKC) hypothesis [19]. According to the EKC hypothesis, as income increases, there is initially a rise in environmental degradation until a certain point, after which environmental quality starts to improve [8]. This suggests that income may have an

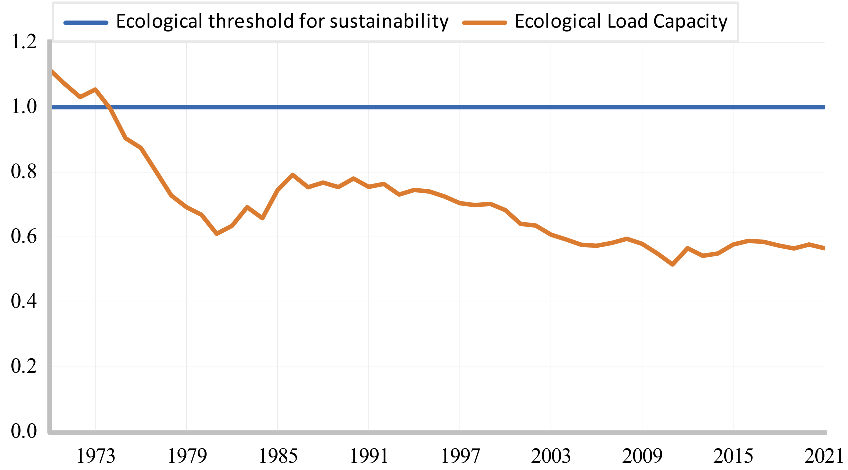


Fig. 1. Ecological load capacity factor, Nigerian economy 1970–2021.

inverted U-shaped relationship with indicators of environmental degradation [9]. One explanation for this phenomenon is that during the early stages of economic growth, the scale effect of income dominates, leading to consumption and production patterns that have adverse ecological impacts [19]. However, as countries progress and income levels rise, there is a potential shift towards more environmentally friendly sectors, production techniques, and sustainable practices [19]. This transition may involve adopting renewable energy sources, improving waste management systems, and implementing conservation efforts, ultimately resulting in a decrease in the ecological footprint [19]. While the EKC hypothesis is typically examined using metrics that reflect environmental degradation, such as carbon dioxide (CO_2) emissions and ecological footprint, it requires adjustments in the theoretical formulation to explain indicators that reflect an improvement in environmental quality, such as the ecological load capacity factor. Recently, Pata and Kartal [26] proposed the ecological load capacity curve (ELCC), which suggests that income may follow a U-shaped relationship with the ecological load capacity factor. In contrast to the EKC assumptions, the ELCC hypothesis suggests that the ecological load capacity factor decreases as income increases but acknowledges the possibility of a turning point where the ELCF begins to increase with further income growth [26].

The recent literature has expanded the theoretical perspectives on drivers of environmental degradation to include the role of economic liberalization measures such as financial development and trade openness (11, 12, 13, 17, 22). The development of financial systems plays a crucial role in mobilizing and allocating financial resources within an economy [7]. It influences investment decisions, access to credit, and the overall economic structure [7]. These economic conditions can have scale, composition, and technique effects on the environmental impact of economic activity [13]. The availability of credit creates alternative financing channels for households and firms, enabling them to increase their income, leading to higher levels of consumption and production, thus increasing the ecological footprint [12,17]. However, financial development can also have negative impacts if it prioritizes profitability over environmental considerations, resulting in the financing of polluting industries or speculative investments that disregard sustainability concerns [13,17]. Nevertheless, as the financial sector expands and evolves, it has the potential to promote sustainable finance initiatives, such as green bonds and loans, which direct funding towards environmentally friendly projects, renewable energy, and energy-efficient technologies [13]. Additionally, incorporating environmental risk assessment into lending practices can help prevent the financing of industries that contribute to environmental degradation [12,13].

The expansion of international trade activities brings potential environmental benefits, including technology transfer and the diffusion of environmental regulations [11,15]. Trade openness can facilitate the adoption of cleaner technologies and practices through the importation of environmentally friendly goods and exposure to more sustainable production methods [11]. These structural and technological effects can contribute to reducing the ecological footprint [15]. However, trade openness can also have negative ecological consequences. This may lead to the relocation of polluting industries from developed to developing countries, where environmental regulations are often less stringent [11]. This phenomenon, known as the "pollution haven hypothesis," can result in increased ecological degradation if an economy becomes a destination for such industries [15]. Moreover, the extraction of natural resources driven by trade can lead to deforestation, habitat destruction, and other forms of environmental degradation if not managed sustainably [38].

2.2. Related empirical literature

The empirical literature has extensively investigated the relationship between income and environmental impact indicators, shedding light on the shape of the curve [10,18,20–25,39,40]. Baek [21] examined a panel of 12 major nuclear generating countries from 1980 to 2009 and observed a monotonically decreasing curve in the relationship between income and CO_2 emissions. Wang and Ye [20] analysed city-level CO_2 emissions using spatial econometric modelling and identified a monotonically increasing curve in China. Dogan et al. [22] employed the autoregressive distributed lag (ARDL) model to investigate the drivers of ecological footprint from 1971 to 2013, finding an inverted U-shaped curve in Mexico, Indonesia, Nigeria, and Turkey. Acar et al. [18] and Ahmed et al. [39] applied ARDL modelling to examine the drivers of the ecological footprint in Azerbaijan (1996–2017) and Pakistan (1984–2017), respectively, both identifying an inverted U-shaped curve. Voumik et al. [25] utilized panel techniques to model CO_2 emissions in the European Union from 1990 to 2021, while Ouedraogo et al. [40] investigated CO_2 emissions in a panel of 33 African countries using data from 1990 to 2015. Both studies confirmed the presence of a U-shaped curve in the relationship between income and CO_2 emissions in their respective regions. Ansari et al. [10] conducted a more detailed analysis and identified a U-shaped curve in the relationship between income and CO_2 emissions, as well as an inverted U-shaped curve in the relationship between income and ecological footprint in the ASEAN countries using data from 1991 to 2016.

Until recently, the empirical literature has primarily focused on modelling CO_2 emissions and ecological footprints. However, Pata and Kartal [26] have recently broadened the scope of analysis by using an alternative measure of sustainability defined as the ecological load capacity factor. The study examined the relationship between income and various measures of environmental impact in South Korea using a dataset spanning 1977 to 2018 and employing the ARDL model. The results unveiled a U-shaped curve in the relationship between income and the ecological load capacity factor. In contrast, when measuring environmental impact through CO_2 emissions and ecological footprint, the study identified an inverted U-shaped curve with income. Algebraically, the U-shaped curve of the ELCC hypothesis defines the inverse of the inverted U-shaped curve of the EKC hypothesis, with the key difference lying in the opposite definition of the impact indicator [26]. Apart from Pata and Kartal [26], other studies that modelled the ecological load capacity factor relied on a linear model specification. Using data from 1977 to 2017 and employing the Fourier ARDL technique, Pata and Samour [27] showed that an increase in income reduces the ecological load capacity factor in France, with a stronger effect in the long run. Another study by Pata and Isik [41], based on data from 1981 to 2017 and using the dynamic ARDL technique, revealed that an increase in income reduces the ecological load capacity base of the Chinese economy. Similar evidence was reported in high-resource-consuming economies by Ni et al. [42], who utilized data from 1996 to 2019 and the cross-sectional augmented ARDL technique. Pata and Balsalobre-Lorente [43] modelled the impact in Turkey from 1965 to 2017 using the dynamic ARDL technique, while Akadiri et al. [28] employed data from 1970 to 2017, the ARDL model, and the frequency domain causality technique to study the case of India. Interestingly, both studies showed a significant negative relationship between income and the ecological load capacity base of the economies. Akadiri et al. [28] provided further insights, showing that income Granger causes the ecological load capacity base of the Indian economy only in the long run.

Another aspect of the related empirical literature comprises studies that have incorporated the role of economic liberalization measures, such as financial development and trade openness, into the environmental impact equation [11,16,17,22,29,31–33,44,45]. Dogan et al. [22], Omoke et al. [16], and Dada et al. [17] are the only studies that have examined the particular case of Nigeria, focusing on the demand side of ecological sustainability accounting using footprints on productive resources. Dogan et al. [22] observed that the ecological footprint of the Nigerian economy decreases with financial development but increases with trade openness. Omoke et al. [16] observed that positive shocks in financial development reduce the ecological footprint of the economy. Dada et al. [17] observed that the ecological footprint of the economy decreases with an increase in trade openness. Among the numerous empirical studies that have examined the ecological impact of financial development and trade openness in other economies, only Agila et al. [31], Latif and Faridi [29], Akhayere et al. [32], Kartal et al. [33], Pata et al. [44], and Caglar and Yavuz [45] have modelled using the ecological load capacity factor.

Latif and Faridi [29] utilized the generalized method of moments technique to examine the specific case of Asian economies from 1996 to 2020. The findings revealed a significant negative impact of banking sector development on the ecological load capacity base of the economies. Kartal et al. [33] employed the bootstrap Fourier Granger causality within the quantile framework to explore the relationship among the variables in the United States from 1965 to 2018. The results revealed a positive causal relationship, indicating that the depth of bank credit to the private sector has an increasing effect on the ecological load capacity base of the economy, particularly in the middle and higher quantiles. Another Fourier ARDL analysis of the United States spanning from 1965 to 2018 by Pata et al. [44] found that financial development has no significant long-term impact on the ecological capacity factor, but it does have a significant negative short-term impact. Akhayere et al. [32] investigated the Turkish economy from 1965 to 2018 using a series of quantile modelling techniques. The results showed that trade openness and bank credit to the private sector decrease the ecological load capacity factor, and their effects remain significant across all quantiles. Agila et al. [31] conducted a study on the South Korean economy between 1970 and 2018, employing a set of quantile and nonparametric causality techniques. Their findings indicated that income and trade globalization have a negative and significant predictive power on the ecological load capacity base of the economy. Furthermore, Caglar and Yavuz [45] conducted a panel study of the European Union from 1995 to 2018, revealing that trade openness has a significant positive impact on the ecological load capacity factor.

2.3. Research gaps in the literature

Upon reviewing the relevant literature, it becomes evident that there are significant gaps that the present study can address. First, there remains a lack of consensus regarding the ecological impact of financial development and trade openness, as well as the specific shape that the impact curve with per capita income should take. Conflicting findings have been reported, and the shape of the curve has been found to vary depending on the choice of ecological sustainability indicators. Therefore, further empirical research is crucial to gain a deeper understanding of the complex nexus between income, finance, trade, and the environment and to draw more definitive conclusions. Second, studies on ecological load capacity are still in the nascent stage, and existing studies have predominantly focused on a limited number of countries, such as South Korea, Turkey, the USA, France, China, and India. Moreover, previous attempts to model ecological sustainability in Nigeria have primarily focused on the demand side of the ecological accounting equation, specifically the ecological footprint, thereby restricting policy options. Hence, Nigeria presents a unique opportunity to expand the literature on this subject. Third, aside from the recent formulation of the load capacity curve by Pata and Kartal [26], other studies that have examined the ecological load capacity factor have predominantly utilized a linear model specification. Consequently, the literature provides limited evidence regarding the shape of the curve between income and the ecological load capacity factor. Therefore, this study contributes to the literature by utilizing the most up-to-date dataset to test the validity of the load capacity curve hypothesis, incorporating the role of financial development and trade openness in Nigeria. Methodologically, this study employs econometric techniques that can differentiate between short-term, medium-term, and long-term policy paths, thereby enhancing the practical implications of the findings.

3. Data and empirical methodology

3.1. Theoretical framework and empirical model

Pata and Kartal [26] proposed the load capacity curve (LCC) hypothesis, which posits that the ecological effects of per capita income can vary as a country progresses economically. The theoretical foundation of the curve suggests that in the early stages of development, the pursuit of higher income leads to increased economic demands for ecological resources, thereby straining the ecological load capacity base. However, the hypothesis recognizes the existence of a turning point level of income beyond which further increases in per capita income reverse the load capacity trend. To facilitate empirical investigation, Pata and Kartal [26] recommended an algebraic transformation of the hypothesis by specifying the ELCF as a function of per capita income, its quadratic term, and accounting for the ecological impact of other socioeconomic drivers. In this study, we extend the analysis by incorporating the role of financial development and trade openness, recognizing their influence on resource allocation, investment patterns, technological advancements, and resource utilization practices [32]. This extended model can be defined as follows, expressed in the natural logarithmic form (ln):

$$\ln \mathrm{ELCF}_t = \alpha + \delta_1 \ln \mathrm{Pg}_t + \delta_2 \ln \mathrm{PgSQ}_t + \varphi \ln \mathrm{BFD} + \pi \ln \mathrm{Trd}_t + e_t \tag{1}$$

In Equation (1), the load capacity factor is denoted as ELCF, per capita income is represented by Pg, financial development is measured by BFD, and the degree of trade openness is denoted as Trd. The elasticity coefficients of BFD and Trd are represented by φ and π, respectively, while e represents the error term. The quadratic term, PgSQ in Eq. (1), extends the impact of income based on the load capacity curve (LCC) hypothesis. The shape of the curve between Pg and ELCF can be empirically validated based on the parameter estimates of δ_1 and δ_2. If δ_1 is negative and δ_2 is positive, both statistically significant, the curve will depict a U-shaped relationship, validating the LCC hypothesis [26]. Conversely, if δ_1 and δ_2 are positive and negative, respectively, and statistically significant, an inverted U-shaped curve exists. Additionally, the turning point level of Pg can be determined by calculating $-\delta_1/2\delta_2$ [26]. Positive and statistically significant estimates of φ and π indicate the respective relevance of BFD and Trd in deepening the ecological load capacity of the Nigerian economy.

3.2. *Description of variables and data information*

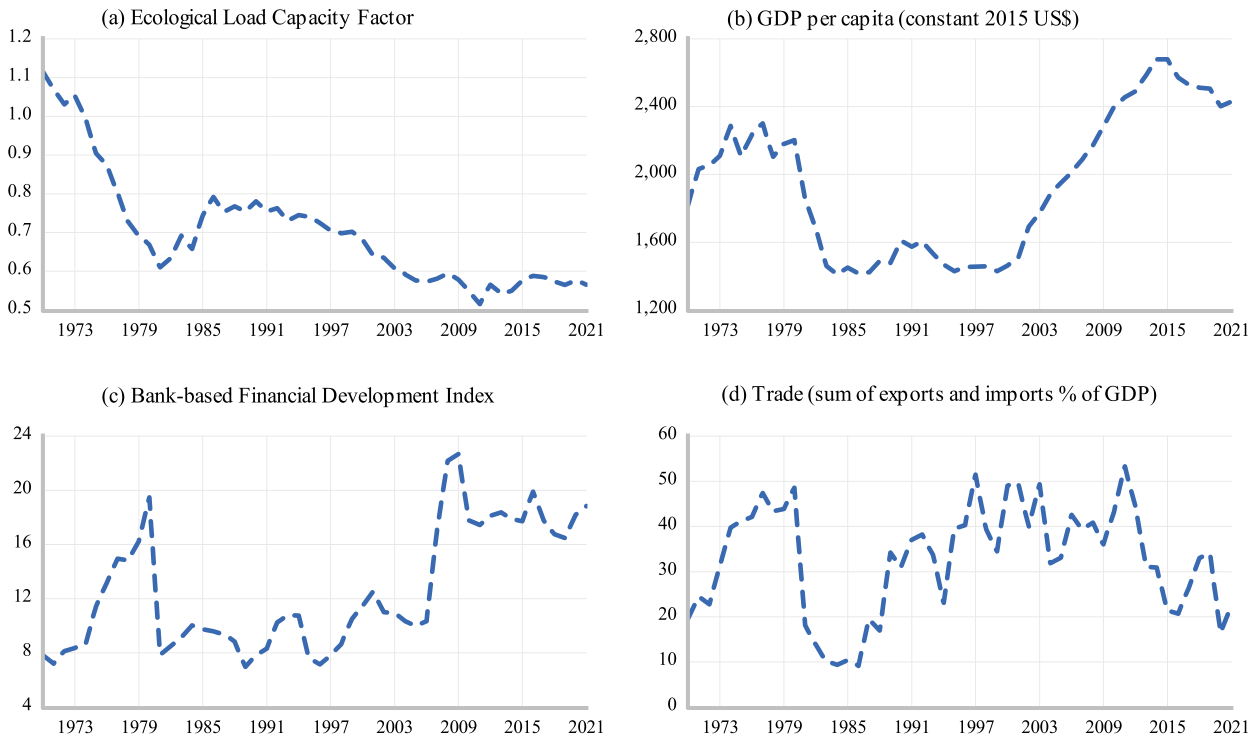
This study utilizes time-series data spanning 1970 to 2021. The National Footprint Network employs an ecological accounting system to track, year by year, the amount of "biologically productive resources" (measured in global hectares) available within a country (referred to as biocapacity, representing the supply side) and the amount required by the country to cover consumption and absorb the waste it generates (referred to as ecological footprint, representing the demand side) [1]. The National Footprint and Biocapacity Accounts update for 2023 provides open access to this dataset. Drawing upon relevant literature, including studies by Pata and Samour [27], Akadiri et al. [28], Latif and Faridi [29], and Pata and Kartal [26], this study calculates the ecological load capacity factor (ELCF) by dividing the biocapacity by the ecological footprint. Based on this calculation, a decrease in ELCF implies a reduction in biocapacity and an increase in ecological footprint [26,27].

This study examines the explanatory relevance of three policy variables: income (Pg), financial development (BFD), and trade openness (Trd). Consistent with the relevant literature, real per capita GDP is used as a proxy for income [19,46]. Trade openness is defined as the total trade (i.e., the sum of exports and imports) as a percentage of aggregate economic output (i.e., % of GDP) [47]. Indicators of financial development comprise bank credit to the private sector (BFD-CRD), liquid liabilities (BFD-LQ), bank deposits (BFD-BD), and bank assets (BFD-BA) (refer to Figure A1 in the Appendix). The selection of these indicators of BFD is justified by the availability of data and the predominantly bank-based structure of the Nigerian financial system. As evident from the correlation matrix in Table 1, these indicators of BFD exhibit a high degree of correlation. To generate a consolidated index (BFD-Index) that incorporates the characteristics of all four indicators, principal component analysis (PCA) is utilized. The PCA estimates are presented in Table 1. A higher value of the BFD indicators indicates a greater depth of banking sector intermediation and the mobilization and redirection of more resources to economic sectors. Fig. 2 presents graphical plots of the study variables, while Table 2 provides a summary definition and data sources, along with basic descriptive statistics of the data. To examine the degree of linear relationship among the variables over the sample period, a correlation coefficient matrix is included. It is evident that ELCF exhibits a stronger negative correlation with BFD (correlation coefficient with BFD-Index = −0.593) and a weaker correlation with Trd (correlation

Table 1
Principal components analysis.

Eigenvalues: (Sum = 4, Average = 1)					
				Cumulative	Cumulative
Number	Value	Difference	Proportion	Value	Proportion
1	3.608	3.295	0.902	3.608	0.902
2	0.313	0.263	0.078	3.921	0.980
3	0.050	0.021	0.013	3.971	0.993
4	0.029	–	0.007	4.000	1.000
Eigenvectors (loadings):					
Variable	PC 1	PC 2	PC 3	PC 4	
BFD-CRD: Private credit by deposit money banks to GDP (%)	0.491	−0.592	0.636	0.068	
BFD-LQ: Liquid liabilities to GDP (%)	0.489	0.639	0.157	0.573	
BFD-BA: Deposit money banks' assets to GDP (%)	0.507	−0.370	−0.756	0.187	
BFD-BD: Bank deposits to GDP (%)	0.513	0.323	−0.011	−0.795	
Ordinary correlations:					
	PCDMB	LIQL	DMBA	BD	
PCDMB	1.000				
LIQL	0.753	1.000			
DMBA	0.943	0.817	1.000		
BD	0.847	0.956	0.897	1.000	

Data Source: Global Financial Development Database update September 2022.


(a) Ecological Load Capacity Factor

(b) GDP per capita (constant 2015 US$)

(c) Bank-based Financial Development Index

(d) Trade (sum of exports and imports % of GDP)

Fig. 2. Graphical plots of study variables: (a) Ecological load capacity factor, (b) GDP per capita (constant 2015 US$), (c) Bank-based financial development index, (d) Trade (sum of exports and imports % of GDP).

Table 2
Summary definition of the variables.

Variables	Definition	Data Sources
ELCF	Ecological Load Capacity Factor = Biocapacity divided by Ecological Footprint	2023 National Footprint and Biocapacity Accounts, GFN [1]
Pg	GDP per capita (constant 2015 US$)	World Development Indicators, WDI [34]
BFD-Index	Bank-based financial development index	Constructed using PCA (see Table 1 and Figure A1 in the Appendix) Data collected from the Global Financial Development Database update September 2022
Trd	Total trade, i.e., sum of exports and imports (% of GDP)	World Development Indicators, WDI [34]

Descriptive Statistics (sample period: 1970–2021)

	ELCF	**Pg**	BFD-Index	**Trd**
Observations	52	52	52	52
Mean	0.702	1945.231	12.570	32.750
Median	0.687	1981.699	10.774	34.103
Maximum	1.115	2679.555	22.679	53.278
Minimum	0.515	1408.209	6.984	9.136
Std. Dev.	0.147	424.060	4.534	12.109
Pairwise Correlation matrixrowhead				
ELCF	1.000			
Pg	−0.287	1.000		
BFD-Index	−0.593	0.770	1.000	
Trd	−0.138	0.154	0.207	1.000

coefficient = −0.138).

3.3. *Econometric methodology*

3.3.1. *Cointegration tests*

This study employs the combined cointegration approach proposed by Bayer and Hanck [48] to examine the presence of a long-run relationship among the variables of interest, as specified in Equation (1). The Bayer-Hanck algorithm (BH) integrates four different cointegration techniques, namely, the Engle and Granger [49] test (EG), Johansen [50] cointegration test (JOH), Boswijk [51] cointegration test (BOS), and Banerjee et al. [52] cointegration test (BA). By utilizing an algorithm that estimates these four cointegration tests, BH eliminates the need for separate estimations. The test statistics are based on Fisher-type equations as follows:

$$EG - JOH = -2[\ln(PEG) + \ln(PJOH)] \tag{2}$$

$$EG - JOH - BA - BO = -2[\ln(PEG) + \ln(PJOH) + \ln(PBA) + \ln(PBO)] \tag{3}$$

The Fisher-type expression in Equation (2) combines only two of the contegration tests, EG and JOH. The extended formulation in Equation (3) combines the four cointegration tests, EG, JOH, BA, and BO, thereby extending the robustness of the BH test. The decision regarding the presence of cointegration is determined by comparing the estimated Fisher-type F-statistics with the critical values (CV). The null hypothesis of no cointegration is rejected when the F-statistics exceed the CV at a 5% level of statistical significance. Additionally, to ensure sensitivity and robustness, this study also performs the autoregressive distributed lag (ARDL) bounds test for a cointegrating relationship [53]. This test is based on the following error-correction equation:

$$\begin{aligned}\Delta\text{lnELCF}_t = {} & \alpha_0 + \sum_{i=1}^{p}\beta_{sh}\Delta\text{lnELCF}_{t-i} + \sum_{i=1}^{p}\delta_{1sh}\Delta\text{lnPg}_{t-i} + \sum_{i=0}^{p}\delta_{2sh}\Delta\text{lnPgSQ}_{t-i} + \sum_{i=0}^{p}\varphi_{sh}\Delta\text{lnBFD}_{t-i} + \sum_{i=0}^{p}\pi_{sh}\Delta\text{lnTrd}_{t-i} + \beta\text{lnELCF}_{t-1} \\ & + \delta_1\text{lnPg}_{t-1} + \delta_2\text{lnPgSQ}_{t-1} + \varphi\text{lnBFD}_{t-1} + \pi\text{lnTrd}_{t-1} + e_t\end{aligned} \tag{4}$$

In Equation (4), the first difference process operator is denoted by the symbol Δ. The null hypothesis (H_o), which assumes no cointegration (i.e., $H_o : \beta = \delta_1 = \delta_2 = \varphi = \pi = 0$), can be tested against the alternative hypothesis ($H_o : \beta \neq \delta_1 \neq \delta_2 \neq \varphi \neq \pi \neq 0$). To conduct this test, the critical values and approximate probability values for the F-statistic and t-statistic are utilized, derived from the response surface regression results of Kripfganz and Schneider [54]. The null hypothesis is rejected if the derived statistics exceed the upper bound critical values with statistically significant approximate probability values [54].

3.3.2. *Long-run parameter estimators*

A number of approaches have gained popularity in the literature for estimating the long-run parameters of cointegrated equations. In this study, two techniques are employed: the dynamic ordinary least squares (DOLS) estimator proposed by Stock and Watson [55] and the autoregressive distributed lag (ARDL) model estimator. The DOLS estimator calculates the long-run parameters of cointegrated equations by incorporating the lead and lag of the differenced regressors, aiming to capture the long-run relationship [55]. This estimator is considered unbiased and achieves fully efficient normal asymptotics [56]. To ensure robustness, the parameter estimates are also re-estimated using the ARDL regression model. The ARDL model captures the long-run estimates through the $\delta_1, \delta_2, \varphi$ and π parameters in Eq. (4).

3.3.3. *Error correction model*

In the short run, the model may experience deviations from the long-term equilibrium state due to external shocks. To address this dynamic process, the error correction term (ECM) is introduced, which corrects for short-term errors and brings the system back to the long-term equilibrium state. This results in the following equation:

$$\Delta\text{lnELCF}_t = \alpha + \sum_{i=1}^{p}\beta_{sh}\Delta\text{lnELCF}_{t-i} + \sum_{i=1}^{p}\delta_{1sh}\Delta\text{lnPg}_{t-i} + \sum_{i=0}^{p}\delta_{2sh}\Delta\text{lnPgSQ}_{t-i} + \sum_{i=0}^{p}\varphi_{sh}\Delta\text{lnBFD}_{t-i} + \sum_{i=0}^{p}\pi_{sh}\Delta\text{lnTrd}_{t-i} + \omega\text{ECM}_{t-1} + e_t \tag{5}$$

In Equation (5), ω is the coefficient of the error correction term (ECM_{t-1}) which indicates the speed of adjustment from a short-run shock to the long-run equilibrium. A positive value of ω suggests that the model does not converge to the long-run equilibrium. Therefore, it is expected that ω will be negative and statistically significant, and the magnitude of its absolute value determines how quickly the equilibrium is restored.

3.4. *Test for granger causality: frequency domain approach*

To determine the direction of causality among the variables, the spectral Granger causality test (bcgcausality) is employed, which operates within the frequency domain framework [37]. This test allows for a comparative assessment of whether a specific component of the "cause" variable (e.g., Y_t) at frequency ω is useful in predicting the component of the "effect" variable (e.g., X_t) at the same frequency, taking into account additional variables in the model [57]. The test is based on the assumption that $Y_t = (x_t, y_t)'$ represents a covariance-stationary vector time series that can be represented using a finite-order $VAR(p)$ process:

$$\Theta(L)Y_t = \varepsilon_t \tag{6}$$

In Equation (6), $\Theta(L) = \text{I}_2 - \Theta_1 L - \Theta_2 L_2 - \ldots - \Theta_p L_p$ represents a 2×2 lag polynomial, I_2 denotes a 2×2 identity matrix, and Θ_i are coefficients corresponding to $i = 1, 2, \ldots, p$, respectively. By taking Fourier transformations of the moving-average polynomial terms, the spectral density of x_t is derived as Equation (7):

$$f_x(w) = \frac{1}{2\pi}\left\{\left|\Psi_{11}\left(e^{-i\omega}\right)\right|^2 + \left|\Psi_{12}\left(e^{-i\omega}\right)\right|^2 \tag{7}$$

To determine the linear feedback from y_t to x_t at frequency ω, Breitung and Candelon [37] employed the formulation proposed by Geweke [58]:

$$M_{y\rightarrow x}(\omega) = \log\left\{\frac{2\pi f_x(\omega)}{|\Psi_{11}(e^{-i\omega})|^2}\right\} = \log\left\{1 + \frac{|\Psi_{12}(e^{-i\omega})|^2}{|\Psi_{11}(e^{-i\omega})|^2}\right\} \tag{8}$$

As defined in Equation (8), if $|\Psi_{12}(e^{-i\omega})| = 0$, then $M_{y\rightarrow x}(\omega) = 0$. This indicates that y_t does not Granger cause x_t at frequency ω. To reflect theoretical formulation and ensure that the causality test is reliable, the framework is extended with additional variables to aid computation conditional on additional variables that are considered to have theoretical influence in the formulated model. To demonstrate the test algorithm, consider lnPg→lnELCF as an example and formulate the following vector autoregression (VAR) equation:

$$\text{lnELCF}_t = c_1 + \sum_{j=1}^{p}\theta_j\text{lnELCF}_{t-j} + \sum_{j=1}^{p}\tau_j\text{lnPg}_{t-j} + \sum_{j=1}^{p}\mathfrak{x}_j\text{lnPgSQ}_{t-j} + \sum_{j=1}^{p}\sigma_j\text{lnBFD} - \text{Index}_{t-j}\sum_{j=1}^{p}\gamma_j\text{ln Trd}_{t-j} + e_t \tag{9}$$

Based on Equation (9), the null hypothesis of $\text{lnPg}\rightarrow\text{lnELCF}(\omega) = 0$ (i.e., no Granger causality from lnPg to lnELCF at frequency ω conditional on $\text{lnBFD} - \text{index}$ and lnTrd) can be tested using the Wald statistic and its approximate probability value.

4. Empirical results and discussion

4.1. Unit root and VAR lag order selection tests

The results of the unit root tests are presented in Table 3. Panel A displays the estimates from the augmented Dickey-Fuller (ADF) test, indicating that all the variables become stationary only after undergoing first differencing (i.e., the variables are I(1)). However, it is important to consider the possibility of a structural break point in the data series, as the ADF test may exhibit a bias towards a false unit root null hypothesis. To account for this, the Zivot and Andrews [59] test is employed. The results, summarized in Panel B, confirm the I(1) integration of all the variables, implying that they are stationary only after being first-differenced. Following the unit root tests, the VAR lag order selection test is conducted, and the results are presented in Table 4. Based on the widely used criterion, the Akaike information criterion (AIC), the most suitable (maximum) lag length for the empirical model under study, is suggested to be 4.

4.2. Cointegration tests

The results of the cointegration tests are summarized in Table 5. To complement the BFD-Index, the individual effects of each of the

Table 3
Unit root tests.

	Level form I(0)		First Difference I(1)		
	t-Statistic	Break Date	t-Statistic	Break Date	Result
Panel A: Augmented Dickey-Fuller (ADF) test					
lnELCF	−2.533		−6.336***		I(1)
lnPg	−0.922		−5.352***		I(1)
lnPgSQ	−0.904		−5.388***		I(1)
lnBFD-Index	−1.904		−6.712***		I(1)
lnBFD-Crd	−2.538		−5.621***		I(1)
lnBFD-LQ	−1.931		−6.706***		I(1)
lnBFD-BA	−2.042		−7.033***		I(1)
lnBFD-BD	−1.642		−6.388***		I(1)
lnTrd	−2.504		−7.879***		I(1)
Panel B: Zivot - Andrews test with a structural break point					
lnELCF	−2.866	1974	−8.181***	1982	I(1) with a break
lnPg	−4.632	1981	−5.919***	2000	I(1) with a break
lnPgSQ	−4.620	1981	−5.953***	2000	I(1) with a break
lnBFD-Index	−4.569	1981	−7.176***	1981	I(1) with a break
lnBFD-Crd	−4.318	1981	−7.530***	1981	I(1) with a break
lnBFD-LQ	−4.722	1981	−7.292***	1981	I(1) with a break
lnBFD-BD	−4.330	1981	−6.916***	1981	I(1) with a break
lnBFD-BA	−3.897	1981	−5.760***	1992	I(1) with a break
lnTrd	−3.449	1989	−8.707***	1987	I(1) with a break

Note: *** indicates rejection of H_0 at 1% significance level.

Table 4
VAR lag order selection.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	117.9646	NA	6.22e-09	−4.706857	−4.511941	−4.633198
1	324.1331	360.7950	3.30e-12	−12.25555	−11.08605*	−11.81359*
2	351.0808	41.54439	3.15e-12	−12.33670	−10.19262	−11.52645
3	366.4660	20.51358	5.14e-12	−11.93608	−8.817416	−10.75754
4	409.7469	48.69096*	2.89e-12*	−12.69779*	−8.604534	−11.15094

Note: * indicates lag order selected by the criterion; LR: sequential modified LR test statistic (each test at 5% level); FPE: Final prediction error; AIC: Akaike information criterion; SC: Schwarz information criterion; HQ: Hannan-Quinn information criterion.

four measures of banking sector development are also modelled. Panel A provides an examination of the Bayer-Hanck test statistics, revealing that the two Fisher-type statistics (EG-JOH and EG-JOH-BA-BO) consistently exceed the critical values at the 5% significance level across all model specifications. This indicates strong statistical evidence of long-run convergence (i.e., cointegration) among the variables, regardless of the BFD indicator considered. Additional cointegration tests are performed using the ARDL-bounds technique. The selected ARDL models for two empirical specifications are reported in Panel B. The critical values (CV) and approximate probability values are derived from Kripfganz and Schneider [54], serving as the basis for testing the null hypotheses of no cointegration. The approximate probability values clearly indicate that both the computed F-statistic and t-statistic exceed the upper critical values at the 1% and 5% significance levels, respectively. Hence, the results obtained from both the Bayer-Hanck and ARDL-bounds tests confirm the existence of a long-run relationship between the ecological load capacity factor, real per capita GDP, financial development (BFD) indicators and trade openness in Nigeria.

4.3. Results: parameter estimates

The results of the DOLS estimations are summarized in Table 6. Across different specifications, it is observed that the coefficient of Pg is negative, while the coefficient for its square term, PgSQ, is positive. Both coefficients are statistically significant. These estimates indicate a U-shaped relationship between Pg and ELCF in Nigeria, validating the newly proposed LCC hypothesis. This finding supports earlier evidence presented by Pata and Kartal [26], which demonstrated a similar relationship in South Korea. In contrast to previous

Table 5
Cointegration tests.

Panel A: Bayer-Hanck test	(1)	(2)	(3)	(4)	(5)
Underlying individual tests:	BFD-Index	BFD-Crd	BFD-LQ	BFD-BD	BFD-BA
Engle-Granger	−2.691	0.547	−2.654	−2.587	−3.151
[P-Values]	[0.731]	[-3.052]	[0.748]	[0.776]	[0.493]
Johansen	52.222***	52.471***	44.950***	54.645***	48.121***
[P-Values]	[0.000]	[0.000]	[0.002]	[0.000]	[0.001]
Banerjee	−3.621	−4.707***	−3.379	−2.513	−5.586
[P-Values]	[0.106]	[0.007]	[0.165]	[0.490]	[0.000]
Boswijk	33.583***	45.876***	24.134**	24.395**	56.100***
[P-Values]	[0.001]	[0.000]	[0.013]	[0.012]	[0.000]
Fisher Type test statistics, Bayer-Hanck Test					
EG-JOH:	19.046***	19.626***	13.455**	18.928***	16.252***
1% Critical value	**(15.845)**				
5% Critical value	**(10.576)**				
EG-JOH-BA-BO	38.360***	84.870***	25.686**	29.168**	87.738***
1% Critical value	**(30.774)**				
5% Critical value	**(20.143)**				
Panel B: Robustness Check using ARDL-bounds test					
Selected Model	ARDL(1,3,0,4,4)	ARDL(1,3,0,4,4)			
F-Statistic	9.983***	9.863***			
t-Statistic	−4.638**	−4.080**			
Kripfganz and Schneider (2020) critical values and approximate P-Values	Statistics	I(0)	I(1)		
10% critical values	F-Stat	2.294	3.446		
	t-Stat	−2.466	−3.571		
5% critical values	F-Stat	2.755	4.058		
	t-Stat	−2.824	−3.987		
1% critical values	F-Stat	3.850	5.501		
	t-Stat	−3.549	−4.823		
Approximate P-Values	F-test	0.000	0.000		
	t-test	0.001	0.015		

** and *** indicate rejection of H_0 (no cointegration) at 5% and 1% levels of statistical significance, respectively; Lower bounds: I(0); Upper bounds: I (1).

Table 6
Long-run parameter analysis: DOLS estimations.

Variables	(1)	(2)	(3)	(4)	(5)
lnPg	−9.444***	−7.650**	−8.174**	−5.800**	−7.832***
	(1.687)	(3.762)	(3.665)	(2.522)	(2.741)
	[-5.597]	[-2.034]	[-2.230]	[-2.300]	[-2.857]
lnPgSQ	0.688***	0.535**	0.618**	0.467***	0.568***
	(0.110)	(0.247)	(0.247)	(0.164)	(0.181)
	[6.245]	[2.166]	[2.506]	[2.854]	[3.145]
lnBFD-Index	−0.993***				
	(0.024)				
	[-40.949]				
lnBFD-Crd		−0.724***			
		(0.071)			
		[-10.205]			
lnBFD-LQ			−1.160***		
			(0.072)		
			[-16.214]		
lnBFD-BD				−1.077***	
				(0.034)	
				[-31.658]	
lnBFD-BA					−0.699***
					(0.031)
					[-22.915]
lnTrd	−0.073***	0.030	−0.022**	−0.110***	−0.227***
	(0.014)	(0.026)	(0.011)	(0.016)	(0.031)
	[-5.282]	[1.131]	[-2.002]	[-7.114]	[-7.246]
Constant	34.365***	28.247**	29.334**	19.713**	28.848***
	(6.489)	(14.294)	(13.754)	(9.722)	(10.489)
	[5.296]	[1.976]	[2.133]	[2.028]	[2.750]
R-squared	0.990	0.963	0.956	0.989	0.983
Turning point (constant 2015 US$)	956.59	1273.51	744.91	497.63	986.70

Standard errors in; t-statistics in [ ]; ***, **, * indicate statistical significance at 1%, 5% and 10% levels, respectively.

empirical studies by Pata and Samour [27], Akadiri et al. [28], Pata and Isik [41], and Pata and Balsalobre-Lorente [43] that employed linear model specifications, the results in Table 6 strongly suggest that the impact of Pg on ELCF varies at different stages of economic growth [26]. The negative Pg coefficients indicate that, at the early stages of growth, income has a scale effect on ecological degradation [26]. This weakens the biocapacity and increases the ecological footprint of the Nigerian economy. One possible explanation is that during the early stages of development, income growth is prioritized for economic benefits rather than ecological and environmental concerns [19,26]. However, the shape of the curve reverses after reaching a turning point level of income. As evident from Table 6, separate models using various BFD indicators estimate different minimum turning point levels of income. It is noteworthy that all suggested threshold levels of income fall within Nigeria's current range of per capita GDP. Specification 1, which accounts for the combined features of the BFD indicators, suggests a minimum turning point of $956.59. This implies that Nigeria has already reached a stage where further increases in Pg levels lead to improvements in ELCF. In fact, it is highly likely that additional increases in Pg can drive a shift in the structural composition of the economy towards more ecologically friendly consumption and production processes. This includes the adoption of renewable energy, energy efficiency measures, technological innovations, and other practices that can decouple economic growth from ecological degradation.

The empirical results, as summarized in Table 6, reveal a significant and negative long-run impact of BFD on ELCF at the 1% level of significance across different model specifications. Specifically, a 1% increase in the BFD index, which combines credit depth, liquid liabilities, deposits, and assets of the banking system, leads to a 0.993% reduction in ELCF. The individual impact of each BFD indicator shows variations in the size of the coefficient estimates, with ELCF decreasing by 0.724%, 1.160%, 1.077%, and 0.699% for a 1% increase in BFD-Crd, BFD-LQ, BFD-BD, and BFD-BA, respectively. In contrast to previous studies that relied solely on credit depth as the indicator of BFD [32,33], the current findings demonstrate that other BFD indicators are also significant in understanding the impact of financial development on ELCF. Specifically, when BFD is measured by using the size of bank assets and the depth of credit supply of the banking system, the resulting effect is relatively smaller. The negative relationship between BFD and ELCF in Nigeria aligns with earlier research conducted by Latif and Faridi [29] on a panel of Asian countries and Akhayere et al. [32] on the Turkish economy. However, it diverges from the positive relationship observed by Kartal et al. [33] in the United States. Considering the composition of ELCF, it becomes evident that BFD increases the ecological footprint without simultaneously augmenting biocapacity, resulting in a weakening of the load capacity factor in Nigeria. As in many developing countries, BFD policy initiatives in Nigeria primarily prioritize economic objectives. This emphasis on economic objectives likely explains the negative relationship between BFD and the country's ELCF. Given that Nigeria's economic targets are influenced by the extraction and processing of natural resources, it can be argued that BFD, in shaping consumption and investment patterns, contributes to biodiversity loss, deforestation, overgrazing, fisheries depletion, and the accumulation of waste and pollution. These factors collectively degrade the ecological load capacity base.

The empirical analysis reveals a negative and statistically significant long-run impact of trade openness on ELCF in specifications (1), (4), and (5) at the 1% level and in specification (3) at the 5% level. The magnitude of the coefficient estimates differs across specifications. Specifically, a 1% increase in trade openness is associated with an ELCF reduction of 0.073% in specification (1), 0.022% in specification (3), 0.110% in specification (4), and 0.227% in specification (5). These findings suggest that trade openness has a scale effect on the ecological footprint in Nigeria, consequently weakening the load capacity base of the economy. Similar results were reported by Agila et al. [31] for South Korea and Akhayere et al. [32] for Turkey. However, Dada et al. [17] reached a contrasting conclusion for Nigeria using the ecological footprint as a measure of environmental sustainability. Over the past few decades, Nigeria has witnessed substantial growth in trade volume, resulting in increased integration into the global economy across diverse economic sectors [60]. However, trade policies have primarily been formulated to leverage Nigeria's comparative advantage in the extraction of natural resources. The results in Table 6 imply that while trade openness has enhanced the export capacity of these extractive sectors, it has not effectively supported technological development in resource-efficient sectors. As a result, trade openness has scaled up the ecological footprint without concurrently boosting biocapacity, thereby weakening the load capacity base of the economy. To address this challenge, a well-designed trade diversification strategy is crucial to stimulate growth in ecologically efficient sectors and mitigate the negative impact of trade openness on ELCF.

4.4. Robustness check using the ARDL model

The results of the ARDL model are summarized in Table 7. The long-run results in Panel A are consistent with the results in Table 6, confirming a valid U-shaped relationship between Pg and ELCF in line with the LCC hypothesis. The estimated threshold turning point is $1603.70 in specification (1) and $1794.64 in specification (2), both falling within Nigeria's current range of per capita GDP level. This suggests that further increases in per capita income can enhance ELCF. Additionally, the BFD indicators and Trd exhibit a statistically significant negative impact on ELCF, further supporting the results in Table 6. The short-run estimates are presented in Panel

Table 7
ARDL analysis.

Variables	Specification (1)			Specification (2)		
	Coeff.	Std. err	t-stat	Coeff.	Std. err	t-stat
Panel A: Long-run estimates						
lnPg	−17.845**	(8.714)	[-2.048]	−15.105**	(7.150)	[-2.113]
lnPgSQ	1.209**	(0.578)	[2.092]	1.008**	(0.473)	[2.132]
lnBFD-Index	−0.627***	(0.115)	[-5.437]			
lnBFD-Crd				−0.444***	(0.071)	[-6.236]
lnTrd	−0.196***	(0.060)	[-3.291]	−0.124**	(0.055)	[-2.257]
Constant	67.549**	(32.918)	[2.052]	57.444**	(27.041)	[2.124]
Turning point (constant 2015 US$)	1603.70			1794.64		
Panel A: Short-run estimates						
ΔlnPg	−5.411**	(2.470)	[-2.191]	−5.397**	(2.466)	[-2.189]
ΔlnPg(-1)	−0.223*	(0.113)	[-1.970]	−0.156	(0.103)	[-1.521]
ΔlnPg(-2)	−0.151	(0.110)	[-1.373]	−0.168	(0.102)	[-1.645]
ΔlnPgSQ	0.372**	(0.164)	[2.268]	0.375**	(0.164)	[2.288]
ΔlnBFD-Index	−0.001	(0.032)	[-0.030]			
ΔlnBFD-Index(-1)	0.120***	(0.043)	[2.787]			
ΔlnBFD-Index(-2)	0.051	(0.039)	[1.302]			
ΔlnBFD-Index(-3)	0.126***	(0.032)	[3.944]			
ΔlnBFD-Crd				0.027	(0.028)	[0.969]
ΔlnBFD-Crd(-1)				0.095**	(0.041)	[2.324]
ΔlnBFD-Crd(-2)				0.056	(0.039)	[1.457]
ΔlnBFD-Crd(-3)				0.123***	(0.030)	[4.120]
ΔlnTrd	−0.063***	(0.019)	[-3.337]	−0.060***	(0.021)	[-2.877]
ΔlnTrd(-1)	0.029	(0.019)	[1.514]	0.026	(0.019)	[1.349]
ΔlnTrd(-2)	0.033*	(0.019)	[1.742]	0.026	(0.019)	[1.393]
ΔlnTrd(-3)	0.038**	(0.017)	[2.253]	0.036**	(0.017)	[2.121]
ECM(-1)	−0.307***	(0.066)	[-4.638]	−0.371***	(0.091)	[-4.080]
R-squared	0.762			0.767		
Panel C: Diagnostic Tests						
Cameron & Trivedi's decomposition of IM-test						
Heteroskedasticity {Prob}	48.00	{0.432}		48.00	{0.432}	
Skewness {Prob}	12.52	{0.707}		13.93	{0.604}	
Kurtosis {Prob}	1.04	{0.308}		1.12	{0.290}	
Total (Normality test) {Prob}	61.56	{0.563}		63.05	{0.510}	
Breusch-Godfrey SC test						
chi2 { Prob > chi2}	1.237	{0.266}		1.558	{0.212}	
Breusch–Pagan/Cook–Weisberg test						
chi2 {Prob > chi2}	0.510	{0.474}		0.40	{0.527}	
Ramsey RESET test						
F-Statistics {Prob > F-stat}	0.390	{0.763}		0.140	{0.933}	
CUSUM	Stable	See Fig. 3		Stable	See Fig. 4	
CUSUM of Squares	Stable	See Fig. 3		Stable	See Fig. 4	

B. Across the two specifications, ΔlnPg demonstrates a negative coefficient, while the square term, ΔlnPgSQ, exhibits a positive coefficient, both statistically significant at the 5% level. These estimates confirm the presence of a U-shaped relationship between Pg and ELCF in the short run. Furthermore, the results show a statistically significant negative coefficient for ΔlnTrd, with the size of the coefficient estimates indicating a 0.060%–0.063% decrease in ELCF for a 1% increase in trade openness in the short run. The coefficient of the lagged error correction term, ECM(-1), is significant at the 1% level in both model specifications, and it assumes the theoretically expected negative sign. Specifically, the estimates suggest that approximately 30.7% and 37.1% of the disequilibrium in the short run is corrected annually in specifications (1) and (2), respectively. These findings validate the results from the bounds test and further reinforce the existence of a long-run relationship between income, financial development, trade openness, and the ecological load capacity factor in Nigeria.

Panel C presents the results of fundamental diagnostic tests that evaluate the suitability of the ARDL model specifications. The findings indicate that both model specifications are free from heteroscedasticity and serial correlation concerns. This is supported by the insignificant statistical values of the Breusch−Pagan/Cook-Weisberg test and the Breusch-Godfrey LM test, respectively. Additionally, the residual terms of the estimated specifications exhibit a normal distribution, as suggested by the probability values obtained from Cameron and Trivedi's decomposition of the IM-test [61]. The results of the Ramsey RESET test confirm that both models (1) and (2) are correctly specified. Figs. 3 and 4 illustrate the plots of the cumulative sum (CUSUM) and cumulative sum of squares (CUSUMSQ) tests. It is evident from these figures that the plots fall within the 5% critical bounds, indicating that the estimated parameters are stable and unaffected by structural instability. Overall, the model specifications successfully pass all diagnostic tests, thus affirming the reliability of the parameter estimates and providing a robust foundation for informed policy decision-making in Nigeria.

4.5. Results: granger causality analysis

Based on the AIC statistics presented in Table 4, a lag length of 4 was determined to be the appropriate choice for conducting the Breitung-Candelon spectral Granger causality test. The test statistics, summarizing the results, can be found in Table 8. Statistical significance indicates the rejection of the null hypothesis of no Granger causality. To assess causal dynamics across different time frames, the test statistics were computed at various frequencies: $\omega = 0.1$ and 0.6 for permanent (long-run) causal dynamics, $\omega = 1.5$ for intermediate (medium-term) frequency, and $\omega = 2.5$ and 3.0 for temporary (short-run) causal dynamics. Figs. 5–10 illustrate graphical representations of the test statistics across all frequency domains. The corresponding wavelengths in years can be calculated using the formula $2\pi/\omega$ [57].

The Granger causality tests conducted between ELCF and Pg reveal the rejection of the null hypothesis in the permanent frequency periods, specifically when the causality runs from Pg to ELCF. However, no evidence of causality is found in any of the frequency domains when the direction of causality is from ELCF to Pg. This implies the presence of unidirectional causality, with real per capita GDP (Pg) exerting a significant long-term impact on the ecological load capacity factor (ELCF). Fig. 5 suggests that it takes approximately 4 years or longer for Pg to induce a significant causal effect on ELCF in Nigeria. Similar findings were reported by Akadiri et al. [28] in the case of the Indian economy. The absence of reverse causality implies that Pg serves as a predictor of ELCF rather than the other way around. Consequently, enhancing the ecological load capacity base of the Nigerian economy requires the adjustment of economic policies, as suggested by Pata and Samour [27]. This may involve a policy focus on stimulating economic output through the adoption of resource-efficient technologies, such as renewable energy.

The Granger causality tests conducted between ELCF and the BFD index reveal the rejection of the null hypothesis in the permanent frequency periods, regardless of the direction of causality. Therefore, the causality between ELCF and BFD is bidirectional and statistically significant exclusively in the long run. Fig. 6 indicates a wavelength of approximately 6 years or longer for BFD to have a significant causal impact on ELCF, while approximately 11 years or more is suggested for a significant reverse impact. Considering the sign of the relationship between the variables (see Tables 6 and 7), the bidirectional causality implies that the variables exert a long-term negative predictive influence on each other in Nigeria. This finding diverges from the positive causal linkages observed in the

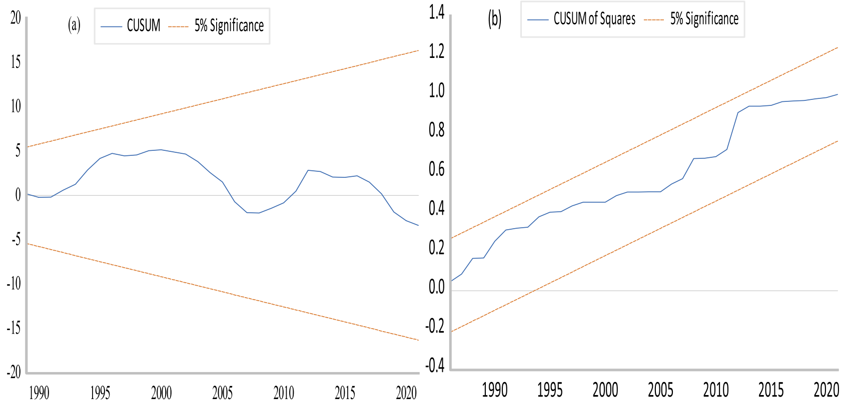


Fig. 3. Stability diagnostics on model Specification 1- (a) CUSUM (b) CUSUM of Squares.

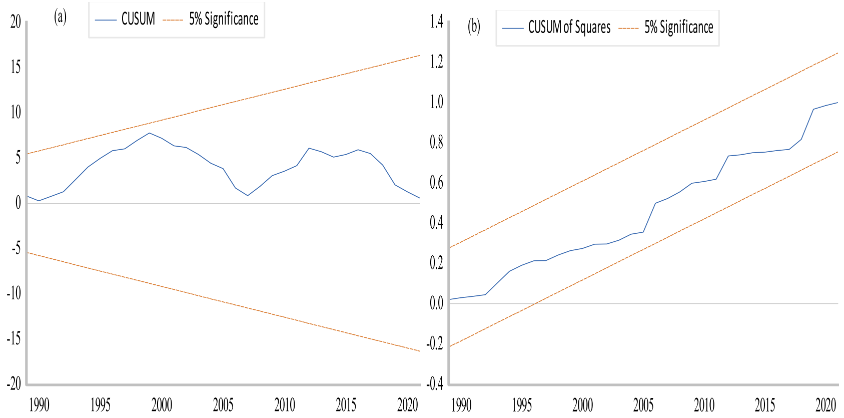


Fig. 4. Stability diagnostics on model Specification 2 - (a) CUSUM (b) CUSUM of Squares.

Table 8
Granger-causality test.

	Permanent (Long-Run)		Intermediate	Temporary (Short-run)	
Null hypothesis	$\omega = 0.1$	$\omega = 0.6$	$\omega = 1.5$	$\omega = 2.5$	$\omega = 3.0$
lnPg ⇏ lnELCF	11.442***	11.987***	3.977	0.699	1.225
	(0.003)	(0.003)	(0.137)	(0.705)	(0.542)
lnELCF ⇏ lnPg	1.073	0.569	0.877	2.028	2.216
	(0.585)	(0.752)	(0.645)	(0.363)	(0.330)
lnBFD-Index ⇏ lnELCF	14.014***	15.739***	2.026	3.124	3.001
	(0.001)	(0.000)	(0.363)	(0.210)	(0.223)
lnELCF ⇏ lnBFD-Index	12.032***	4.003	0.727	0.681	1.031
	(0.002)	(0.135)	(0.695)	(0.711)	(0.597)
lnTrd ⇏ lnELCF	10.820***	5.482*	1.140	4.690*	5.059*
	(0.005)	(0.065)	(0.566)	(0.096)	(0.080)
lnELCF ⇏ lnTrd	0.447	0.099	0.397	0.639	0.510
	(0.800)	(0.952)	(0.820)	(0.727)	(0.775)
Extended Causality tests					
lnPg ⇏ lnBFD-Index	1.402	2.012	1.066	3.775	4.057
	(0.496)	(0.366)	(0.587)	(0.151)	(0.132)
lnBFD-Index ⇏ lnPg	0.980	1.097	6.895**	3.940	3.430
	(0.613)	(0.578)	(0.032)	(0.140)	(0.180)
lnPg ⇏ lnTrd	0.365	0.836	0.348	0.760	0.784
	(0.833)	(0.659)	(0.841)	(0.684)	(0.676)
lnTrd ⇏ lnPg	1.322	1.839	0.928	1.551	1.599
	(0.516)	(0.399)	(0.628)	(0.461)	(0.450)
lnBFD-Index ⇏ lnTrd	0.906	0.943	0.271	0.319	0.406
	(0.636)	(0.624)	(0.874)	(0.853)	(0.816)
lnTrd ⇏ lnBFD-Index	1.332	1.978	2.556	1.286	1.119
	(0.514)	(0.372)	(0.279)	(0.526)	(0.572)

Note: $y \nRightarrow x$ indicates the null hypothesis of No Granger-causality from y to x at frequency w.
(e.g. lnA ⇏ lnELCF tests H_O for Granger-causality running from lnA to lnELCF).
P-Values in ; *** P-Val <0.01, ** P-Val<0.05, * P-Val <0.1 suggest the rejection of the null hypothesis at 1%, 5% and 10% levels, respectively.

middle and higher quantiles in the United States, as observed by Kartal et al. [33].

Regarding the Granger causality tests between ELCF and Trd, the null hypothesis is rejected in the permanent frequency periods when the direction of causality is from Trd to ELCF. However, no evidence of causality is found in any of the frequency domains when the direction of causality runs from ELCF to Trd. Therefore, the test statistics suggest the existence of unidirectional causality, with trade openness (Trd) exerting a significant long-term impact on the ecological load capacity factor. Fig. 7 suggests that it takes approximately 10 years or more for trade openness to induce a significant causal impact on ELCF in Nigeria.

Extended tests are conducted to investigate the tripartite causal linkages among Pg, BFD, and Trd. Interestingly, only one of the tests yields statistically significant estimates, indicating a unidirectional causality from BFD to Pg in the medium term (see Fig. 8). This implies that BFD indirectly influences ELCF through Pg. Overall, these findings confirm the potential of financial and trade policies in predicting sustainability challenges related to the utilization of ecologically productive resources in Nigeria.

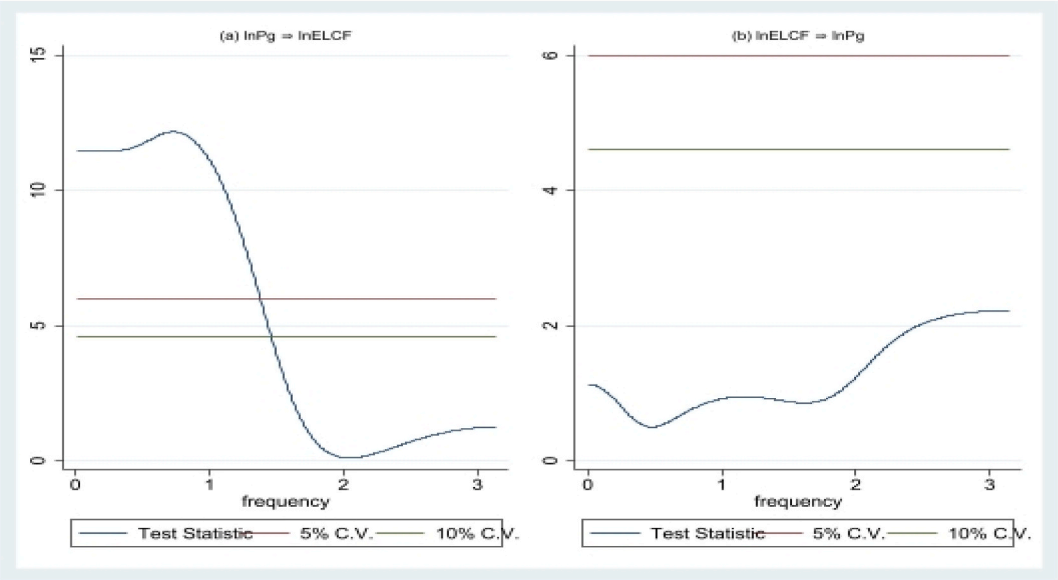


Fig. 5. Granger-causality test – (a) from lnPg to lnELCF (b) from lnELCF to lnPg.

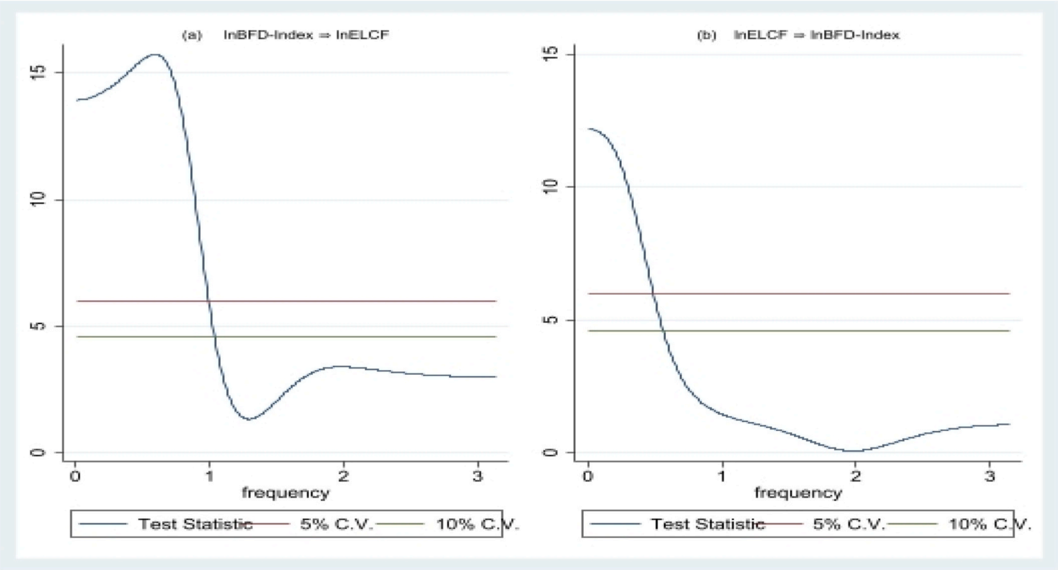


Fig. 6. Granger causality test - (a) from lnBFD-Index to lnELCF (b) from lnELCF to lnBFD-Index.

5. Conclusion and policy direction

5.1. Conclusions

This study explores the relationship between income, financial development, trade openness, and the ecological load capacity factor (ELCF) in Nigeria from 1970 to 2021. The study has three specific objectives: first, to determine the validity of the newly proposed load capacity curve (LCC) hypothesis in explaining the relationship between per capita income and ELCF in Nigeria; second, to analyse the impact of financial development and trade openness on ELCF in Nigeria; and third, to test the direction of causality between the variables across different time periods to define pathways for mitigation policies. Unlike previous studies that solely relied on the demand side of ecological accounting using the footprint metric to measure ecological sustainability in Nigeria, this study takes a different approach by employing the load capacity factor. By integrating both the supply and demand dimensions of ecological accounting, the ELCF enables a more comprehensive assessment of ecological sustainability. The empirical investigation involved

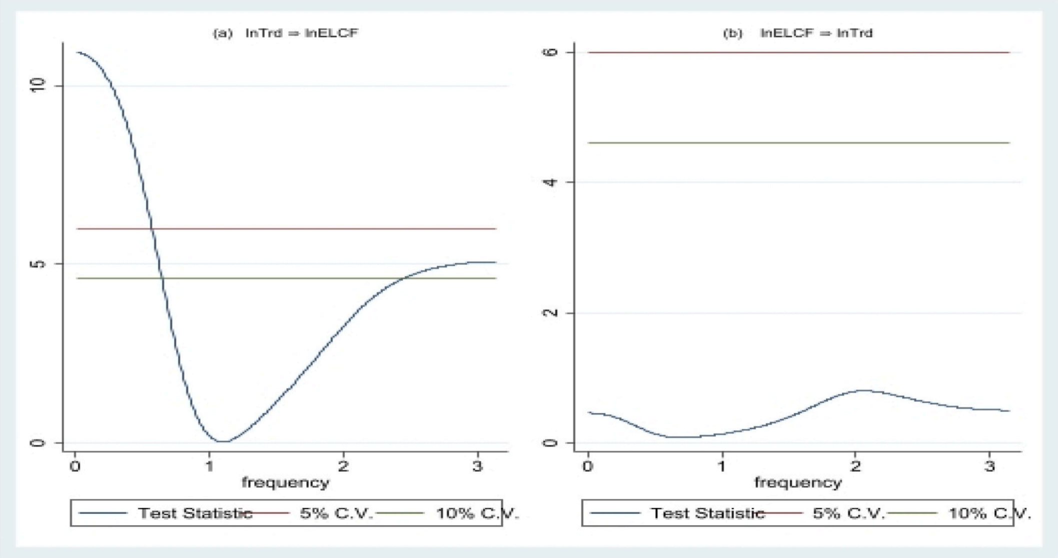


Fig. 7. Granger-causality test – (a) from lnTrd to lnELCF (b) from lnELCF to lnTrd.

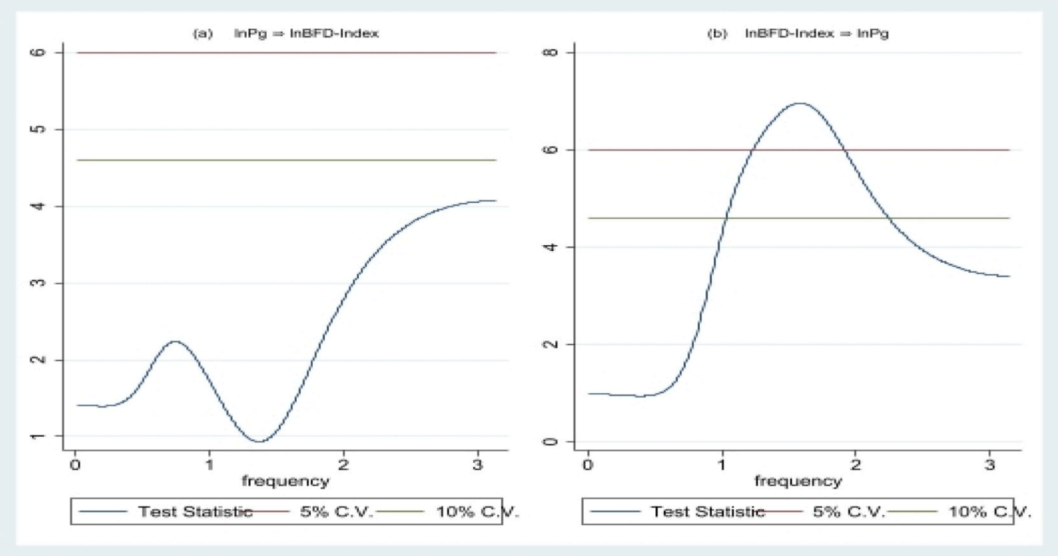


Fig. 8. Granger causality test – (a) from lnPg to lnBFD-Index (b) from lnBFD-Index to lnPg.

multiple steps. First, cointegration tests were conducted using the Bayer-Hanck (BH) and ARDL-bounds testing techniques. Second, the dynamic ordinary least squares (DOLS) estimator was employed to estimate fully efficient cointegration regression for the long-run parameters. To ensure robustness, the ARDL technique was used to account for both short- and long-run relationships in the parameter estimates. Finally, the Breitung-Candelon spectral Granger causality technique was applied to determine the direction of causality among the variables.

The results of the Bayer-Hanck and ARDL-bounds cointegration tests reveal a long-run equilibrium relationship between income, financial development, trade openness, and ELCF in Nigeria. The regression analyses and Granger causality tests yield the following noteworthy findings.

- The analysis confirms the existence of a valid U-shaped curve between real per capita GDP and ELCF, thereby validating the LCC hypothesis in Nigeria. Various model specifications indicate income threshold turning points ranging from $497.63 to $1794.64, all of which fall within Nigeria's current range of per capita GDP. No significant causality is observed in the medium-term and short-run periods. However, in the long term, there is unidirectional causality running from income to ELCF, which takes approximately four years to induce a significant causal impact on the ecological load capacity factor.

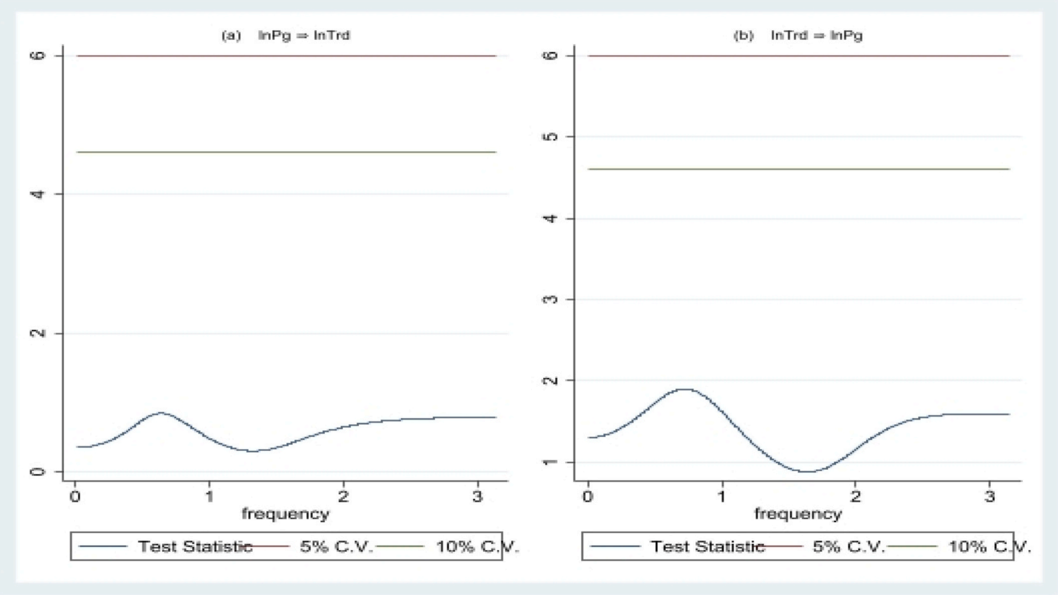


Fig. 9. Granger-causality test – (a) from lnPg to lnTrd (b) from lnTrd to lnPg.

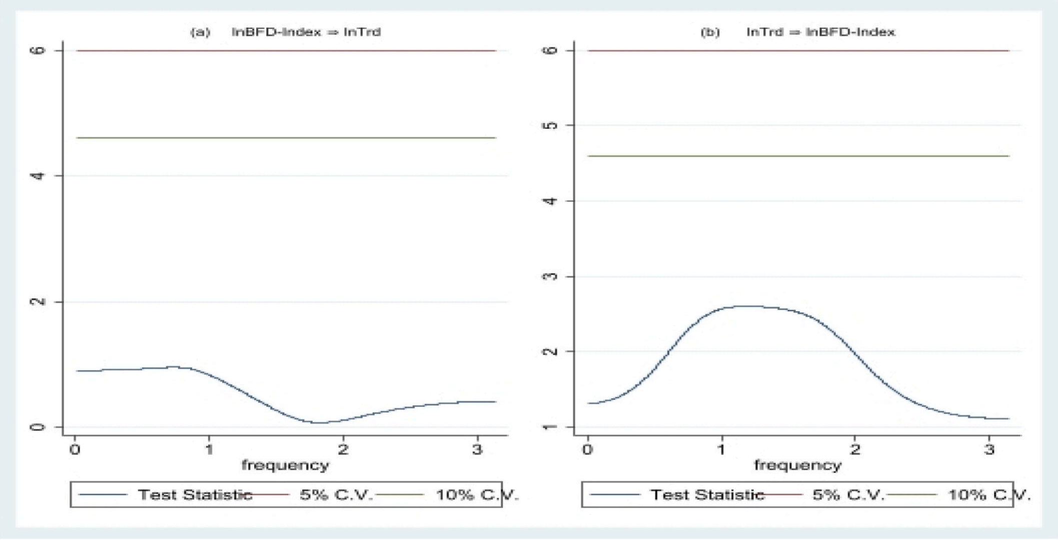


Fig. 10. Granger-causality test – (a) from lnBFD-Index to lnTrd (b) from lnTrd to lnBFD-Index.

- A negative relationship is found between financial development (BFD) indicators and the ecological load capacity factor in Nigeria. The causality is bidirectional and significant only in the long-run periods. It takes approximately six years for BFD to exert a significant causal impact on the ecological load capacity factor, while the feedback effect becomes significant after approximately eleven years. Additionally, a significant unidirectional causality is observed from BFD to income in the medium term.
- The relationship between trade openness and the ecological load capacity factor in Nigeria is negative. In the long-run periods, there is a significant unidirectional causality running from trade openness, taking approximately ten years to induce a significant causal impact on the ecological load capacity factor.

5.2. Policy implications

The above findings have significant implications for shaping development policies in Nigeria. First, it is crucial to sustain the growth in per capita income to foster ecologically friendly consumption and production patterns, as lower income levels tend to contribute to ecological degradation. This necessitates a shift in the structural composition of the economy towards more environmentally friendly consumption and production processes. Policy efforts can focus on promoting renewable energy use, energy efficiency, and technological innovation to improve per capita income while reducing strain on the ecological load capacity of the economy. Second, current policy initiatives in banking intermediation contribute to unsustainable consumption patterns, limiting the conservation of ecological productive resources (EPRs) for future needs. The observed two-way negative causality suggests that protecting EPRs is essential for sustaining the economic benefits associated with financial development. Therefore, there is a need to realign policy initiatives to prioritize investments and access to green and efficient technologies, providing mitigation benefits. Adjusting interest rate policies based on the ecological demands of proposed projects can incentivize ecologically sound investments. Additionally, banks can develop corporate green credit packages specifically tailored to support investments in environmentally friendly sectors. Third, trade policy initiatives in Nigeria primarily prioritize economic targets without considering the decline of EPRs. This explains the negative causal relationship between trade openness and the ecological resource base of the economy. It is imperative to diversify trade composition by promoting a shift towards environmentally sustainable trade structures. This can be achieved by implementing strict environmental regulations to ensure compliance with approved specifications for technology imports by domestic firms. Furthermore, efforts should focus on building capacity in the production of medium- and high-tech tradable goods with ecological considerations.

In summary, these findings emphasize the importance of sustainable economic growth, environmentally conscious banking policies, and a diversified and ecologically friendly trade structure. These policy directions can contribute to the conservation of ecological resources and promote a more sustainable and resilient development path for Nigeria.

5.3. Limitations and directions for future research

This study has some limitations that should be acknowledged. First, the empirical investigation solely focused on modelling the ecological load capacity factor in Nigeria, limiting its applicability for comparative analysis. Future empirical studies can expand their scope to include other African blocs, such as West Africa, East Africa, Southern Africa, and North Africa economies, enabling a broader understanding of ecological load capacity variations across regions. Second, this study utilized banking sector development indicators as measures of financial development. To gain a more comprehensive understanding of the impact of financial development on ecological sustainability, future empirical studies can consider incorporating market-based indicators and exploring their influence on ecological factors. Third, this study employed ARDL and frequency domain causality techniques to analyse the causal relationships among the selected variables. Future empirical studies can explore alternative models and techniques, such as quantile ARDL regression (QARDL). By addressing these limitations and taking into account the suggested directions, future studies can provide fresh and valuable empirical insights into the nexus between income, finance, trade, and the environment, as well as their implications for sustainable development.

Author contribution statement

Benedette Nneka Okezie, Chinazaekpere Nwani, Hilary Ikechukwu Nnam & Perpetual Ijeoma Onuoha: Conceived and designed the experiments, performed the experiments, analysed and interpreted the data, contributed reagents, materials, analysis tools or data, wrote the paper.

Data availability statement

The datasets used and/or analysed can be accessed online: 2023 National Footprint and Biocapacity Accounts, *Global Footprint Network*. Available online: https://data.footprintnetwork.org/; WDI available at https://databank.worldbank.org/source/world-development-indicators; Global Financial Development Database update September 2022, *World Bank*, https://www.worldbank.org/en/publication/gfdr/data/global-financial-development-database.

Declaration of competing interest

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.

Appendix

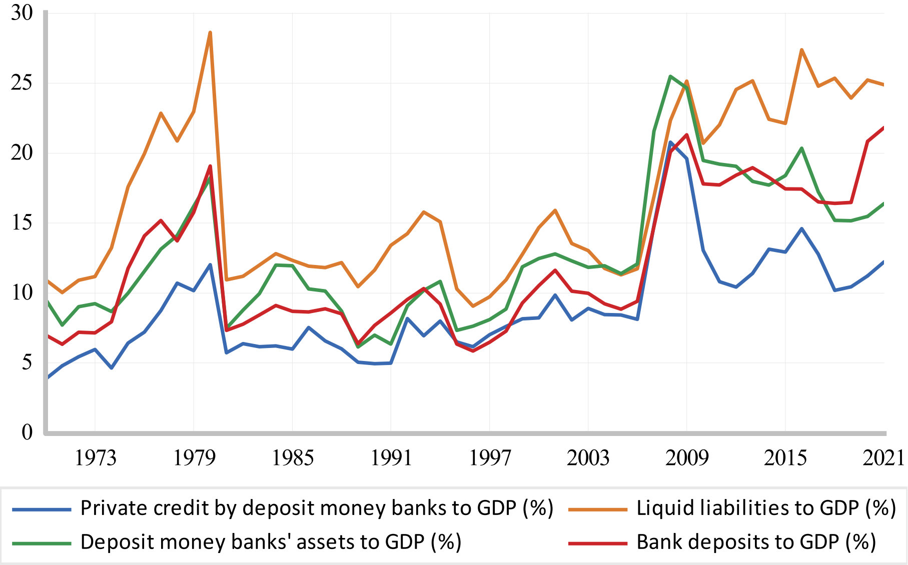


Fig. A1. Bank-based indicators of financial development

References

[1] Gfn, in: National Footprint and Biocapacity Accounts, 2023, Global Footprint Network, 2023. https://data.footprintnetwork.org/?_ga=2.143546428.849031653.1677937436-2147145951.1637574805#/countryTrends?cn=5001&type=BCtot,EFCtot.

[2] J. Qin, W. Duan, Y. Chen, V.A. Dukhovny, D. Sorokin, Y. Li, X. Wang, Comprehensive evaluation and sustainable development of water–energy–food–ecology systems in Central Asia, Renew. Sustain. Energy Rev. 157 (2022), 112061.

[3] H. Jie, I. Khan, M. Alharthi, M.W. Zafar, A. Saeed, Sustainable energy policy, socio-economic development, and ecological footprint: the economic significance of natural resources, population growth, and industrial development, Util. Pol. 81 (2023), 101490.

[4] H. Nautiyal, V. Goel, Sustainability assessment: metrics and methods, in: Methods in Sustainability Science, Elsevier, 2021, pp. 27–46.

[5] K. Blackburn, V.T. Hung, A theory of growth, financial development and trade, Economica 65 (257) (1998) 107–124.

[6] D.H. Kim, S.C. Lin, Y.B. Suen, The simultaneous evolution of economic growth, financial development, and trade openness, J. Int. Trade Econ. Dev. 21 (4) (2012) 513–537.

[7] R. De Haas, A. Popov, Finance and green growth, Econ. J. 133 (650) (2023) 637–668.

[8] M.G. Grossman, B.A. Krueger, Environmental Impacts of A North American Free Trade Agreement (No. W3914), National Bureau of Economic Research, 1991. https://www.nber.org/papers/w3914.

[9] G.M. Grossman, A.B. Krueger, Economic growth and the environment, Q. J. Econ. 110 (2) (1995) 353–377.

[10] M.A. Ansari, Re-visiting the Environmental Kuznets curve for ASEAN: a comparison between ecological footprint and carbon dioxide emissions, Renew. Sustain. Energy Rev. 168 (2022), 112867.

[11] M. Shahbaz, G. Gozgor, P.K. Adom, S. Hammoudeh, The technical decomposition of carbon emissions and the concerns about FDI and trade openness effects in the United States, International Economics 159 (2019) 56–73.

[12] J.T. Dada, A. Adeiza, N.A. Ismail, M. Arnaut, Financial development–ecological footprint nexus in Malaysia: the role of institutions, Manag. Environ. Qual. Int. J. 33 (4) (2022) 913–937.

[13] C. Nwani, Financing low-carbon growth in Africa: policy path for strengthening the links between financial intermediation, resource allocation and environmental sustainability, Cleaner Environmental Systems 6 (2022), 100082.

[14] W. Wang, M.A. Rehman, S. Fahad, The dynamic influence of renewable energy, trade openness, and industrialization on the sustainable environment in G-7 economies, Renew. Energy 198 (2022) 484–491.

[15] T.S. Adebayo, H. Sevinç, D.E. Sevinç, O.S. Ojekemi, D. Kirikkaleli, A Wavelet-Based Model of Trade Openness with Ecological Footprint in the MINT Economies, Energy & Environment, 2023, 0958305X221150489.

[16] P.C. Omoke, C. Nwani, E.L. Effiong, O.O. Evbuomwan, C.C. Emenekwe, The impact of financial development on carbon, non-carbon, and total ecological footprint in Nigeria: new evidence from asymmetric dynamic analysis, Environ. Sci. Pollut. Control Ser. 27 (17) (2020) 21628–21646.

[17] J.T. Dada, A. Adeiza, A.I. Noor, A. Marina, Investigating the link between economic growth, financial development, urbanization, natural resources, human capital, trade openness and ecological footprint: evidence from Nigeria, J. Bioecon. 24 (2022) 153–179.

[18] S. Acar, N. Altıntaş, V. Haziyev, The effect of financial development and economic growth on ecological footprint in Azerbaijan: an ARDL bound test approach with structural breaks, Environ. Ecol. Stat. 30 (2023) 41–59.

[19] M. Ben Jebli, M. Madaleno, N. Schneider, U. Shahzad, What does the EKC theory leave behind? A state-of-the-art review and assessment of export diversification-augmented models, Environ. Monit. Assess. 194 (6) (2022) 414.

[20] Z. Wang, X. Ye, Re-examining environmental Kuznets curve for China's city-level carbon dioxide (CO2) emissions, Spatial Statistics 21 (2017) 377–389.

[21] J. Baek, A panel cointegration analysis of CO2 emissions, nuclear energy and income in major nuclear generating countries, Appl. Energy 145 (2015) 133–138.

[22] E. Dogan, N. Taspinar, K.K. Gokmenoglu, Determinants of ecological footprint in MINT countries, Energy Environ. 30 (6) (2019) 1065–1086.

[23] U.K. Pata, A.E. Hizarci, Investigating the Environmental Kuznets Curve in the Five Most Complex Countries: Insights from a Modified Ecological Footprint Model, Energy & Environment, 2022, 0958305X221120255.

[24] F.J. Hasanov, J.I. Mikayilov, S. Mukhtarov, E. Suleymanov, Does CO 2 emissions–economic growth relationship reveal EKC in developing countries? Evidence from Kazakhstan, Environ. Sci. Pollut. Control Ser. 26 (2019) 30229–30241.

[25] L.C. Voumik, M. Rahman, S. Akter, Investigating the EKC hypothesis with renewable energy, nuclear energy, and R&D for EU: fresh panel evidence, Heliyon 8 (2022), e12447.

[26] U.K. Pata, M.T. Kartal, Impact of nuclear and renewable energy sources on environment quality: testing the EKC and LCC hypotheses for South Korea, Nucl. Eng. Technol. 55 (2) (2023) 587–594.
[27] U.K. Pata, A. Samour, Do renewable and nuclear energy enhance environmental quality in France? A new EKC approach with the load capacity factor, Prog. Nucl. Energy 149 (2022), 104249.
[28] S.S. Akadiri, T.S. Adebayo, J.S. Riti, A.A. Awosusi, E.M. Inusa, The effect of financial globalization and natural resource rent on load capacity factor in India: an analysis using the dual adjustment approach, Environ. Sci. Pollut. Control Ser. 29 (59) (2022) 89045–89062.
[29] N. Latif, M.Z. Faridi, System GMM analysis for asian economies: examining the impact of financial development on load capacity factor (LCF), Front. Energy Res. 10 (2023) 2045.
[30] R. Siche, L. Pereira, F. Agostinho, E. Ortega, Convergence of ecological footprint and emergy analysis as a sustainability indicator of countries: Peru as case study, Commun. Nonlinear Sci. Numer. Simulat. 15 (10) (2010) 3182–3192.
[31] T.A.B. Agila, W.M. Khalifa, S. Saint Akadiri, T.S. Adebayo, M. Altuntaş, Determinants of load capacity factor in South Korea: does structural change matter? Environ. Sci. Pollut. Control Ser. 29 (46) (2022) 69932–69948.
[32] E. Akhayere, M.T. Kartal, T.S. Adebayo, D. Kavaz, Role of energy consumption and trade openness towards environmental sustainability in Turkey, Environ. Sci. Pollut. Control Ser. 30 (8) (2023) 21156–21168.
[33] M.T. Kartal, A. Samour, T.S. Adebayo, S.K. Depren, Do nuclear energy and renewable energy surge environmental quality in the United States? New insights from novel bootstrap Fourier Granger causality in quantiles approach, Prog. Nucl. Energy 155 (2023), 104509.
[34] WDI, World development indicators, World Bank. (2023). Available online: https://databank.worldbank.org/home.aspx.
[35] I.S. Abubakar, S.S. Akadiri, Revisiting oil rents-output growth nexus in Nigeria: evidence from dynamic autoregressive distributive lag model and kernel-based regularized least squares approach, Environ. Sci. Pollut. Control Ser. 29 (30) (2022) 45461–45473.
[36] G. Li, A. Zakari, V. Tawiah, Energy resource melioration and CO2 emissions in China and Nigeria: efficiency and trade perspectives, Resour. Pol. 68 (2020), 101769.
[37] J. Breitung, B. Candelon, Testing for short-and long-run causality: a frequency-domain approach, J. Econom. 132 (2) (2006) 363–378.
[38] Z. Gong, Y. Wu, V. Tawiah, Z. Abdulrasheed, The environmental footprint of international business in Africa; the role of natural resources, Resour. Pol. 80 (2023), 103239.
[39] Z. Ahmed, A.E. Caglar, M. Murshed, A path towards environmental sustainability: the role of clean energy and democracy in ecological footprint of Pakistan, J. Clean. Prod. 358 (2022), 132007.
[40] M. Ouedraogo, D. Peng, X. Chen, S.H. Hashmi, Testing the mineral resources-induced environmental Kuznets curve hypothesis in Africa, Nat. Resour. Res. 31 (5) (2022) 2435–2459.
[41] U.K. Pata, C. Isik, Determinants of the load capacity factor in China: a novel dynamic ARDL approach for ecological footprint accounting, Resour. Pol. 74 (2021), 102313.
[42] Z. Ni, J. Yang, A. Razzaq, How do natural resources, digitalization, and institutional governance contribute to ecological sustainability through load capacity factors in highly resource-consuming economies? Resour. Pol. 79 (2022), 103068.
[43] U.K. Pata, D. Balsalobre-Lorente, Exploring the impact of tourism and energy consumption on the load capacity factor in Turkey: a novel dynamic ARDL approach, Environ. Sci. Pollut. Control Ser. 29 (9) (2022) 13491–13503.
[44] U.K. Pata, M.T. Kartal, T.S. Adebayo, S. Ullah, Enhancing environmental quality in the United States by linking biomass energy consumption and load capacity factor, Geosci. Front. 14 (3) (2023), 101531.
[45] A.E. Caglar, E. Yavuz, The role of environmental protection expenditures and renewable energy consumption in the context of ecological challenges: insights from the European Union with the novel panel econometric approach, J. Environ. Manag. 331 (2023), 117317.
[46] R. York, E.A. Rosa, T. Dietz, STIRPAT, IPAT and ImPACT: analytic tools for unpacking the driving forces of environmental impacts, Ecol. Econ. 46 (3) (2003) 351–365.
[47] L. Dingru, S.T. Onifade, M. Ramzan, M.A.S. AL-Faryan, Environmental perspectives on the impacts of trade and natural resources on renewable energy utilization in Sub-Sahara Africa: accounting for FDI, income, and urbanization trends, Resour. Pol. 80 (2023), 103204.
[48] C. Bayer, C. Hanck, Combining non-cointegration tests, J. Time Anal. 34 (1) (2013) 83–95.
[49] R.F. Engle, C.W. Granger, Co-integration and error correction: representation, estimation, and testing, Econometrica: J. Econom. Soc. (1987) 251–276.
[50] S. Johansen, Statistical analysis of cointegration vectors, J. Econ. Dynam. Control 12 (2–3) (1988) 231–254.
[51] H.P. Boswijk, Testing for an unstable root in conditional and structural error correction models, J. Econom. 63 (1) (1994) 37–60.
[52] A. Banerjee, J. Dolado, R. Mestre, Error-correction mechanism tests for cointegration in a single-equation framework, J. Time Anal. 19 (3) (1998) 267–283.
[53] M.H. Pesaran, Y. Shin, R.J. Smith, Bounds testing approaches to the analysis of long run relationships, J. Appl. Econom. 16 (2001) 289–326.
[54] S. Kripfganz, D.C. Schneider, Response surface regressions for critical value bounds and approximate p-values in equilibrium correction models 1, Oxf. Bull. Econ. Stat. 82 (6) (2020) 1456–1481.
[55] J.H. Stock, M.W. Watson, A simple estimator of cointegrating vectors in higher order integrated systems, Econometrica: J. Econom. Soc. (1993) 783–820.
[56] J.G. Montalvo, Comparing cointegrating regression estimators: some additional Monte Carlo results, Econ. Lett. 48 (3–4) (1995) 229–234.
[57] H. Tastan, Testing for spectral Granger causality, STATA J. 15 (4) (2015) 1157–1166.
[58] J. Geweke, Measurement of linear dependence and feedback between multiple time series, J. Am. Stat. Assoc. 77 (378) (1982) 304–313.
[59] E. Zivot, D.W.K. Andrews, Further evidence on the great crash, the oil-price shock, and the unit-root hypothesis, J. Bus. Econ. Stat. 20 (1) (1992) 25–44.
[60] S. Gygli, F. Haelg, N. Potrafke, J.E. Sturm, The KOF globalisation index-revisited 14 (3) (2018) 543–574.
[61] K. Sebastian, C.S. Daniel, ardl: estimating autoregressive distributed lag and equilibrium correction models, TUPD Discussion Papers 18 (2022) 1–33.