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Balancing the Scales: Does Public Debt and Energy Poverty Mitigate or Exacerbate Ecological Distortions in Nigeria?

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Research Department

Balancing the Scales: Does Public Debt and Energy Poverty Mitigate or Exacerbate Ecological Distortions in Nigeria?

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Abstract

Amid Nigeria's economic growth and energy challenges, the escalating public debt levels and persistent energy poverty raise critical questions about their potential impacts on the environment. Given the potential conflict between economic development, energy poverty alleviation, and ecological conservation, it becomes pertinent to understand whether increased public debt and efforts to address energy poverty inadvertently contribute to or alleviate ecological imbalances within the country. Hence, this research investigates the effect of public debt and energy poverty on the load capacity factor (LCF) in Nigeria. Using the STIRPAT model and annual data from 1990 to 2021, the study explores the relationships among total public debt, energy poverty, gross domestic product per capita, urbanization, and LCF. Descriptive analysis, correlation assessments, and unit-root tests precede the data analysis conducted with the autoregressive distributed lag (ARDL) model and dynamic ARDL (DARDL) technique. Key findings reveal significant negative effects of urbanization and energy poverty on LCF. Additionally, the ARDL and DARDL procedure highlights a positive long-term relationship between public debt and LCF. Both ARDL and DARDL analyses show a negative short-term relationship between GDP growth per capita and LCF, signaling the need for sustainable economic practices. The study concludes with policy recommendations that aim to promote sustainable development and address ecological imbalances by tackling energy poverty and public debt challenges in Nigeria.

Keywords: Public Debt, Energy Poverty, Load Capacity Factor, STIRPAT Model, Sustainability

1. Introduction

Environmental scientists and scholars have increasingly devoted a great deal of their research to environmental deterioration and sustainable development issues (Ofori et al, 2023). Also, several accords, like the 2015 Paris Agreement (COP21) and the 2021 Glasgow Climate Pact (COP26), have been negotiated in recent times to address environmental challenges and develop workable solutions to global warming and climate change. Resultantly, many countries across the globe are taking different initiatives to attain net-zero carbon emissions and ensure a sustainable environment (Obobisa et al., 2022a; Obobisa et al., 2022b). To do so, national and regional efforts that promote the adoption of renewable energy, green trade, green accounting, and green human resource management, among other things are gaining momentum (Murshed et al., 2022; Dimnwobi et al., 2022a; Obobisa et al., 2022a; Obobisa et al., 2022b). Additionally, a growing body of research has been conducted to determine the impact of specific economic factors on environmental pollution in various economies (Gorus & Aslan, 2019; Aboagye et al., 2020; Elfaki et al, 2022). Many of these research conclusions point to the need for empirical attention to additional factors not adequately discussed in the literature. It is hardly unexpected, then, that the impact of the debt stock and energy poverty has recently piqued the interest of researchers (Alhassan & Kwakwa, 2022; Sadiq et al, 2022; Farooq et al., 2023; Ansari et al., 2022; Bilgili et al.,2022; Zhang et al., 2022).

Like most developing economies, Nigeria has pledged to mitigate climate change by lowering carbon dioxide (CO2) emissions (Maduka et al., 2022). Notwithstanding several laudable policies to combat CO2 emissions introduced by the nation's decision-makers over time, the continued rise in CO2 emissions remains worrisome, given that Nigeria is particularly vulnerable to climate change because of the significant reliance on natural resources for energy and food. For example, statistics from World Bank (2022) highlighted that CO2 emissions grew from 72770kt in 1990 to 115280kt in 2019. Consequently, it is critical to focus on unexplored variables that could influence or mitigate environmental pollution in Nigeria. Empirical evidence suggests that factors such as economic expansion, population growth, globalization, financial advancement, agricultural development, and energy use, among others, influence the country's carbon dioxide emissions (Sulaiman & Abdul-Rahim, 2018; Agboola & Bekun, 2019; Uche & Effiom, 2021; Akadiri et al., 2022; Maduka et al, 2022). However, in Nigeria, attention is yet to be paid to how important factors like public borrowing and energy poverty affect CO2 emissions.

Nigeria's public borrowing has significantly risen in recent years. For instance, the nation's debt level rose from $57.39 billion in December 2016 (DMO, 2016) to $103.11 billion in December 2022 (DMO, 2022). Unsurprisingly, a reoccurring national debate has centred on the sustainability and implications of the nation's debt stock. However, the nation's decision-makers have fiercely justified these huge borrowings as vital to fund ecological sustainability initiatives like eco-friendly research and development and renewable energy projects, which will eventually improve the state of the environment. According to Alhassan and Kwakwa (2022), public borrowing can help to improve the environment by investing in and researching eco-friendly technologies. Government debt, on the other hand, may cause strain on the environment due to the requirement to boost economic output to meet debt obligations (Farooq et al. 2023). Similarly, Qi et al (2022) observed that debt may increase deforestation and hinder the growth of renewable energy sources. However, the ecological effect of public borrowing has not yet been taken into consideration in the Nigerian literature.

Similarly, poor power access continues to afflict Nigeria (Africa's biggest and most populous economy), highlighted by the unstable nature of the nation's chosen energization plans. The lack of robust implementation of electrification plans in the country portends great risk for the nation (Monyei et al., 2022; Isihak, 2023). Nigeria, which has a population of more than 213 million, only has a 55.4% access rate to electricity, according to the World Bank (2022), with just 24.6% and 83.9% of its rural and urban populations, respectively, having access to power. The majority of homes that are connected to the power grid endure regular voltage changes and daily outages, prompting the widespread reliance on diesel and gasoline-powered generators as well as other high-polluting fuels to meet electricity needs (Omoju et al 2020; Dimnwobi et al, 2022b; Dimnwobi et al, 2023a). The use of these unclean fuels leads to indoor air pollution, and as per the World Health Organization (WHO), indoor air pollution-related ailments account for 3.8 million annual fatalities. When people are starved of clean energy access, they are unable to use modern cooking appliances and rely on readily available environmentally unfriendly and inexpensive fuels such as firewood (Asongu & Odhiambo 2023; Okere at el., 2023a).

Therefore, deepening the sustainability discourse also lies in exploring the intricate relationship among these variables - public debt, energy poverty, and the environment. Indeed, public debt plays a significant role in financing infrastructure development, including energy projects aimed at addressing energy poverty (Bednar & Reames, 2020). However, excessive public debt can pose challenges to the government's ability to invest in energy infrastructure, thereby exacerbating energy poverty and limiting environmental sustainability (Adebayo & Samour, 2022; Bolson et al., 2022). Energy poverty, characterized by the lack of access to reliable and affordable energy services, further compounds the challenges of achieving an optimal environment (Khan et al., 2023; Adebayo, & Samour, 2022). Hence, insufficient energy infrastructure and limited energy access hinder the generation and distribution of electricity, resulting in environmental damage (Bolson, et al., 2022; Adebayo, & Samour, 2022). Addressing these interconnected issues requires a balanced approach that manages public debt sustainability, promotes energy access, and invests in efficient energy infrastructure to optimize environmental sustainability and alleviate energy poverty in Nigeria.

Given the foregoing premise, two research questions are addressed in this study. (1) Does public debt stock aggravate or mitigate environmental pollution in Nigeria? (2) Has energy poverty worsened or improved Nigeria's environmental performance? In tackling these research questions, this study makes important contributions to the literature. First, this study is a first-of-its-kind attempt to analyze the environmental effect of public borrowing and energy poverty. Several considerations drive the motivation for researching the influence of public debt and energy poverty on environmental deterioration. To start with, the United Nations' Sustainable Development Goals (SDGs) advocate for a balance of economic progress, social inclusion, and environmental protection. Understanding the link between debt, energy insecurity, and environmental degradation might help decision-makers devise effective strategies for achieving these objectives. Additionally, to address global concerns, research on the connections between public debt, energy poverty, and environmental degradation might promote international cooperation. Countries may share knowledge and create collaborative solutions to achieve sustainable development by realizing the interconnectedness and complexity of these variables. On the other hand, energy poverty affects a sizable section of Nigeria's population, and access to dependable and clean energy sources is severely constrained. The use of conventional fuels, such as biomass, results in deforestation and indoor air pollution, which hurt human health and the environment. Examining the connection between energy poverty and environmental deterioration might assist direct policies meant to increase access to energy while minimizing harmful environmental effects. Furthermore, Nigeria, like many other developing nations, is heavily indebted. Effective debt management and planning for sustainable development depend on having a clear understanding of how public debt affects environmental deterioration. This field of study can shed light on how debt management tactics might be coordinated with environmental sustainability objectives. Similarly, Nigeria is dedicated to combating climate change and meeting its obligations under international treaties such as the Paris Agreement. Research on the influence of public debt and energy poverty on environmental degradation might assist Nigeria in assessing its progress toward its climate obligations and identifying areas for improvement, hence influencing policy decisions and international cooperation efforts.

Second, while most studies have employed total electricity access to proxy energy poverty, the present study employed three inclusive proxies of energy poverty namely total electricity access, and rural and urban electricity access. The urban-rural differences in access to electricity are valuable for highlighting evidence of disparities in access to power in Nigeria between urban and rural areas. Third, most studies have utilized CO2 emissions and ecological footprint (EF) as an indicator of the environment (Mewamba-Chekem & Noumessi, 2021; Alhassan & Kwakwa, 2022; Bilgili et al., 2022; Sadiq et al, 2022). However, both metrics provide for just a demand-side study of environmental strain. This strategy ignores natural resources' ability to cope with anthropogenic stresses on water, soil, and air ecosystems. To sidestep these shortcomings, this study employs the load capacity factor (LCF), which incorporates both biocapacity and EF, making it possible to evaluate the environment from both the demand and supply sides. This strategy elevates environmental preservation debates to a new level, allowing Nigerian policymakers to assess the environment from a comprehensive viewpoint to make informed decisions. Fourth, this study employed the dynamic ARDL. This novel method can analyze, stimulate, and display charts of variable fluctuations, both positive and negative, as well as their correlations over both the short- and long-term. Consequently, more reliable, objective, and accurate results can be derived through this method. Fifth, the study focused on one of the world's energy-poorest nations, with high debt levels and vulnerability to climate change to obtain reliable and authentic empirical evidence to address major environmental challenges. Finally, our research contributes to the existing body of knowledge by providing policymakers with an approach to mitigating the negative repercussions of environmental degradation.

The other segments of the paper are structured as follows. The following section provides a literature assessment of the subject matter. Section three details the data set, model, and technique and section four offers the empirical outcomes. The paper is wrapped up in the final section.

2. Literature Review

2.1. Theoretical Connections between public debt and environmental performance

The connection between public debt and environmental pollution can be explained through the environmental Kuznets curve (EKC), public choice theory, and ecological modernization theory. According to the EKC theory, there is a negative U-shaped association between income levels and environmental deterioration. When specifically considering public debt and environmental pollution, the following explanations can be derived: During the early stages of economic development, public borrowing might be used to fund infrastructure projects and initiatives aimed at industrialization (Dimnwobi et al., 2023b). This can result in an increase in pollution levels as industries lacking proper pollution control measures experience rapid growth, leading to environmental degradation. But when economies grow and civilizations advance, they frequently become more conscious of ecological issues. At this point, public borrowing can be allocated to fund environmental integrity initiatives including making investments in renewable energy, putting pollution control laws into place, and encouraging sustainable behavior (Farooq et al., 2023). As a result, environmental pollution can decrease despite the presence of public debt.

Second, public choice theory evaluates how interest groups, political dynamics, and the behaviour of policymakers influence the outcomes of environmental policies. The following justifications can be drawn from the relationship between public debt and environmental pollution. Interest groups, such as industries that place a higher priority on immediate financial gain than long-term environmental sustainability, may have an impact on the decisions made about public debt (Onuoha et al., 2023a). As a result, public debt might be used to fund industries that contribute to pollution or to support policies that have negative environmental effects. When deciding how to deploy borrowed funds, decision-makers may put economic development ahead of environmental considerations due to fiscal pressures and constraints. This could result in less investment in pollution mitigation initiatives or a failure to adopt and enforce environmental legislation (Onuoha et al., 2023b).

Lastly, the ecological modernization theory proposes that through technological innovation and economic restructuring, both economic growth and environmental improvements can be achieved. The following explanations can be drawn from the nexus between governmental debt and environmental pollution. Public debt can be used to finance investments in environmentally friendly policies, clean energy, and green technologies. This may lead to the adoption of more environmentally friendly industrial techniques and the encouragement of economically viable ventures, ultimately resulting in a decrease in environmental pollution. The reduction of public debt can assist in the transition to a more resource and sustainability-conscious economy. It can support programs encouraging resource preservation, circular economy principles, and environmentally friendly patterns of production and consumption (Sun & Liu, 2020).

2.2. Empirical Literature on public debt and environmental performance

In terms of empirical evidence, Clootens (2017) appraised the governmental debt-environmental deterioration in 59 different countries between 2000 and 2010 and the study confirms that environmental preservation efforts may be constrained by high levels of government debt. In Turkey, Katircioglu and Celebi (2018) revealed that external debt had no significant influence on ecological damage. A similar study conducted by Akam et al (2021a) and Akam et al (2021b) revealed that ecological conditions are not significantly influenced by foreign debt stock in four African and 33 economies respectively. Bese et al (2021a) and Bese et al. (2021b) discovered that increasing foreign debt is considerably responsible for ecological damage in India and China respectively. Focusing on emerging economies from 1990 to 2019, Sadiq et al (2022) highlighted that foreign debt aids ecological preservation. In a related study for Ghana, Alhassan and Kwakwa (2022) concluded that government borrowing initially protects the environment but when the debt level is doubled, public borrowing will no longer be environmentally friendly. In a comparable study for China, Qi et al (2022) revealed that public borrowing significantly lowers the amount of pollution in cities. For selected Islamic nations between 1996 and 2018, Farooq et al. (2023) documented that public borrowing damages environmental conditions. Xie et al (2023) demonstrated that local government debt levels significantly reduce corporate environmental emissions in China. Likewise, Bachegour and Qafas (2023) demonstrate that Morocco's carbon dioxide emissions are significantly impacted negatively by its external debt. In a recent study for SSA, Dimnwobi et al (2023b) revealed that public borrowing undermines the environment.

The foregoing highlights that very little attention has been devoted to the debt-environment relationship as prior studies provide opposing viewpoints on the significance of public debt in achieving improved environmental conditions. We observed from the literature that past studies adopted carbon emissions or ecological quality to capture environmental performance. This study departs from these studies by employing the load capacity factor owing to its completeness and comprehensiveness. Since the LCF concurrently captures the supply and demand sides of the environment, it is a superior proxy for determining the level of environmental quality. Using metrics that capture only the demand side of the environment cannot provide a true picture of the environment and consequently, the LCF, a more complete environmental quality metric, was deployed in this study.

In light of these discussions, we assessed these hypotheses (No 1):

H_0: Public borrowing has no considerable effect on environmental degradation in Nigeria

H_1: Public borrowing significantly impacts environmental degradation in Nigeria

2.3. Theoretical Linkages between energy poverty and the environment

There are several theories linking energy poverty to environmental performance. In this study, these theories namely energy justice theory, environmental justice theory, and transition theory are documented. Energy justice theory emphasizes the fair distribution of energy access, benefits, and impacts on the environment (Sun et al., 2023). The theory emphasizes that marginalized and low-income communities often face limited access to clean and affordable energy sources. Consequently, they may depend on hazardous and inefficient energy sources like kerosene or solid biomass that worsen the environment and pollute the air. These factors pose health risks and harm ecosystems (Acheampong & Opoku, 2023). On the flip side, environmental justice theory highlights that different socioeconomic groups are disproportionately affected by environmental benefits and burdens. According to the hypothesis, populations that are underprivileged and marginalized experience pollution at a higher rate because they have less access to clean energy sources (Wang et al., 2023). These communities frequently reside close to businesses or power plants that produce pollution or suffer from the harmful consequences of energy production processes. This leads to environmental inequities, which perpetuate environmental deterioration and exacerbate existing socioeconomic imbalances (Hardy, 2023).

Finally, transition theory appraises the process of shifting from inefficient to more efficient energy systems. In the context of energy poverty and environmental degradation, transition theory emphasizes the necessity of a fair and inclusive energy transition. It acknowledges that combating energy insecurity and environmental degradation necessitates a switch from fossil fuel-based energy sources to clean and renewable alternatives. This shift should prioritize offering inexpensive and accessible clean energy alternatives to energy-poor populations. By doing this, it will be possible to stop the cycle of environmental deterioration brought on by their reliance on dirty energy sources (Bilgili et al., 2022)

Using the theories of energy justice, environmental justice, and transition, we may comprehend the complex relationship between energy poverty and environmental deterioration. These theories emphasize the pressing need to address energy poverty in a way that is both ecologically responsible and socially ethical, guaranteeing equitable access to energy, lowering environmental costs for underserved groups, and promoting a fair transition to cleaner energy systems.

2.2. Empirical Literature on Energy Poverty and Environmental Sustainability Nexus

Focusing on the outcome of past studies, Mewamba-Chekem and Noumessi (2021) discovered that energy poverty had a minor influence on the ecological decline in selected SSA economies from 1996 to 2015. Ansari et al. (2022) assessed the macroeconomic consequences of energy insecurity in SSA and found that energy poverty (measured by access to electricity) fosters ecological preservation. For some selected Asian economies, Bilgili et al. (2022) found that expanding electricity access (i.e., reducing energy insecurity) reduces ecological decline. While the foregoing studies documented that energy poverty is environmentally friendly, some studies found the opposite. For instance, Hishan et al (2019) highlighted that clean cooking technology and electricity access positively influenced the ecological decline in a sample of 35 SSA nations from 1995 to 2016. Dumor et al. (2022)'s assessment of African nations from 1980 to 2020 showed that access to electricity undermines ecological quality. Using electricity access in the total population to capture energy insecurity, Hassan et al. (2022) documented that energy poverty deteriorates the BRICS's environment. Zhao et al (2021) appraised the connection between energy poverty and ecological contamination in China and highlighted that this relationship is significantly positive. Zhang et al. (2022) assessed the impact of the energy deficit on China’s construction industry’s carbon intensity and discovered that energy poverty increases the sector's carbon intensity. Focusing on 40 developing nations, Baiwei et al (2023) discovered that energy poverty reduces ecological damage.

Taking the preceding findings into account, there is no agreement among researchers regarding the influence of energy poverty and ecological preservation. Furthermore, the load capacity factor was not taken into account as an ecological indicator. Also, several past studies have majorly utilized national electricity access as a proxy for energy poverty, which is not a comprehensive measure of energy poverty. This study uses three proxies for energy poverty which include overall access to electricity, and urban and rural electrification. For these reasons, the study will add to the existing body of knowledge.

From the foregoing discussions, these hypotheses were tested, (No 2)

H_0: Nigeria’s environmental sustainability is not significantly influenced by energy poverty

H_1: Nigeria’s environmental sustainability is significantly impacted by energy poverty

3. Methodology

3.1. Data description

The analysis made use of annual data from 1990 through 2021. The LCF, which is the dependent variable, is derived by dividing biocapacity by ecological footprint. Public borrowing and energy poverty are the key independent variables. The study employed three modern inclusive proxies of energy poverty, notably access to electricity in the overall population, in rural areas, and in urban areas. In line with past research (Alhassan & Kwakwa, 2022; Ansari et al., 2022; Dimnwobi et al., 2021; Farooq et al., 2023), we used economic growth and urbanization as control variables. The sources of the variables are compiled in Appendix 1.

3.2. Model Specification and data sources

Ehrlich and Holdren (1971) and its later version by Chertow, (2001) proposed the IPAT model to examine how human activities affect the environment and its resources. The model shows that environmental impacts are determined by

$$I = P * A * T \quad (1)$$

Where I is the environmental impact, such as pollution or resource use. P is the human population\urbanization or the number of people involved in the activity. A is the affluence or the level of consumption per person. T is the technology or the impact per unit of consumption. Thus, the IPAT model offers an alternative explanation of the impact of human activities on the environment, as domiciles in York et al. (2003). Recognizing the limited empirical coverage of the IPAT model, Dietz and Rosa (1994) introduced the STIRPAT model as an econometric regression tool for statistical analysis. The STIRPAT model aims to examine the relationship between population, wealth, technology, and environmental impacts. It is formulated as follows:

$$I_t = \beta_0 . P_t^{\beta_1} . A_t^{\beta_2} . T_t^{\beta_3} \quad (2)$$

Based on Equation 2, the constant term β_0 acts as a scaling factor for the function. The variables β_1, β_2, and β_3 represent the elasticities of P, A, and T, respectively. These elasticities need to be determined using suitable econometric methods to provide insights for policymaking. The variable "t" represents the time element. Expanding on previous research conducted by (Okere et al., 2021; Muoneke et al., 2022) the model incorporates additional factors of public debt (PB) and energy poverty (EP), resulting in the following formulation:

$$I_t = \beta_0 . P_t^{\beta_1} . A_t^{\beta_2} . PB_t^{\beta_3} . EP_t^{\beta_4} . \varepsilon_t \quad (3)$$

By applying the natural logarithm (ln) transformation to Equation 3, this study establishes the following functional relationship to guide empirical investigation:

$$lnLCF_t = \beta_0 + \beta_1 lnPG_t + \beta_3 lnGDPC_t + \beta_2 + lnEP_t + \beta_4 lnPD_t + \varepsilon_t \quad (4)$$

Equation 4 introduces a logarithmic framework representation of the variables (ln) and relates them to different aspects of environmental impacts. In this equation, LCF represents the environmental impacts measured by the ecological load capacity factor. PG denotes urbanization, and GDPC serves as a proxy for affluence, specifically GDP per capita. Additionally, EP[1] and PD represent energy poverty and public debt, respectively.

3.3. Dynamic ARDL Simulations

In this study, an autoregressive distributed lag (ARDL) model is employed to examine the specifications outlined in Equation (4). The analysis utilizes a dynamic simulation algorithm developed by Jordan and Philips (2018), and was carefully implemented by (Abbasi, et al. 2021; Iorember et al. 2022; Okere et al. 2023b). The initial steps involve estimating the following ARDL equation in error-correction form

$$\Delta lnLCF_t = a_0 + \psi_0 lnLCF_{t-1} + \psi_1 lnPG_{t-1} + \psi_2 lnGDPC_{t-1} + \psi_3 lnEP_{t-1} + \psi_4 lnPB_{t-1} + \sum_{i=1}^{p} \varphi_1 \Delta lnLCF_{t-1} + \sum_{j=0}^{q1} \varphi_{2j} \Delta lnPG_{2t-1} + \sum_{j=0}^{q2} \varphi_{3j} \Delta lnGDPC_{3t-1} + \sum_{j=0}^{q3} \varphi_{4j} \Delta lnEP_{4t-1} + \sum_{j=0}^{q4} \varphi_{5j} \Delta lnPB_{5t-1} + \varepsilon_t \qquad (5)$$

In Equation (5), the change in LCF is expressed as a function of various variables. These variables include a_0, which represents the value of LCF at time t-1 (in levels), as well as the values at time t-1 of PG, GDPC, EP, and PB (also in levels). Additionally, the equation incorporates the first differences (Δ) of LCF and PG, GDPC, EP, and PB, up to p and qk lags respectively. To assess the presence of cointegration between the variables, we test the null hypothesis (H_0) that $\psi_0 + \psi_1 + \psi_2 + \psi_3 + \psi_4$ equals zero, against the alternative hypothesis (H_1) that $\psi_0 + \psi_1 + \psi_2 + \psi_3 + \psi_4$ is not

[1] In order to incorporate energy poverty into our modeling framework, we included several variables: access to electricity in the overall population, in rural areas, and in urban areas. These variables were used to construct an index or composite indicator for energy poverty, referred to as EP. The EP index was derived using the principal component analysis method, utilizing the following formula:

$$EP = \sum_{t=1}^{n} w_i f v_i$$

In Equation above, fv_i represents the value of individual indicators of energy poverty at a specific time period, and wi denotes the weight assigned to each indicator in explaining the variation of EP across all variables. These weights are determined through the application of principal component analysis. The EP index is estimated as a linear combination of the three variables that serve as proxies for energy poverty, with the individual contributions of these variables to the standardized variance of PC 1 acting as the respective weights (wi) (See Dimnwobi, et al., 2022b; Muoneke, et al., 2023).

equal to zero. We rely on F and t-tests, using critical values and approximate p-values (APVs) derived from Kripfganz and Schneider (2020). If the calculated F- and t-statistics exceed the upper critical bound at any relevant statistical significance level, as determined by the APVs, the null hypothesis (H_0) is rejected, confirming the presence of cointegration between the variables.

$$\Delta lnLCF_t = a_0 + \psi_0 lnLCF_{t-1} + \varphi_1 \Delta lnPG_t + \psi_1 lnPG_{t-1} + \varphi_2 \Delta lnGDPC_t + \psi_2 lnGDPC_{t-1} + \varphi_3 \Delta lnEP_t + \psi_3 lnEP_{t-1} + \varphi_4 \Delta lnrPB_t + \psi_4 lnPB_{t-1} + \varepsilon_t \quad (6)$$

In the specified model (eq. 6), the coefficients φ_1, φ_2, φ_3, and φ_4 represent the short-run coefficients, while ψ_1, ψ_2, ψ_3, and ψ_4 represent the long-run coefficients. These coefficients quantify the immediate (short-run) and long-term effects of the explanatory variables on the variable of interest, LCF. To visually explore the dynamic effects of a ±1 shock in the explanatory variables on LCF, we employ the graph option with 5000 simulations. This option allows for the generation of a graphical representation that illustrates how the shock in the explanatory variables influences the behaviour of LCF over time.

3.4. Frequency Domain Causality Test

To gain additional insights, Granger causality tests are conducted, following the approach proposed by Breitung and Candelon (2006). These tests utilize the spectral representation of the time series. The spectral representation decomposes the time series into different frequency domains, enabling the examination of Granger causality at each frequency component.

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

The causality from y_t to x_t at frequency, ω is derived as:

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

In this study, we adopt the Toda-Yamamoto equation in the frequency domain framework, as described by Tastan (2015). The Toda-Yamamoto equation, originally proposed by Toda and Yamamoto (1995), offers a modified Wald test (MWALD) for Granger causality. This test does not require pretesting for cointegration and accommodates the possibility of combining stationary and non-stationary series (I(0) and I(1)) within a model, as discussed by Tastan (2015). To demonstrate the test algorithm, we investigate the relationship between lnPG and lnLCF and obtain the augmented VAR [p + dmax] equation shown below:

$$\ln LCF_t = c_1 + \sum_{j=1}^{p} \theta_j \ln LCF_{t-j} + \sum_{j=1}^{p} \tau_j \ln PG_{t-j} + \sum_{j=1}^{p} \sigma_j Z_{t-j} + \sum_{k=p+1}^{p+dmax} \theta_k \ln LCF_{t-k}$$

$$+ \sum_{k=p+1}^{p+dmax} \tau_k \ln PG_{t-k} + \sum_{k=p+1}^{p+dmax} \sigma_k Z_{t-k} + e_t \qquad (9)$$

In the context of the VAR system, the parameter dmax represents the highest order of integration within the model. The null hypothesis being tested is lnPG→lnLCF(ω) = 0, which signifies the absence of Granger causality from lnPG to lnLCF at frequency ω, given the conditioning variables z_t (i.e., lnGDPC, lnEP, and lnPB). This hypothesis can be evaluated using Equation (8) to calculate the Wald statistic and its approximate probability value. By employing the test algorithm, we can visualize the derived statistics across all frequencies. This graphical representation allows us to observe and analyze the permanent (long-run), intermediate (medium-term), and temporary (short-run) causal dynamics, considering the varying time scales of the causality effects.

4. Data presentation and discussion of findings

4.1. Preliminary result

Preliminary evaluations of enlisted variables, such as trend analysis (see appendix 2), descriptive, correlation analyses, and unit-root tests, are conducted before the formal presentation of the data analysis and interpretation. An important preliminary investigation is also performed to examine the long-term coevolution of the variables using the bounds test for cointegration. The findings from these analyses are compiled and presented in Tables 1 to 3. Table 1 presents descriptive statistics and correlation matrices for the data analyzed in our study. These tables provide information about the common characteristics of the variables used. The results indicate that the mean values of the variables are relatively higher, suggesting that the distributions of the variables are asymmetrical rather than symmetrical. Specifically, some variables show a right-skewed distribution, while lnLCF is negatively skewed or biased to the left. When comparing the standard deviation to the mean, the coefficients of the standard deviations are higher. This indicates that the data points are spread out over a wider range from the mean, implying greater uncertainty and variability in the observations. Therefore, further empirical investigation is warranted.

Additionally, certain variables demonstrate leptokurtic distribution (kurtosis > 3), such as lnEP, while others exhibit platykurtic distribution (kurtosis < 3). The lower part of Table 2B displays the correlation results, which were used to examine the strength of the linear relationship between the variables. The negative correlation coefficients between lnLCF and all other variables suggest an inverse and linear association. Moreover, the correlation matrix indicates the absence of multicollinearity among the variables considered. Specifically, the correlation coefficients between the explanatory variables are all below the threshold level of 60%, alleviating concerns regarding multicollinearity.

Table 1. Descriptive and correlation features of the variables

	Descriptive statistics				
	*ln*LCF	*ln*URB	*ln*GDP	*ln*EP	*ln*PB
Mean	-0.166	1.584	3.255	1.659	3.511
Maximum	-0.095	1.701	3.406	1.773	4.312
Minimum	-0.244	1.472	3.127	1.436	2.582
Std. Dev.	0.045	0.072	0.104	0.077	0.472
Skewness	0.080	0.073	0.143	-0.809	-0.248
Kurtosis	1.606	1.682	1.388	3.470	2.161
Jarque-Bera	2.377	2.122	3.238	3.410	1.146
Probability	0.304	0.346	0.198	0.181	0.563
	Correlation Matrix				
	LCF	URB	GDP	EP	PB
*ln*LCF	1.000				
*ln*URB	-0.402	1.000			
*ln*GDP	-0.695	0.441	1.000		
*ln*EP	-0.407	0.221	0.398	1.000	
*ln*PB	-0.312	0.310	0.269	0.412	1.000

Source: Authors Computation

To ensure the stationarity properties of the variables used in our study, additional efforts were focused on verification, considering that time-series variables inherently follow random-walk processes. By establishing their underlying characteristics in advance, we can obtain reliable empirical estimates for more coherent policy recommendations. Based on the summarized results presented in Table 2, we can confirm that the series under consideration exhibit mixed integration characteristics. Specifically, employing the more robust Zivot-Andrews tests, we find that the dependent variable (LCF) and some explanatory variables (PG, GDPC, and EP) require first-order differencing to achieve stationarity, while PB is stationary at its original levels. Consequently, the series are mutually integrated at both order zero (I(0)) and order one (I(1)). Given these distinctive attributes, it is appropriate to employ the Bounds test cointegration procedure and the simulation procedure using the dynamic ARDL econometric framework.

Table 2: Unit-root tests

Series	Test at Level I(0)		Test at first difference I(1)		Remarks
	test-statistic	Break Point	test-statistic	Break Point	
Augmented Dickey-Fuller test					
*ln*LCF	1.061		-6.193***		I(1)
*ln*PG	-4.166***		-6.116***		I(0)
*ln*GDPC	1.229		-4.262***		I(1)
*ln*EP	-3.875**		-7.005***		I(0)
*ln*PB	-1.071		-7.590***		I(1)
Zivot-Andrews unit root test allowing for a structural break					
*ln*LCF	-3.516	2001	-6.106***	2012	I(1)
*ln*PG	-2.114	2014	-10.341***	2013	I(1)
*ln*GDPC	-4.001	1993	-6.176***	1984	I(1)
*ln*EP	-4.322	1989	-8.210***	2016	I(1)
*ln*PB	-4.819**	1991	-6.110***	1986	I(0)

*Note: ***= p<1%, ** = p<5%, * = p<10%,*
Source: Authors Computation

Table 3 provides a summary of the long-term coevolution analysis conducted on the load capacity factor (LCF) in Nigeria and its determinants. We present the findings of the analysis in terms of both F-statistics and t-statistics, demonstrating the long-term coevolution of the series. The evaluation includes the utilization of enhanced critical and approximation p-values based on the Kripfganz and Schneider (2019) approach. The results overwhelmingly support the presence of cointegration among the series. Both the F-statistics and t-statistics surpass all critical values, including those at the 1%, 5%, and 10% significance levels. This suggests a robust cointegration relationship between LCF and the factors of urbanisation, gross domestic product per capita, energy poverty, and public debt.

Table 3: Bounds test for cointegration

	Tests for cointegration			Diagnostic tests		
Specification	F-statistic	t-statistic			chi2	Prob
	4.803***	-5.068***		Ramsey RESET	1.02	0.303
Critical values and approximate p-values: Kripfganz and Schneider (2019)F-statistic t-statistic	F-statistic			χBG-LM	0.538	0.312
Level of significance	I(0)	I(1)		χBP-CW	0.111	0.755
1%	4.285	6.126				
5%	2.954	4.346		CUSUM	Stable	
10%	2.48	3.823		CUSUMsq	Stable	
	t-statistic					
1%	-0.001	-0.017				
5%	-2.888	-4.304				
10%	-2.471	-3.786				
Approximate p-values	0.001	0.005				

*Note: ***= p<1%, ** = p<5%,;* BG-LM is the *Breusch-Godfrey LM test for serial correlation;* BG is the Breusch-Pagan / Cook-Weisberg test for heteroskedasticity; the Akaike information criterion suggests $p = 3$ (see Appendix 3). Source: Authors Computation

Furthermore, diagnostic tests indicate that the model is stable, as depicted in Figure 1. The residuals of the model satisfy all necessary econometric assumptions, ensuring the reliability of the analysis.

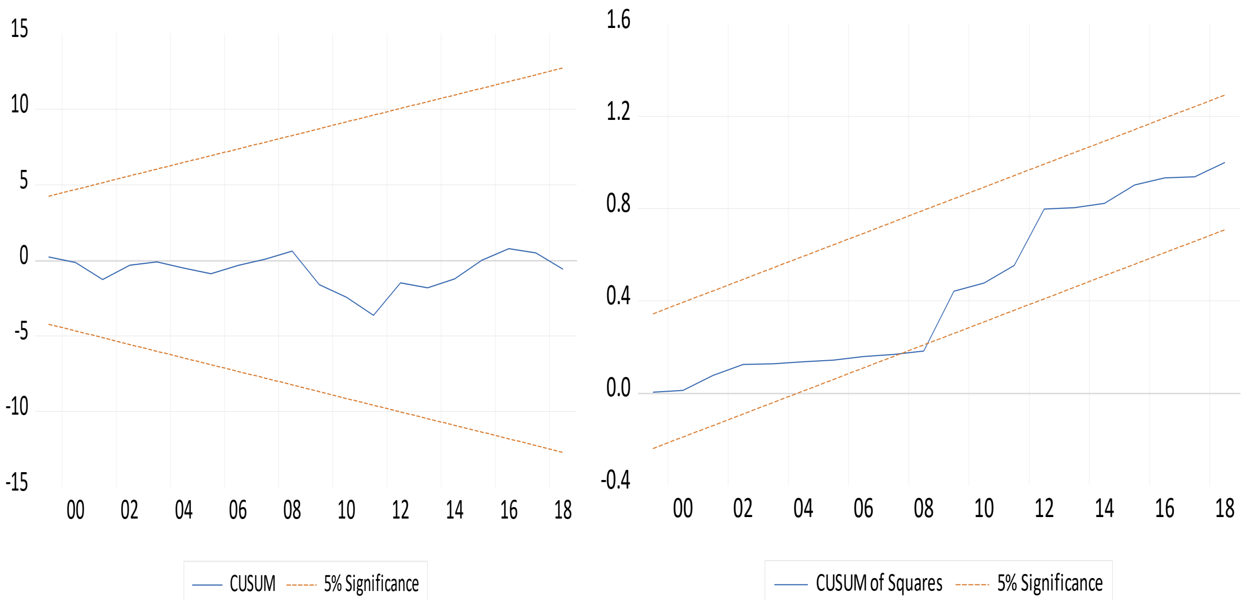

Figure 1. Stability tests

4.2. Empirical Result

Table 4 summarizes the implications of the enlisted series on environmental quality, specifically the ecological load capacity factor, in both the short and long term. The data used for this analysis comes from both the conventional ARDL process and the newly introduced dynamic ARDL (DARDL) techniques. The ARDL estimates indicate that urbanization and energy poverty significantly diminish the ecological load capacity factors in Nigeria. Specifically, the estimates reveal that a percentage change in urbanization and energy poverty reduces the ecological load capacity factors by 4.208% and 2.475% respectively in the long run.

The underlying explanation of these outcomes is four-fold. First, the demand for resources like electricity, water, and materials often increases as an area becomes more urbanized. As cities expand, they need additional transportation, housing, and infrastructure, which can increase resource use and ecological damage. Similar to resource depletion, environmental degradation can be made worse by energy poverty, which can lead to wasteful and unsustainable energy consumption. Second, energy poverty and rapid urbanization could put a pressure on Nigeria's current infrastructure systems. Pollution and ecological deterioration can be caused by insufficient waste management, wastewater treatment, and sanitary infrastructure. Furthermore, insufficient energy infrastructure may lead to the usage of more environmentally destructive, energy sources such as diesel generators or biomass. Third, deforestation and land use change may be exacerbated by urbanization and energy insecurity. Natural ecosystems are frequently destroyed as cities expand to build infrastructure or satisfy the rising need for energy resources. Deforestation affects ecosystems' ability to offer critical functions, like carbon sequestration and water management, as well as biodiversity loss. Fourth, in Nigeria, insufficient environmental legislation and enforcement measures may contribute to the detrimental effects of urbanization and energy poverty. Without stringent laws and strong enforcement, businesses and individuals may be less likely to embrace ecologically friendly practices, which would raise the ecological burden and degrade the environment.

Consequently, this outcome highlights that these two factors are detrimental to achieving environmental sustainability in Nigeria. Importantly, our outcome on the urbanization-environment nexus aligns with recent outcomes by Jian et al. (2022) and Alhassan and Kwakwa (2022) while that of energy poverty concurs with Hassan et al. (2022) and Zhang et al. (2022).

Therefore, policymakers should focus on implementing policies that enhance access to electricity, develop robust energy infrastructure, and ensure a stable and consistent electricity supply to promote sustainable economic growth and improve quality of life. It is worth noting that these results led to the rejection of the null hypothesis (No 2). Interestingly, the estimates obtained from the DARDL technique strongly support the estimates from the traditional ARDL procedure. However, there are notable inconsistencies in the short-term estimates.

Table 4: Long-run and short-run estimates (ARDL and Dynamic ARDL estimations)

	Long-run estimates			**Short-run estimates**	
Variables	**ARDL**	**Dynamic ARDL**	**Variables**	**ARDL**	**Dynamic ARDL**
*ln*PG	-4.208* (1.747) [-2.408]	-0.077** (0.035) [2.153]	Δ*ln*PG	-36.505*** (6.305) [-5.790]	-2.907 (7.187) [-0.404]
*ln*GDPC	-0.838 (0.484) [-1.731]	-0.086 (0.178) [-0.486]	Δ*ln*GDPC	-1.613*** (0.391) [-4.125]	-0.771* (0.390) [-1.975]
*ln*EP	-2.475* (1.019) [2.428]	-0.319* (0.110) [-2.895]	Δ*ln*EP	0.407 (0.229) [1.780]	-0.393 (0.249) [-1.580]
*ln*PB	0.081* (0.037) [2.147]	0.021** (0.008) [2.526]	Δ*ln*PB	-0.177** (0.051) [-3.442]	-0.044 (0.038) [1.151]
Constant	-0.486 (0.751) [-0.648]	0.567 (0.498) [1.140]	ECT(-1)	-0.668** (0.186) [-3.589]	-0.681** (0.241) [-2.825]

*Note: ***= p<1%, ** = p<5%,* = p<10%,* Source: Authors Computation

The investigation reveals the implications of public debt on the ecological load capacity factor in Nigeria. The traditional ARDL procedure demonstrates a positive and significant relationship, particularly in the long term. The estimate shows that a 1% long-term change in public debt leads to a 0.081% improvement in the ecological LCF in Nigeria. The robustness of the DARDL procedure confirms the findings of the traditional ARDL technique. Specifically, the DARDL procedure indicates that the ecological load capacity factor improves significantly by 0.021% in response to a 1% change in public debt.

The discovery that public debt improves the ecological load capacity factor in Nigeria may appear contradictory, but there are a few probable explanations for these findings. First, public debt could be used to fund activities and projects connected to the environment and sustainability. The ecological load capacity factor, for instance, can be raised by investing in renewable energy infrastructure, conservation programs, or sustainable agriculture methods. These investments have the potential to slow down environmental damage and advance sustainable development. Second, governments may be able to effectively execute and enforce ecological regulations and laws with the help of public borrowing. Adequate finance can help to assist the establishment and execution of ecological laws, monitoring systems, and enforcement measures, resulting in improved environmental management and increased ecological load capacity. Third, utilizing public debt can enhance the capabilities of institutions tasked with overseeing ecological management and governance. This entails enhancing the capability of environmental authorities, offering personnel training, and encouraging better collaboration among stakeholders. By enhancing institutional capacity in this way, environmental protection and management practices can be improved, which in turn benefits the ecological load capacity. Fourth, public debt may make it easier to finance investments in cutting-edge technologies and R&D projects that support ecologically friendly behaviours. These developments may result in more effective resource usage and less pollution, which would increase the nation’s ecological load capacity.

These results concur with the results of Sadiq et al. (2022) in emerging economies, Alhassan and Kwakwa (2022) in Ghana, and Qi et al. (2022) in China, where empirical investigations suggest that a well-coordinated use of public debt has the potential to improve environmental quality. However, caution must be exercised to mitigate potential damage to the ecological load capacity factor, considering the notable short-term negative effects of public debt. Based on these results, the study rejects the null hypothesis (No 1), indicating an improving effect of public debt on environmental quality in Nigeria.

Additionally, both the ARDL and DARDL procedures reveal a negative relationship between affluence, as measured by GDP growth per capita, and the ecological load capacity factor in Nigeria. These negative effects are observed in both the long run and the short run. However, it is important to note that while the negative effects are not statistically significant in the long run, they are statistically significant in the short run for both the ARDL and DARDL analyses. There may be other complex and subtle elements at play given the conclusion that economic growth in Nigeria has a negative but insignificant association with the ecological load capacity factor. Here are several explanations for these outcomes. First, although economic expansion can help raise living standards and enhance resource availability, it can also harm the environment if unsustainable development methods are used. The deployment of environmentally hazardous technologies, increasing energy use, or overuse of natural resources, for instance, could negate any benefits that economic growth would have for ecological load capacity. Second, the insignificant correlation between economic growth and ecological load capacity in Nigeria may be caused by the absence of effective environmental rules and insufficient enforcement measures. Weak legislative frameworks might permit economic expansion to proceed without taking environmental concerns seriously, which would have few noticeable effects on the ecological load capacity factor. Third, economic expansion frequently necessitates trade-offs between development and environmental preservation. Certain environmentally destructive behaviours may be regarded as externalities or unexpected effects in the pursuit of economic advancement. The relationship between economic growth and ecological load capacity may seem insignificant if the adverse environmental effects are not sufficiently addressed or taken into account.

This finding reinforces the observations made in several existing studies (Dimnwobi et al., 2021, Adekoya et al., 2022; Gyamfi et al., 2022) that many global economies, in their pursuit of economic growth, have sacrificed environmental cleanliness. Therefore, policymakers are strongly encouraged to adopt policy strategies that are both strategic and environmentally sustainable. It is crucial to implement policies that do not compromise a clean environment in exchange for increasing income. By doing so, Nigeria can mitigate ecological deficits and ensure a balance between economic growth and environmental preservation.

The negative and statistically significant error correction terms of -0.668 and -0.681 for ARDL and DARDL indicate a strong and meaningful long-run relationship between the variables under consideration. This negative sign suggests that there is a restorative mechanism at work, driving the variables back towards their long-run equilibrium whenever they deviate in the short run. The magnitude of -0.668 and -0.681 signify the speed of adjustment, indicating that for every unit of deviation from the equilibrium, the variables will adjust by approximately 0.668 and 0.681 units in the opposite direction, bringing them closer to their long-run relationship.

4.3. Dynamic ARDL Simulations

To reinforce the findings of the DARDL estimator regarding the effects of the enlisted series on the ecological load capacity factor in Nigeria, dynamic simulation graphs are utilized. Figures 2 to 5 provide visual representations of the dynamic simulations, illustrating the impacts of a graph of shocks on urbanization, per capita income, energy poverty, and public debt on the ecological load capacity factors in Nigeria. The dots on the graphs represent the average predicted values, while the lines (ranging from thickly shaded to lightly shaded) define the lower, middle, and upper confidence intervals. Figure 2 demonstrates that a positive shock in urbanization leads to a significant negative change in the predicted ecological load capacity factor in the long run (even significant at the upper confidence level). Conversely, a negative shock in urbanization indicates an improvement in ecological capacity. The findings indicate that the process of urbanization has a detrimental effect on the projected ecological load capacity, implying potential adverse consequences for the environment. This evidence carries economic ramifications, including heightened expenses associated with pollution mitigation and the scarcity of resources. The imperative to achieve a balanced scale between economic growth and environmental conservation assumes paramount importance, necessitating the implementation of policies that prioritise sustainability and foster innovation. These outcomes align with the empirical estimates obtained from both the ARDL and DARDL techniques. Figure 3 confirms the negative but statistically insignificant effect of per capita income on the ecological load capacity factor in Nigeria in the long run. However, in the short run, a positive shock in per capita income generates a significant positive change in the predicted ecological load capacity factor, while a negative shock in per capita income leads to a decrease in ecological capacity. The information provides two economic implications. Over the long term, the association between per capita income and ecological carrying capacity in Nigeria is negative but lacks statistical significance, suggesting that income may not be a strong driver of ecological change over longer periods. Conversely, in the short run, positive shocks in per capita income are associated with immediate improvements in ecological capacity, while negative shocks result in reductions in capacity. This underscores the need for balanced policies aimed at both short-term economic stability and long-term environmental sustainability. Figure 4 illustrates that a positive shock in energy poverty has a significant negative impact on the predicted ecological load capacity factor, whereas a negative shock in energy poverty results in a positive change in the predicted value of the ecological load capacity factor.

The findings imply that a positive shock signifying a rise in energy poverty has a substantial detrimental impact on the environment's capacity to sustainably accommodate human activities. Conversely, a negative shock, indicative of ameliorated energy poverty, results in a favourable alteration in the environment's ability to regulate human endeavours. This observation underscores the interconnection among energy accessibility, environmental well-being, and the imperative to tackle energy deprivation for the sake of economic and ecological welfare. Additionally, Figure 5 showcases the dynamic simulations of public debt on the ecological load capacity factor in Nigeria. The simulation graphs reveal a mitigating effect of public debt on the ecological load capacity factor in the long run. Interestingly, a positive shock in public debt leads to a significant positive change in the predicted ecological load capacity factor, while a negative shock in public debt results in a decrease in ecological capacity. A positive exogenous shock in public debt yields a notable enhancement in the environment's capacity to sustainably manage human activities. On the contrary, a detrimental impact on ecological capacity is observed as a consequence of an adverse shock in public debt. This statement emphasizes the impact of public debt management on environmental sustainability and emphasizes the significance of making strategic debt choices to achieve a balance scale between economic growth and ecological welfare.

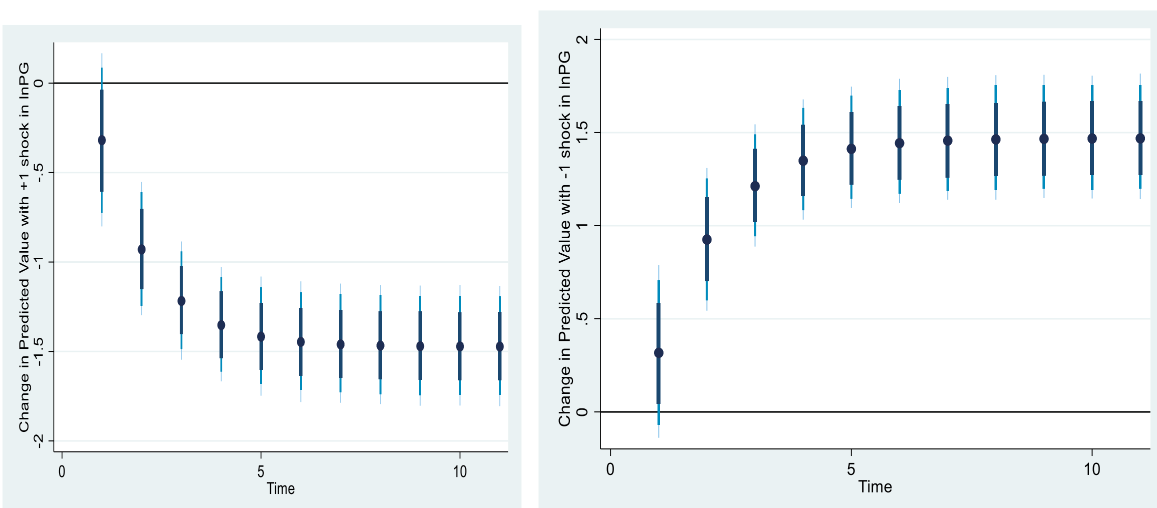

Fig 2: Plot of the impact of ±1% change in *ln*PG on *ln*LCF

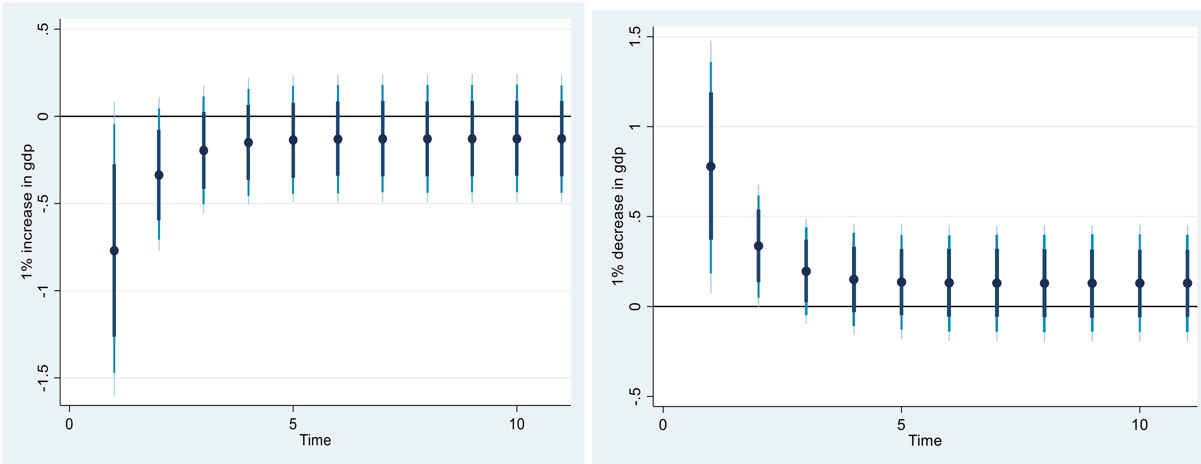

Fig 3: Plot of the impact of ±1% change in *ln*GDPC on *ln*LCF

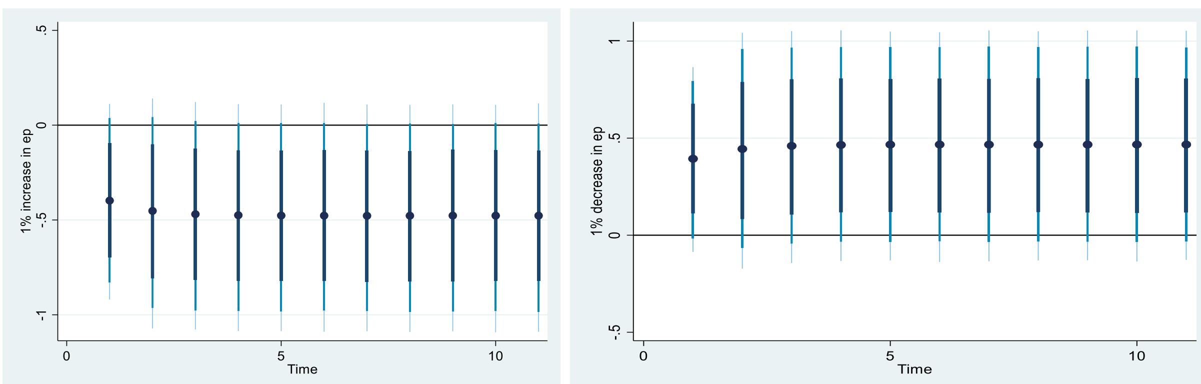

Fig 4: Plot of the impact of ±1% change in *ln*EP on *ln*LCF

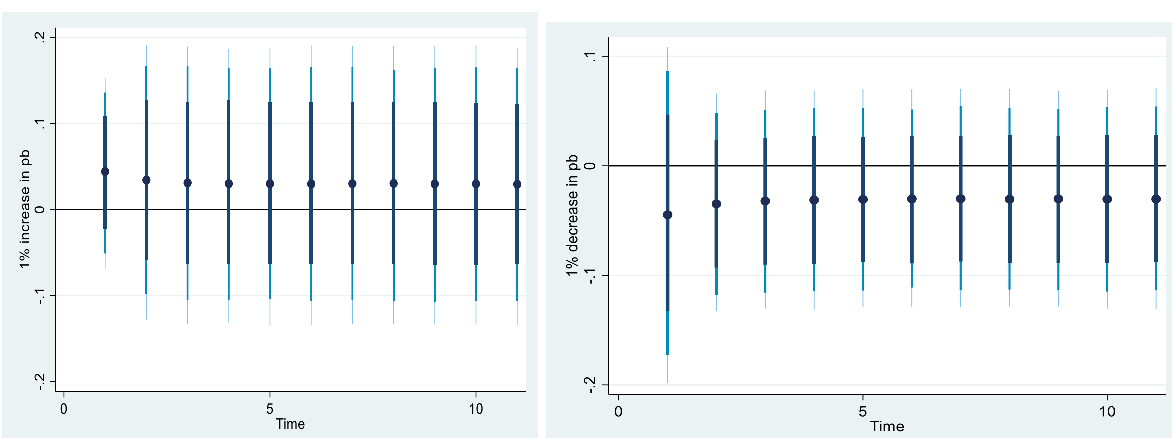

Fig 5: Plot of the impact of ±1% change in *ln*PB on *ln*LCF

4.4. Granger-causality Test

Graphical plots are also provided (refer to Figs. 6-9) to display the test statistics for all frequency components. Figure 6 reveals a one-way causality from urbanization growth to the ecological load capacity factor (LCF), with statistical significance observed in the intermediate and permanent frequency components. Similarly, Figure 8 demonstrates a one-way causality from energy poverty to LCF, with a consistent wavelength of 3 or more years for LCF to significantly respond to changes in energy poverty. Likewise, Figure 9 displays a one-way causality from public debt to LCF, with a consistent wavelength of 1 or more “years” for LCF to significantly respond to changes in public debt. These findings confirm the significant role of energy poverty and public debt as predictors of Nigeria's capacity to mitigate or exacerbate ecological distortions resulting from increasing human activities. Another noteworthy finding depicted in Figure 7 is the absence of a causality relationship between LCF and economic growth at various levels. This implies that despite Nigeria’s recent remarkable economic growth indicators, it is crucial to prioritize the protection and sustainable utilization of the ecological resources that underpin this progress.

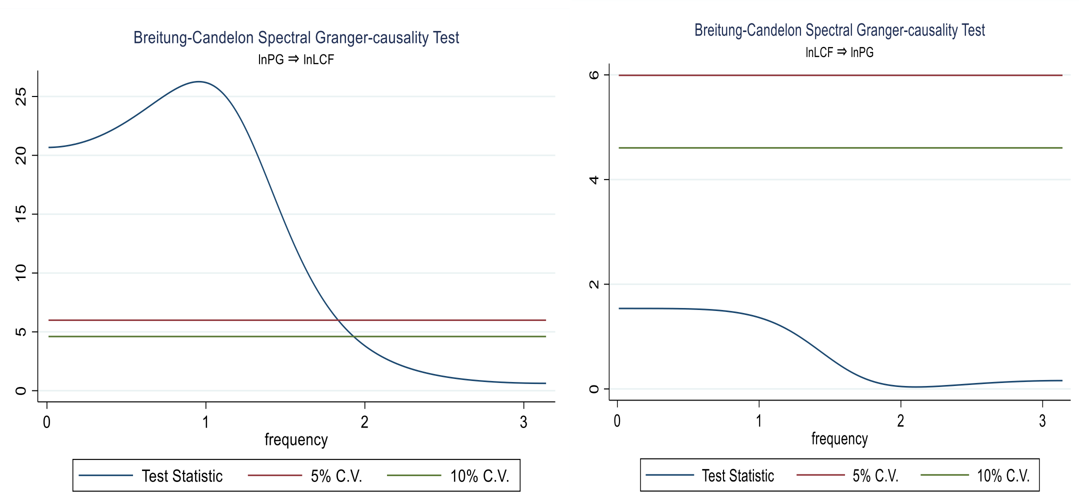

Fig 6. Causality between LCF and PG

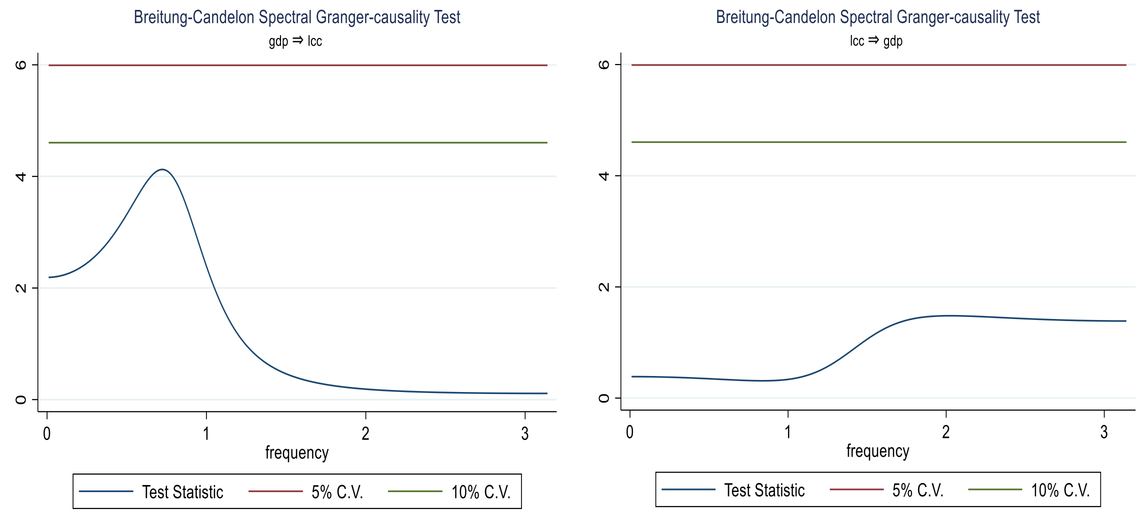

Fig 7. Causality between LCF and GDPC

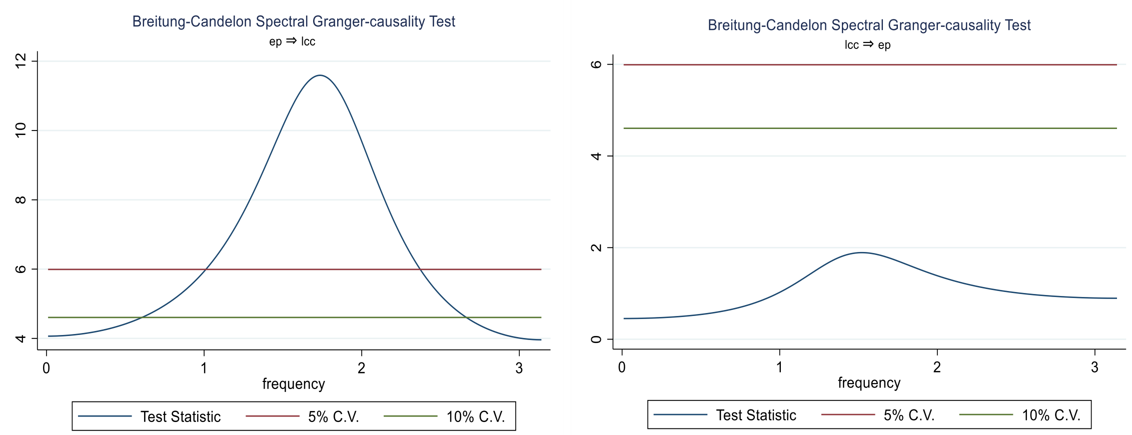

Fig 8. Causality between LCF and EP

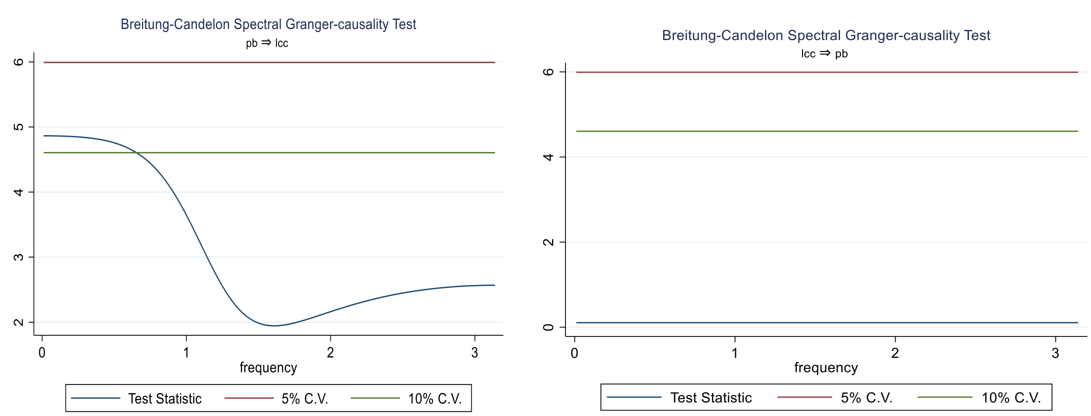

Fig 9. Causality between LCF and PD

5. Summary and policy options

This study investigates the influence of public debt and energy poverty on the LCF in Nigeria. The LCF, calculated by dividing biocapacity by ecological footprint, serves as the dependent variable. Total public debt and energy poverty (measured through access to electricity in the overall population, rural areas, and urban areas) are considered the key independent variables, while gross domestic product per capita and urbanization are included as control variables. The analysis employs the STIRPAT model, utilizing annual data from 1990 to 2021. Descriptive, correlation analyses and unit-root tests are conducted to assess the variables before the formal data analysis using the autoregressive distributed lag (ARDL) model and the dynamic ARDL (DARDL) technique. The Toda and Yamamoto test were employed for Granger causality, while dynamic simulation graphs are implemented to reinforce the findings of the DARDL estimator. The ARDL estimates indicate that urbanization and energy poverty have a significant negative impact on the ecological load capacity factors in Nigeria. The DARDL technique reinforces these findings and demonstrates consistency with the traditional ARDL procedure. Notably, the traditional ARDL procedure reveals a positive and significant relationship between public debt and the ecological load capacity factor in the long run. The robustness of the DARDL procedure confirms these findings. Additionally, both the ARDL and DARDL analyses show a negative relationship between GDP growth per capita and the ecological load capacity factor, which is statistically significant in the short run. However, the negative effects are not statistically significant in the long run. The causality tests indicate a one-way causality from energy poverty to LCF, with LCF significantly responding to changes in energy poverty after a consistent wavelength of 3 or more years. Similarly, a one-way causality from public debt to LCF is observed, with LCF significantly responding to changes in public debt after a consistent wavelength of 1 or more years.

The findings of the study demonstrate substantial correlations between the variables, emphasizing the necessity for governmental interventions to improve ecological sustainability and support a balanced socioeconomic development path. As a result, the following policy recommendations are made based on the research findings: First, considering energy poverty has a significant negative influence on LCF, it is critical to prioritize sustainable energy access and rural electrification programs. To guarantee equitable access to clean and inexpensive energy sources, the government needs to focus on the expansion of power infrastructure in rural areas through the Rural Electrification Agency (REA). Furthermore, with the recent decentralization of the electricity sector as a result of the adoption of the Electricity Act 2023, public-private partnerships can be promoted to attract investment and expedite the speed of electrification.

Second, the transition to renewable energy sources deserves to be prioritized to offset the negative environmental consequences of energy poverty and reduce reliance on fossil fuels. Feed-in tariffs, tax breaks, and subsidies are examples of policy incentives that can be employed to promote the development of renewable energy systems. Furthermore, increased expenditure o n research and development is required to improve the efficiency and affordability of renewable energy sources, making them more accessible to a wider population.

Third, it is critical to promote energy efficiency techniques across all sectors to optimize energy usage and reduce environmental impacts. The importance of implementing energy efficiency standards and appliance labelling, promoting energy-saving construction codes, and raising awareness about energy conservation techniques cannot be overstated. Individuals, businesses, and industries are capable of being encouraged to adopt energy-efficient technologies and practices through public awareness campaigns, educational initiatives, and financial incentives.

Fourth, while public debt has been shown to have a favourable long-term influence on LCF, it is critical to guarantee sustainable debt management strategies. Prudent fiscal measures, such as transparent borrowing operations, debt sustainability assessments, and effective debt servicing frameworks, are required to be implemented. In this context, the Debt Management Office will need to be reenergized to fulfill its objective of ensuring “good debt management practices that have a positive impact on economic growth and national development”, among other goals. Likewise, debt revenue should be channelled toward investments in green infrastructure, renewable energy projects, and environmental conservation programs to ensure a beneficial impact on ecological sustainability.

Fifth, given the significant negative impact of urbanization on LCF, integrated planning, and sustainable urban development solutions are required. To reduce the ecological footprint associated with urbanization, urban design needs to prioritize ecological balance, biodiversity conservation, and sustainable resource management. Sixth, given the negative impact of GDP per capita growth on LCF, environmental education, and awareness initiatives have to be included in the national curriculum at all levels to build an ecologically sustainable society. This would assist Nigerians gain a better awareness of the interconnections between human activity, energy poverty, public debt, and ecological sustainability. Additionally, public awareness campaigns, community engagement projects, and capacity-building programs should be expanded to empower people to make educated decisions and embrace sustainable behaviours.

In conclusion, this inquiry emphasizes the importance of energy poverty and state debt as determinants of Nigeria's ability to alleviate or worsen environmental distortions resulting from human activity. The findings highlight the importance of effective strategies to address energy poverty and manage public debt to promote sustainable development and increase ecological load capacity in Nigeria. The recommendations stress the significance of sustainable energy access, renewable energy transition, energy efficiency, debt management, integrated planning, and environmental education in particular. Implementing these measures will not only help to ensure environmental sustainability, but will also promote socio-economic development, poverty reduction, and a more resilient future for Nigeria. However, it is important to note a few study limitations and a research agenda for the future. This investigation, for example, focuses on load capacity parameters in Nigeria and may not apply to other nations or locations with differing socioeconomic and ecological circumstances.

Future research could involve broadening the geographical scope to investigate cross-country comparisons to capture regional differences. In addition, the study uses annual data to examine the relationship between public debt, energy poverty, and load capacity parameters. Subsequent investigations could leverage dynamic modelling techniques, such as panel data analysis or dynamic panel models, to better capture short- and long-term dynamics and assess the lagged effects between variables. Again, the study focuses essentially on economic and energy-related issues. As a result, incorporating social and institutional factors such as governance, institutional capacity, social equity, and security will be beneficial in providing a more comprehensive understanding of the determinants of LCF and their relationship with energy poverty and public debt. Finally, it is necessary to investigate the integration of energy, environmental, and fiscal policies to comprehend potential trade-offs and synergies between economic growth, debt management, energy poverty alleviation, and ecological sustainability.

Data availability

The data for the study was collected from Global Footprint Network Database (https://data.footprintnetwork.org); Central Bank of Nigeria Database (https://www.cbn.gov.ng/) and World Development Indicators database (https://databank.worldbank.org/source/world-development-indicators).

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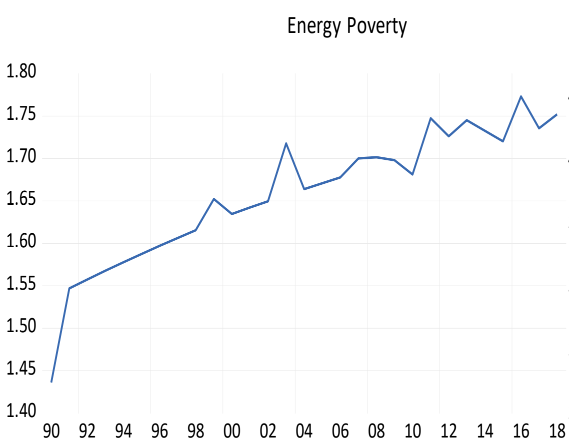
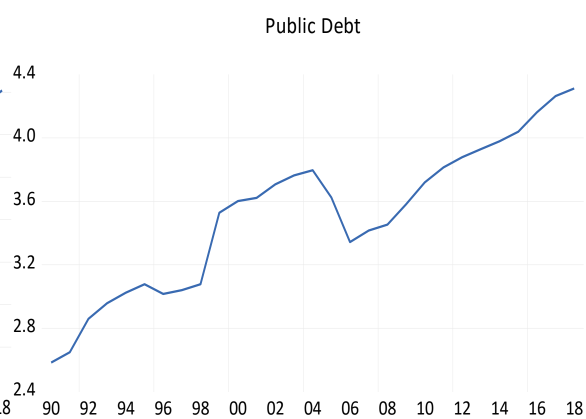
Appendix 1: Data Summary

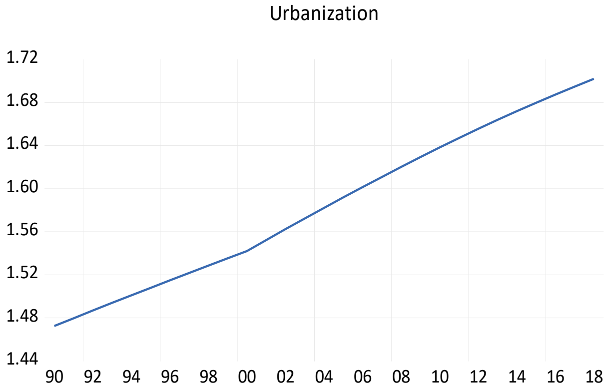
Variables	Measurements	Sources
Load capacity factor (LCF)	Biocapacity divided by ecological footprint	Global Footprint Network Database
Total public Debt (PB)	Billions of naira	Central Bank of Nigeria Database
Total access to electricity	% total population	World Bank Database
Urban Access to electricity	% urban population	World Bank Database
Rural Access to electricity	% rural population	World Bank Database
Energy poverty index (EP)	Computed using the three energy access variables	Authors Computation
Gross Domestic Product Per Capita (GDPC)	Constant 2010 US$	World Bank Database
Urbanization (PG)	% overall population	World Bank Database

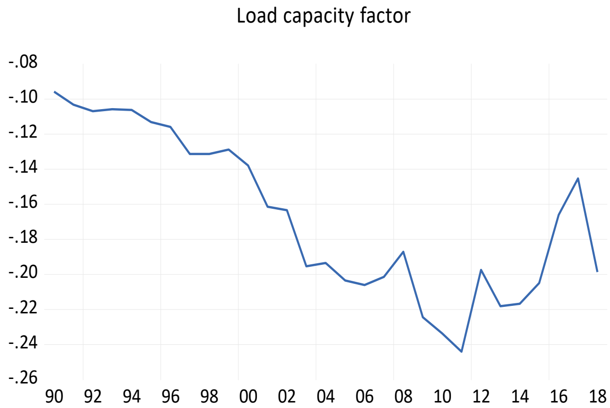
Source: Authors Computation

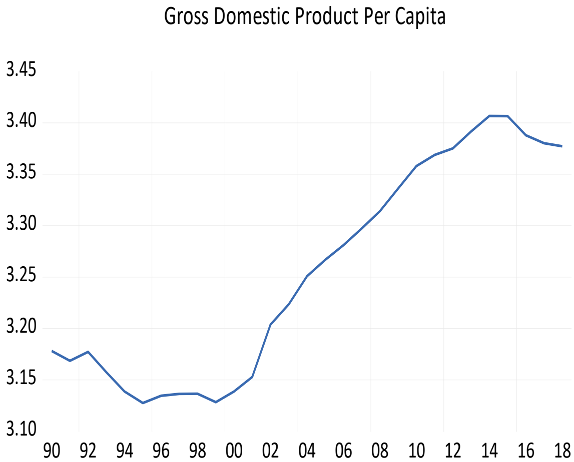
Appendix 2: Graphical plots of the study variables











Appendix 3: VAR Lag Order Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
1	190.7060	NA	4.53e-11	-9.640344	-8.529381*	-9.256840*
2	222.2301	42.60577*	3.52e-11*	-9.956003	-8.734077	-9.188995
3	240.8732	32.44931	3.98e-11	-11.04880*	-5.717009	-7.899385