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Original Article

Powering Progress: An Empirical Investigation of the Impact of Energy Consumption on Economic Growth in Nigeria

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Abstract

Energy is the backbone of modern economies, driving development, innovation, and sustainability. This study discusses the crucial role of energy resources in shaping a country's future, quality of life, health, and climate. Focusing on Nigeria, one of the fastest-growing economies globally, the paper explores the impact of energy consumption on economic progress from 1980 to 2022. Energy poverty and insecurity, coupled with unreliable access to modern energy services, have hindered Nigeria's economic potential. Employing up-to-date empirical analysis and future forecast techniques, the study finds that energy consumption positively influences both short-term and long-term economic growth. The population growth rate negatively affects long-term growth, while the inflation rate hampers long-term growth but spurs short-term growth. Carbon emissions contribute positively to growth, while foreign direct investment boosts long-term growth but suppresses short-term growth. The study recommends policies to stimulate sustainable economic growth, attract foreign investments, enhance energy infrastructure, manage inflation, and promote environmental sustainability. Emphasising the need for policy coherence, the study advises coordinated efforts across monetary, fiscal, trade, and energy sectors to ensure consistent and effective strategies for long-term sustainable growth in Nigeria.

Keywords: *ARDL Analysis; Economic Growth; Energy Consumption; Forecast Analysis; Impacts; Nigeria*

Introduction

Energy resources and their consumption, together with economic growth, are pivotal drivers of development, especially in this age of smart living and rapid technological advancement (Mewenemesse & Yan, 2023; Qi *et al*., 2022; Onuoha *et al*., 2022; Hu & Dong, 2023; Feng & Zhao, 2022). Access to reliable and affordable energy is crucial for economic growth and social well-being (World Bank, 2022; Hidayat *et al*., 2024). Economic growth is essential for reducing poverty and improving the quality of life. However, the relationship between energy consumption and economic growth is intricate and varies across countries and regions.

Nigeria, with a population of over 223 million, a Gross Domestic Product (GDP) of USD$477.376 billion, and a GDP per capita of USD$2,237 in 2022 (World Bank, 2023), is one of the fastest-growing economies in Africa. Even so, it faces significant energy challenges, such as inadequate infrastructure for electricity delivery to urban and rural areas, unreliable power supply, and high energy costs. These challenges hinder Nigeria's economic progress (Dike, 2017; World Bank, 2022; Statista, 2022; Adebayo & Özkan, 2024; Enerdata, 2022).

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The Nigerian government has implemented numerous measures to address the energy crisis, including regulations and initiatives to expand access to electricity, improve energy efficiency, and stimulate investment in energy infrastructure. These efforts notwithstanding, Nigeria's energy sector remains underdeveloped and struggles to meet rapidly growing energy demand (Dike, 2017; IEA, 2019a).

Previous research (Gershon *et al.*, 2024; Mutumba, Odong & Bagire, 2024; Dokas *et al*., 2022; Qi *et al*., 2022; Hidayat *et al*., 2024) found a positive correlation between energy consumption and GDP growth in emerging economies. However, there is limited up-to-date empirical data on the interplay between energy consumption and economic development in Nigeria (Dike, 2017; Adenikinju *et al*., 2019).

In recent years, policymakers and stakeholders have been increasingly concerned about the profound impact of energy consumption on Nigeria's economic growth and development, especially given the country's significant energy challenges and limited access to reliable and affordable energy.

This study will examine how Nigeria's energy consumption affects its economic development while controlling for variables such as inflation, population, FDI, CO_2 emissions, and total trade balance. Utilising time series data from 1980 to 2022, the study then plans to examine how Nigeria's economic prosperity relates closely to its consumption of energy resources and offer insights for policymakers to enhance the role of the energy sector in promoting sustainable economic progress and addressing Nigeria's persistent energy crisis. Moreover, the examination contributes to an expanding body of literature on the nexus between energy consumption and economic progress, both in Nigeria and developing countries.

Objective

This paper aims to explore the interplay between energy consumption and economic expansion in Nigeria, focusing on three central enquiries whose answers remain essential: What trends prevail regarding past as well as present-day utilisation patterns of energy within Nigeria? Does a significant and unmistakable correlation exist linking levels of consumed energy with subsequent economic advancement witnessed throughout various sectors of Nigerian society? If an apparent connection exists between these two variables - energy usage and GDP growth - then which other factors exert influence upon such interdependence?

Literature Review

Nigeria has significant potential for economic expansion, driven by its large population, favourable demographics, abundant natural resources, and strategic geographical location. In spite of these possibilities, the country struggles with insufficient energy accessibility and security, ranking low globally. In 2020, only 55.4% of the population had access to electricity, highlighting a significant gap (IEA, 2021; Statista, 2022).

Historically, Nigeria has faced persistent energy challenges, including frequent power interruptions, limited access to modern energy services, and high energy costs. The oil and gas industry dominates Nigeria's energy sector, contributing over 90% of export earnings and government revenue (Dike, 2017; Adenikinju, 2008; Adenikinju *et al*., 2019). However, the sector's potential is impeded by inadequate infrastructure, weak regulation, and insufficient investment in renewable energy (Mewenemesse Yan, 2023; Qi *et al*., 2022; Onuoha *et al*., 2022; IEA, 2019a).

The energy crisis severely affects Nigeria's economic progress, with estimates suggesting a loss of 2-3% of GDP annually due to inadequate power supply (Adenikinju, 2008; Adenikinju *et al*., 2019). The industrial sector's growth is stunted, making Nigerian exports less competitive.

According to the report of the World Bank (2022), Nigeria's primary energy consumption increased from 110.6 million tonnes of oil equivalent (MTOE) in 2010 to 143.3 (MTOE) in 2018, while GDP grew from USD$369.1 billion to USD$448.1 billion. However, Nigeria's per capita energy consumption remains one of the lowest globally, with only 55.4% of the population having electricity access in 2020 (IEA, 2021; Our World in Data, 2023).

Efforts to improve energy access and efficiency include the government's Power Sector Recovery Programme (PSRP), launched in 2015 to address power sector issues and improve energy access (World Bank, 2022). Yet, Nigeria's energy sector remains underdeveloped, with significant gaps in electricity generation, transmission, and distribution capabilities and regulatory framework.

The International Energy Agency (IEA, 2019a) reports that Nigeria, despite having the capacity to generate 12,522 MW of electricity, often dispatches only around 4,000 MW due to inadequate maintenance and gas supply. All-inclusive reforms and investments are needed to unlock the sector's full potential.

The IEA Africa Energy Outlook 2019 is a detailed report on energy in Africa, especially Sub-Saharan Africa, covering eleven nations that account for around 75% of the region's GDP and energy needs. Global energy consumption is projected to rise by 56% by 2040. This offers Africa opportunities for increased energy access and new investments, potentially boosting economic activity and job creation. Nigeria, facing significant power shortages and growing reliance on imported oil and gas, needs to more than double its energy sector investments by 2030 to meet growing demands, according to the report. The country's potential for renewable energy remains predominantly unexplored. Improving energy access for low-income households is crucial for sustainable economic growth in Nigeria. This requires significant action from the government and stakeholders.

A detailed presentation of the IEA's Nigeria and Africa energy sector case scenarios is presented below Tables (1 and 2) and Figures (1 and 2).

Table 1: Key indicators and policy initiatives

	Stated policies				**Africa case**		**CAAGR 2018-40**	
	2000	2018	2030	2040	2030	2040	STEPS	AC
GDP ($2018 billion, PPP)	392	1169	1636	2420	2258	3678	3.40%	5.30%
Population (million)	122	196	263	329	263	329	2.40%	2.40%
*With electricity access	40%	60%	80%	85%	100%	100%	1.60%	2.30%
*With access to clean cooking	1%	10%	28%	38%	100%	100%	6.40%	11.20%
Co_2 emissions (Mt. Co_2)	37	83	134	191	181	257	3.80%	5.30%

Note: STEPS = Stated Policies Scenarios, AC = Africa Case
Source: IEA, 2019b

Table 2: Key targets and measures

Policy	**Key targets and measures**
Performance targets	20% (unconditional) to 45 (conditional) reduction in GHG emissions by 2030 compared to the business-as-usual scenario.
	Increase oil production to 2.4 mb/d and become a net exporter by 2020, and end gas flaring by 2030.
Industrial development targets	Dedicate at least 30% of the federal budget to capital expenditure.
	Achieve GDP growth of 7% and create over 15 million jobs by 2020, and double manufacturing output to 20%.

Key energy indicators

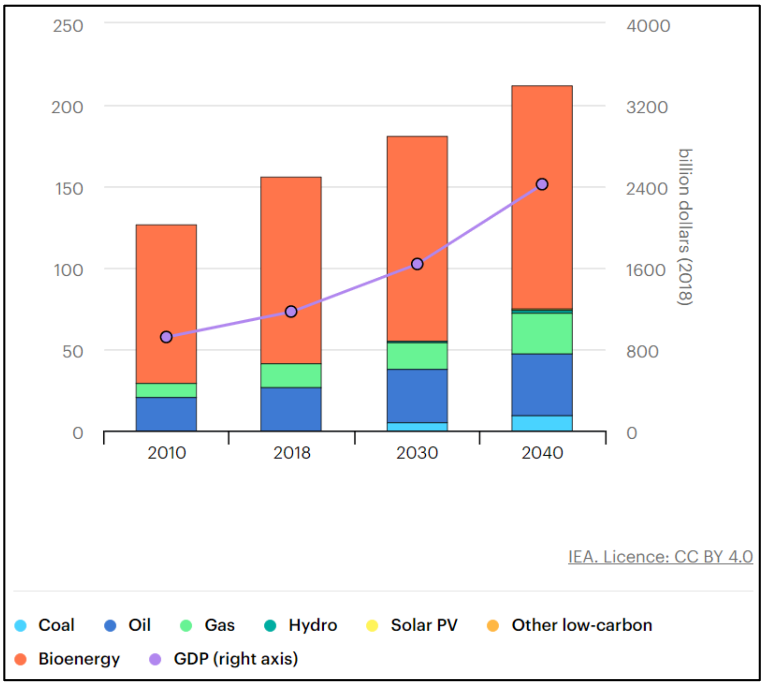

Figure 1: Nigeria primary energy demand and GDP in the stated policies scenario, 2010–2040 *(Source: IEA, 2019a)*

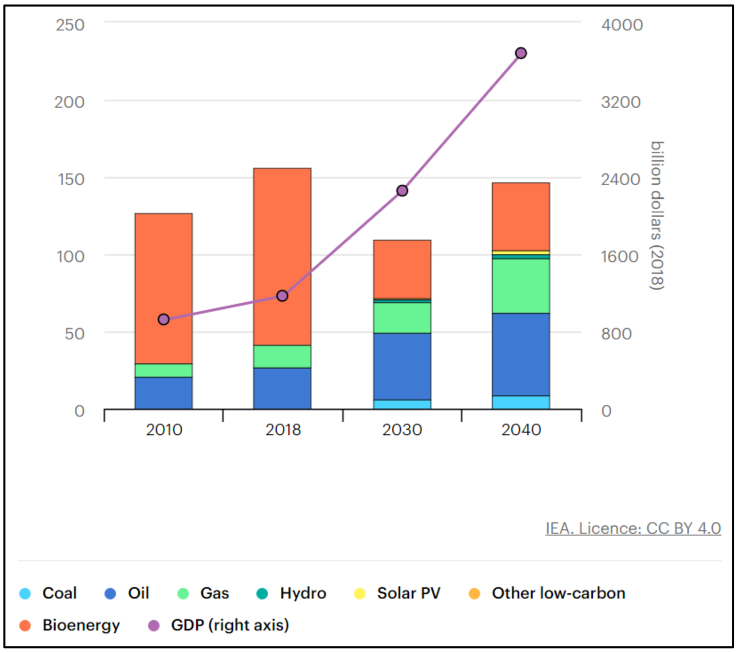

Figure 2: Nigeria primary energy demand and GDP in the Africa Case, 2010–2040 *(Source: IEA, 2019a)*

Nigeria, one of Africa's largest economies with a GDP of USD$447.38 billion in 2022, could supply an economy three times larger with less energy if it diversifies its energy mix. South Africa follows as another country with great potential. In the African case, gas is meeting a growing portion of energy demand, supported by the government's gas masterplan (Figure 3 and 4).

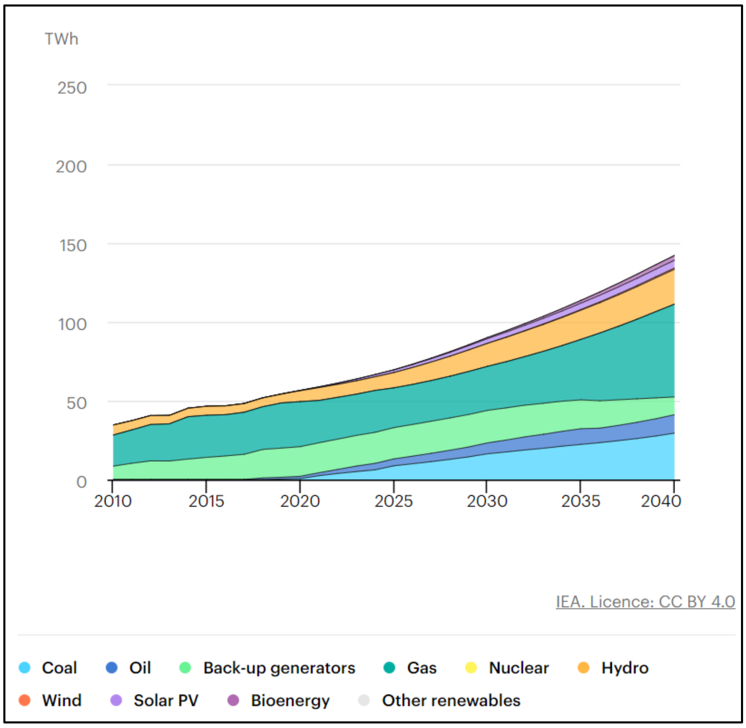

Figure 3: Nigeria electricity generation by technology in the stated policies scenario, 2010-2040 *(Source: IEA, 2019a)*

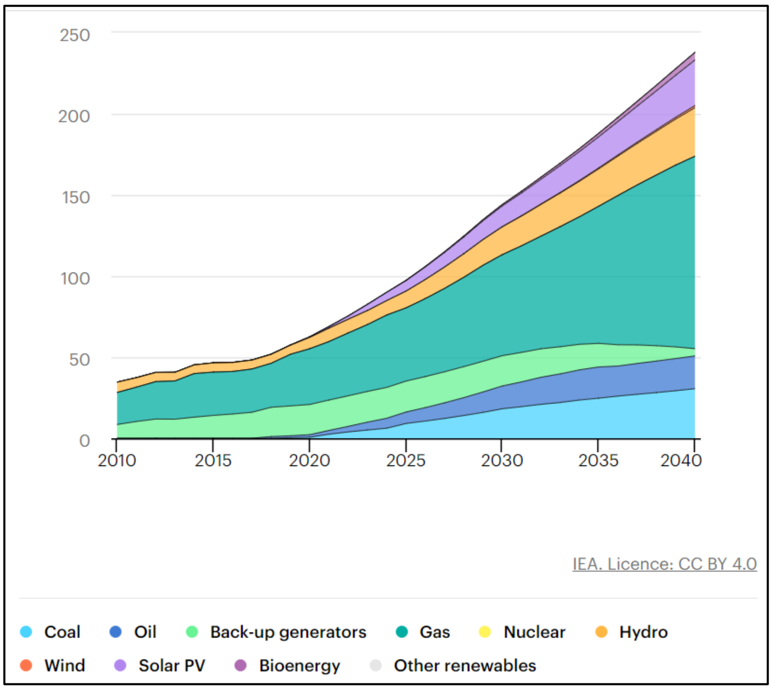

Figure 4: Nigeria electricity generation by technology in the Africa Case, 2010–2040 *(Source: IEA, 2019a)*

On the continent, Nigeria has the largest oil-fired backup generator fleet, with approximately 80% of power generated from gas. In the African case (AC), natural gas is the main source of power, although solar PV is becoming more prevalent as the country begins to use its vast solar resource (Figure 5 and 6).

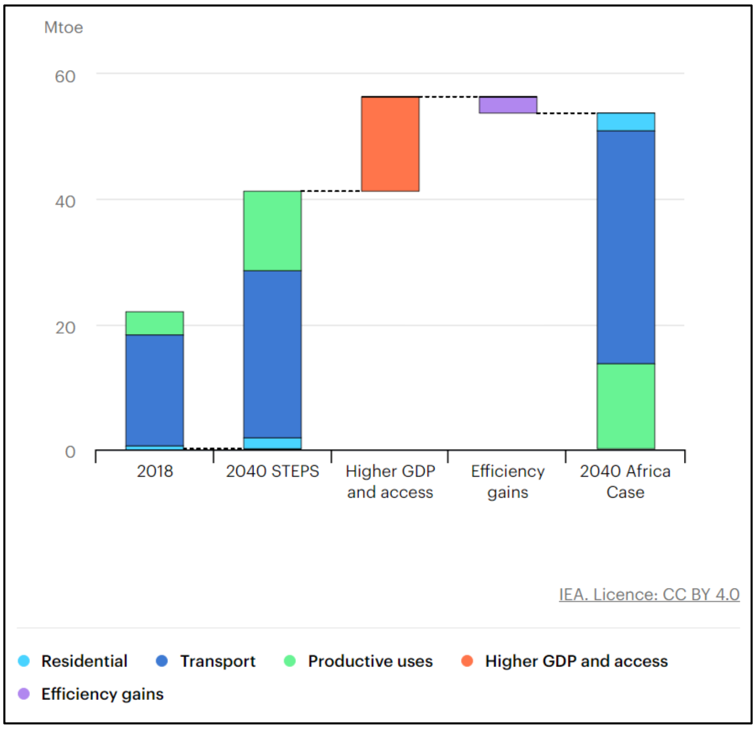

Figure 5: Fossil fuel final energy consumption in Nigeria by scenario, 2018–2040 *(Source: IEA, 2019a)*

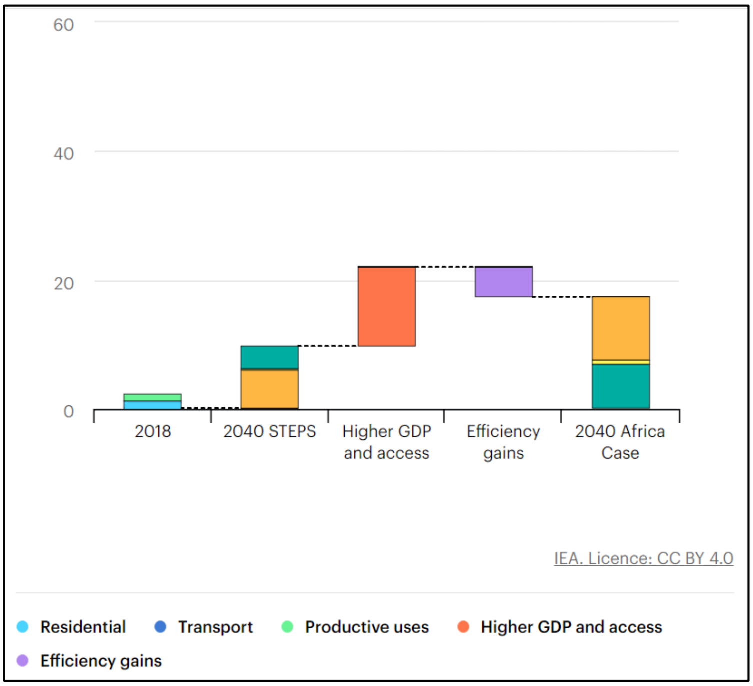

Figure 6: Electricity final energy consumption in Nigeria by scenario, 2018–2040 *(Source: IEA, 2019a)*

Nigeria is a major industrial producer and exporter of chemicals. It will triple chemical production in African countries by the end of 2040 with gas-based methanol and ammonia plants. On the Africa continent, Nigeria has the second-largest vehicle stock: the number of vehicles could surge from 14 to 37 million by 2040 with only two-fold more oil consumption if more stringent fuel economy standards were introduced (Figure 7).

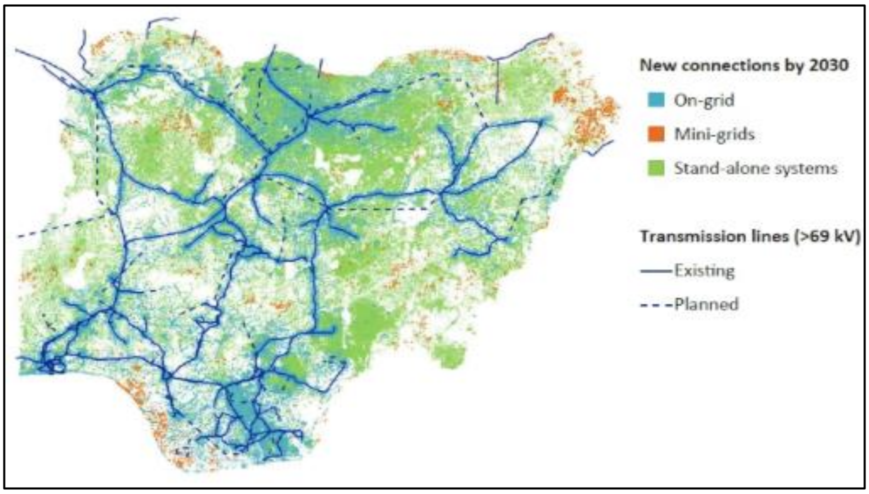

Figure 7: Nigeria electricity access solutions by type in the Africa Case *(Source: IEA, 2019a)*

When reliability and supply improve, the grid could provide electricity for more than 60% of the population. In the African context, by stepping up efforts to provide off-grid solutions to those populations far from a grid, Nigeria could achieve universal access.

While STEPS has made some progress in expanding access to clean cooking services, over three-quarters of the population will remain without it by 2030 (Figure 8).

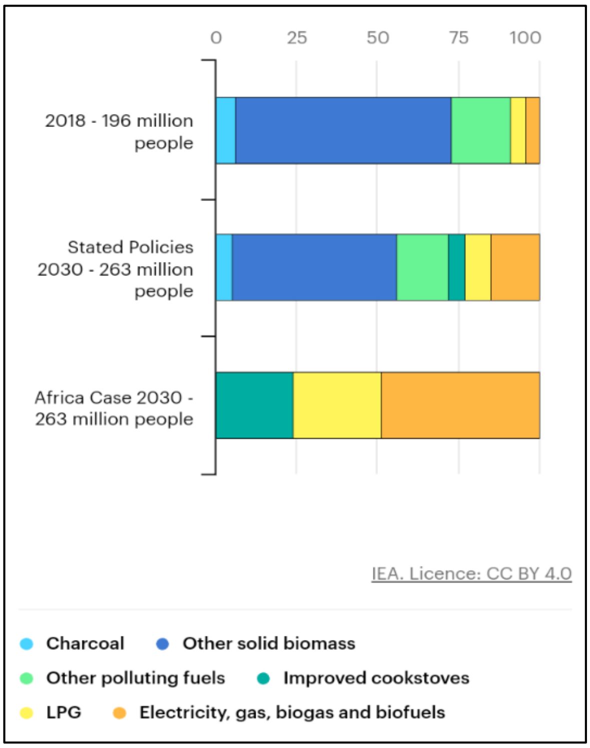

Figure 8: Nigeria fuels and technologies used for cooking by scenario, 2018–2030 *(Source: IEA, 2019a)*

Access to gas networks in urban areas and improved cookstoves in rural regions are the key factors in achieving universal access in the African case (AC) (Figure 9 and 10).

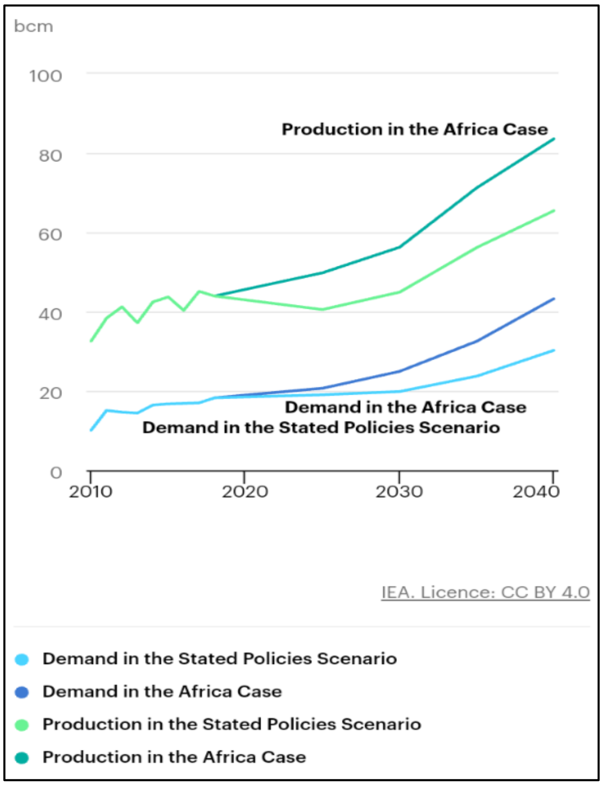

Figure 9: Nigeria gas demand and production by scenario, 2010–2040 *(Source: IEA, 2019a)*

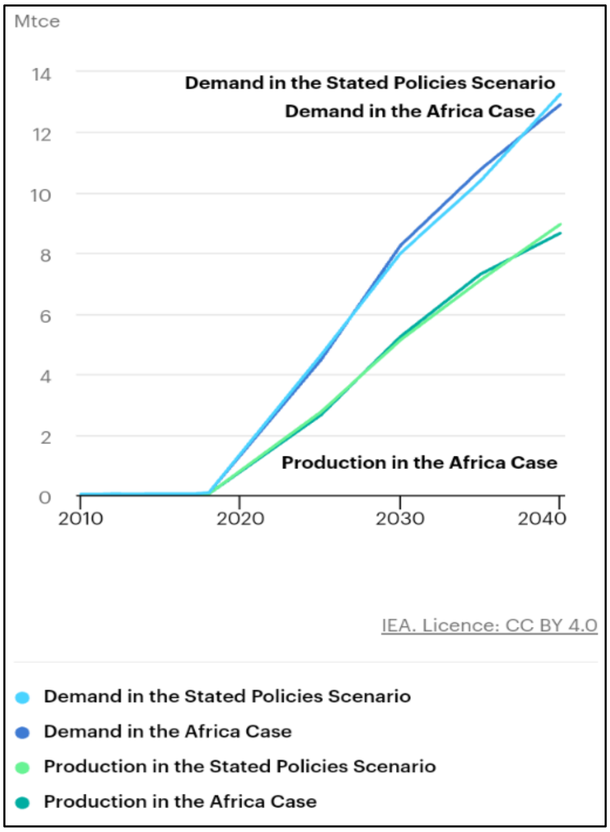

Figure 10: Nigeria coal demand and production by scenario, 2010–2040 *(Source: IEA, 2019a)*

Increasing competition on international oil markets and delayed reforms are limiting oil output recovery. In both the industrial and electricity sectors, gas consumption increases significantly, prompting measures to boost production and curb gas flaring (Figure 11).

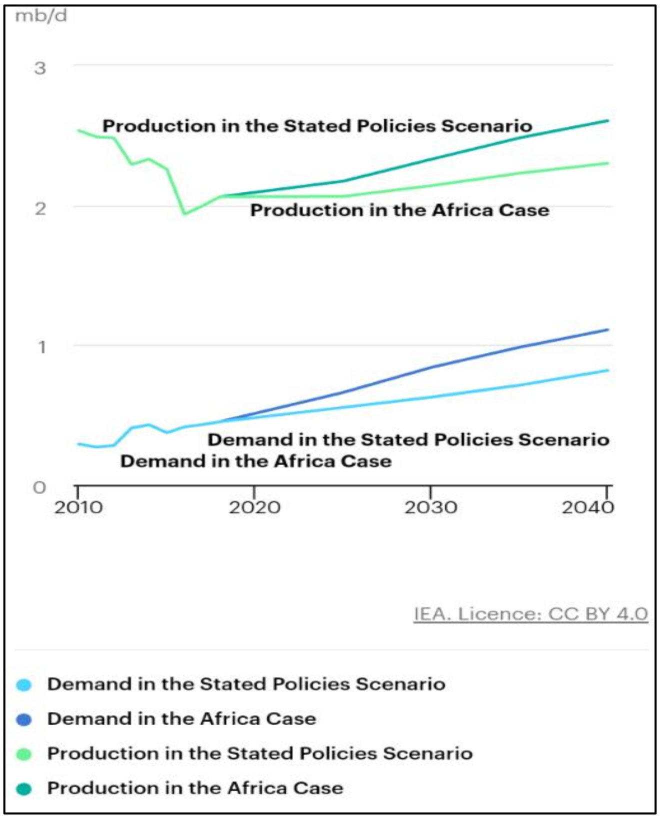

Figure 11: Nigeria oil demand and production by scenario, 2010–2040 *(Source: IEA, 2019a)*

STEPS requires a significant investment in energy of $445 billion, with over 80% invested in upstream oil and gas production (Figure 12).

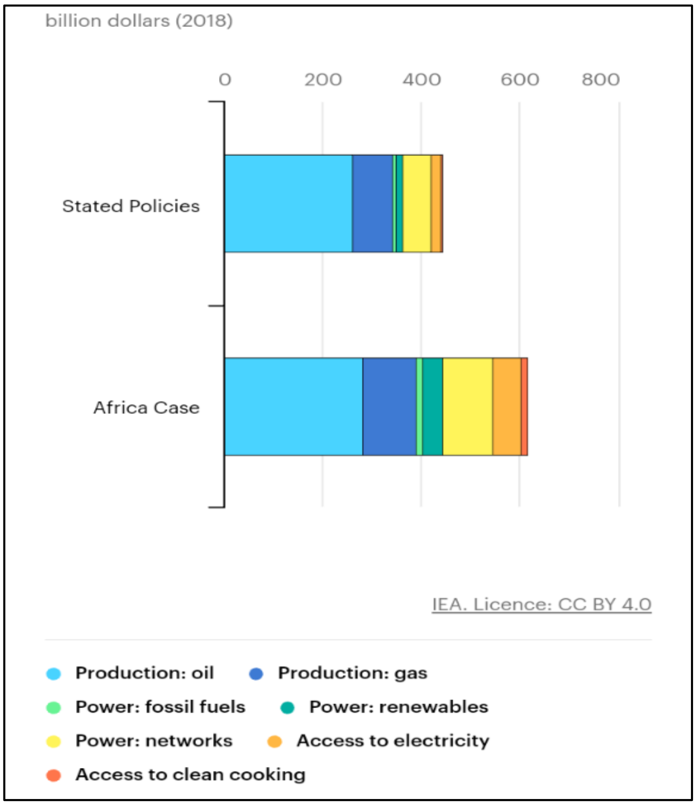

Figure 12: Nigeria cumulative investment needs, 2019–2040 *(Source: IEA, 2019a)*

To address the African energy case, investment in the power sector must be significantly increased, with expenditures on electrical networks and renewable energy rising by 85% and 165%, respectively, compared to STEPS.

The government has implemented policies like the Renewable Energy Master Plan (REMP), seeking to increase renewable energy's share in the national energy mix to 30% by 2030. Nigeria has also partnered with international organisations like UNDP, the World Bank, AFDB, and the IFC to strengthen its energy sector.

The National Integrated Infrastructure Masterplan (2015) projected that USD$1 trillion is needed over the next 30 years for energy development, with USD$600 billion for power and USD$400 billion for oil and gas (Enerdata, 2023). Despite more than $1 trillion spent on the power sector in nine years, the energy crisis continues to impede Nigeria's economic progress.

Understanding the complex interplay between energy consumption and economic progress in Nigeria through up-to-date empirical research is crucial in line with current realities.

Economic growth and development critically depend on energy resources. It impacts economic outcomes based on a nation's structure, development level, energy regulations, and energy mix. Energy empowers individuals and enterprises to operate optimally. In underdeveloped nations with limited energy infrastructure, the link between energy consumption and economic progress is generally stronger than in developed nations (Olaoye, 2024; Amin & Song, 2023; Muazu, Yu & Alariqi, 2023; Mohammadi, Saghaian & Zandi Dareh Gharibi, 2023; Soava & Mehedintu, 2023; Gershon *et al*., 2024; Dahmani, Mabrouki & Ben Youssef, 2023; Mutumba, Odong & Bagire, 2024; Hidayat *et al*., 2024). Another influencing factor is the type of energy used. Renewable energy sources, such as wind and solar, show a weaker association with economic growth compared to fossil fuels in developing countries. Understanding these dynamics is essential for effective energy policy formulation (Jia, Fan & Xia, 2023).

Energy consumption can be described as the aggregate amount of energy utilised to inhabit a building, produce something, or carry out an action in a specific location, including homes, factories, organisations, cities, states, and countries. Energy consumption is derived from renewable and non-renewable energy sources. The cost of energy use is influenced by the source, rate, and volume of use. Energy consumption can be derived mathematically as:

$E = p^* (t/100)$

E = kilowatts or joules per hour (kWh), p = power used per unit in watts, and t = consumption time period.

A nation's economic development is often measured by its per-capita GDP. Per-capita GDP is computed by dividing the total value of all goods and services produced within a country's borders by its population. It is often used as a benchmark for economic progress as it signifies the amount of output a nation generates per individual. Research on the link between energy consumption and economic development encompasses theoretical perspectives, which explore mechanisms of impact, and empirical studies, which test these theories using diverse data sources and methodologies. Several theories have been proposed to examine this complex relationship across different nations and regions.

The pertinent theories consist of the neoclassical growth theory, the endogenous growth model, the energy efficiency paradox, and the environmental Kuznets curve (EKC) hypothesis. The theoretical literature on energy consumption and economic growth can be traced back to the neoclassical growth models, such as Solow (1956), which postulated that energy was an exogenous factor that exerted no influence on economic growth. However, this assumption was challenged by endogenous growth models, such as Romer (1986), which acknowledged that energy constituted an indispensable input for production and innovation and thus had the potential to impact economic growth through its influence on capital accumulation, human capital formation, and technological progress. The energy efficiency paradox posits that enhancements in energy efficiency can trigger an upsurge in energy consumption.

Furthermore, certain models have also taken into account the environmental implications of energy consumption, such as pollution and climate change, which could have detrimental effects on economic growth by depleting natural resources, compromising health, and undermining welfare (Olaoye, 2024; Feng & Zhao, 2022; Muazu, Yu & Alariqi, 2023; Abdulqadir, 2023; Madaleno & Nogueira, 2023). Additionally, the EKC hypothesis suggests that environmental degradation initially intensifies as a country undergoes development but then starts to diminish as the country becomes more developed (Ihugba *et al*., 2024).

The empirical literature on energy consumption and economic growth nexus has employed various econometric methods, including cross-country regressions, panel data analysis, time series analysis, case studies, and meta-analysis. Data sources range from international databases to country-specific data and synthetic data. Results have been diverse and inconclusive, with some studies finding a positive relationship (Feng & Zhao, 2022; Madaleno & Nogueira, 2023; Aswadi *et al*., 2023; Mutumba, Odong & Bagire, 2024; Qi *et al*., 2022; Gershon *et al*., 2024; Dahmani, Mabrouki & Ben Youssef, 2023; Hidayat *et al*., 2024), others discovering a negative correlation (Zhao *et al*., 2023; Moustapha, Yu & Danqauh, 2020; Yusuf, 2023), and some identifying nonlinear relationships or no correlation at all (Onuoha *et al*., 2022; Liu *et al*. 2023; Muazu, Yu & Liu, 2023).

Numerous studies have explored the connection between energy consumption and economic expansion in developing nations like Nigeria, generally concluding that a relationship exists (Qi *et al*., 2022; Onuoha *et al*., 2022; Feng & Zhao, 2022; Soava & Mehedintu, 2023; Mewenemesse & Yan, 2023; Hu & Dong, 2023; Yusuf, 2023; Abdulqadir, 2023; Olaoye, 2024). The strength and direction of this relationship vary across countries and regions, influenced by factors such as development level, energy infrastructure, and policy dynamics. Studies highlight the need to balance economic growth with sustainable energy practices, considering variables like urbanisation, trade, population growth, and environmental impact.

Despite extensive studies, there is a need for up-to-date empirical evidence specifically for Nigeria, particularly after implementing policies like the Power Sector Recovery Programme (PSRP) and the Renewable Energy Master Plan (REMP). This literature review serves as the bedrock for this study and the ensuing empirical analysis of the relationship between energy consumption and economic growth in Nigeria.

Research Methodology

This research employs the Autoregressive Distributed Lag (ARDL) model to estimate the long-run and short-run interplay between these variables. The ARDL model is chosen for its capacity to handle variables with different integration orders, capture dynamic relationships, mitigate endogeneity and reverse causality, and provide robust estimates with limited sample sizes or non-stationary data. This methodology surpasses VAR models by accommodating more variables and offering flexibility in determining optimal lag structures (Pesaran, Shin & Smith, 2001). Moreso, the model accounts for the influence of macroeconomic variables such as FDI, inflation, population growth, CO_2 emissions, and total trade balance.

The model is specified as follows:

$$GDP_t = \beta_0 + \beta_1 ECG_t + \beta_2 POP_t + \beta_3 INF_t + \beta_4 CO2_t + \beta_5 FDI_t + \beta_6 TBL_t + \mu_t$$

Where:

GDP_t is the real gross domestic product in Nigeria in year t

ECG_t is the total energy consumption in Nigeria in year t

POP_t is the Total Population in Nigeria in year t

INF_t is the inflation rate in Nigeria in year t

$CO2_t$ is the Carbon emissions in Nigeria in year t

FDI_t is the Foreign Direct Investment in Nigeria in year t

TBL_t is the total trade balance in Nigeria in year t

β_0 is the intercept term;

β_1 to β_6 are the coefficients of the variables ECG_t, FDI_t, INF_t, POP_t, $CO2_t$, and TBL_t, respectively. μ_t is the error term.

The ARDL model identifies short-run and long-run connections between the variables. i.e., GDP, ECG, POP FDI, INF, CO_2, and TBL, capturing their dynamics over time. The model specification aims to address endogeneity and other econometric issues, providing empirical evidence to inform policy on energy usage, infrastructure investment, and economic development. Model estimation was conducted using E-Views software, and the statistical significance was tested with t-tests at a 5% level. Diagnostic tests were also carried out to ensure model validity. The study is guided by this hypothesis: H0 (no relationship) vs. H1 (positive relationship) between energy consumption and economic growth in Nigeria. Results from the regression analysis will determine if the null hypothesis is rejected, confirming a positive nexus.

Using annual time series data from 1980 to 2022 sourced from the World Bank, Macrotrends, the United Nations, the Nigerian National Bureau of Statistics, and the Central Bank of Nigeria, the study will employ quantitative methodology and incorporate key macroeconomic variables like total energy consumption, per-capita GDP, and others. This period is chosen because it captures the time range when Nigeria began to implement economic reforms aimed at promoting economic growth and development. The time series data analysis involves descriptive statistics and ARDL model technique estimation to explore the dynamic relationship, controlling for other variables, and includes forecast analysis for energy consumption growth rate and GDP growth. This study is distinct in its use of up-to-date data and methods, incorporating future forecast analysis for better policy planning. Empirical results include estimates of long-run and short-run coefficients and their statistical significance under the results and discussion section below. Findings offer policy implications for the Nigerian government and stakeholders, aid in understanding the interplay between energy consumption and economic growth and inform decisions on energy infrastructure investments and economic progress.

Results and Discussion

Descriptive statistics results

Table 3: Descriptive statistics

	GDP	ECG	POP	INFL	CO_2	FDI	TBL
Mean	5.9	3.1	2.67	18.78	0.65	1.43	5.89
Median	6	1.72	2.65	12.56	0.62	1.09	5.84
Maximum	148.61	20.56	3.11	72.84	0.92	5.79	23.05
Minimum	-43.4	-2.44	2.47	5.39	0.47	-1.15	-5.58

The descriptive statistics in Table 3 above summarise the distribution and characteristics of the variables (GDP, ECG, POP, INFL, CO_2, FDI, and TBL) in the dataset analyzed. The mean GDP growth rate was 5.9%, indicating average economic growth per capita over the sample period. The mean energy consumption growth rate (ECG) was 3.1%, reflecting the energy sector's impact on economic activities. The mean population growth rate (POP) was 2.67%, showing the influence of demographic trends. The mean inflation rate (INFL) was 18.78%, indicating annual price level increases. The mean carbon emissions were 0.65, suggesting environmental impacts. Foreign direct investment averaged 1.43% of GDP, while the total trade balance averaged 5.89%. Maximum and minimum values suggest high variation in these indicators.

ARDL bounds test of co-integration

Augmented Dickey-Fuller Unit Root Tests results suggest that none of the study variables were integrated of order two I (2). Variables have a mixed order of integration, meeting ARDL requirements and ensuring valid and reliable co-integration analysis.

Table 4: F-Bounds test result for co-integration

Null Hypothesis: No level relationship				
I(0)	**I(1)**	**Significance**	**Test Statistics**	***K* Value**
1.99	2.94	10%	6.7900	6
2.27	3.28	5%		
2.55	3.61	2.5%		
2.88	3.99	1%		

The bounds test method uses the F-test to investigate long-run relationships between variables, evaluating the joint significance of lagged levels. With an F-statistic of 6.79, exceeding the 3.99 critical value at 1%, a significant long-run relationship is confirmed. I (0) and I (1) represent the integration order.

Long-run impact of energy consumption on economic growth in Nigeria

Having established the presence of a co-integrating relationship among the variables, Table 5 presents the long-run coefficients, t-statistics, and p-values of GDP per capita growth, energy consumption growth, population growth, inflation rate, carbon emissions, FDI, and total trade balance.

Table 5: ARDL long-run estimated results

Variables	**Coefficients**	***t*-ratio**	***P*-Value**
ECG	9.1164	2.1219	0.0715
POP	301.9759	2.085	0.0755
INFL	1.2787	1.6793	0.137
CO_2	237.4464	1.7206	0.129
FDI	-24.676	-1.9519	0.0919
TBL	-5.9041	-1.3399	0.2221

The p-value was significant at 10% level.

The results in Table 5 reveal significant findings regarding the interplay between economic growth and various economic indicators in Nigeria. The long-run coefficient of energy consumption growth (ECG) showed a positive and significant relationship with economic growth at the 10% level. A 1% increase in ECG leads to a 9.12% rise in GDP, highlighting the crucial role of energy in economic development. This aligns with endogenous growth theory and supports findings from Qi *et al*. (2022); Aswadi *et al*. (2023); Madaleno and Nogueira (2023); Gershon *et al*. (2024); Hidayat *et al*. (2024); and Halilbegović, Pekmez and Rehman (2023).

Population growth rate (POP) also positively impacts economic growth, with a 1% increase leading to a 23.06% rise in GDP at a significant 10% level. This supports endogenous growth theory, which posits that population growth enhances innovation and economic scale, contrasting with the Malthusian hypothesis. Studies by Anthony-Orji, Orji and Ogbuabor (2021) corroborate these findings.

Contrary to expectations, the long-run coefficient of inflation rate (INFL) was positive but insignificant, suggesting a 1.27% rise in GDP per 1% inflation rate. Thus supports the structuralist view that moderate inflation can drive growth. Batayneh, Salamat and Momani (2021) and Roncaglia de Carvalho, Ribeiro and Marques (2018) also examined the impact of inflation on economic growth.

Carbon emissions (CO_2) also positively but insignificantly impact economic growth, implying that changes in emissions could boost GDP. This finding supports the endogenous growth view and studies by Hundie (2021) and Olaoye (2024).

Foreign direct investment (FDI) exhibits a negative and significant impact, with a 1% change in FDI leading to a 24.68% GDP decrease. This contradicts the neoclassical and endogenous growth hypotheses but aligns with dependency theory and findings by Wang *et al*. (2022).

Lastly, total trade balance (TBL) had a negative but insignificant impact on economic growth, with a 1% change in TBL leading to a 5.90% GDP decrease. This supports the Keynesian hypothesis and studies by Blavasciunaite, Garsviene, and Matuzeviciute (2020) and Rehman *et al*. (2021).

In summary, energy consumption and population growth positively impact Nigeria's economic growth, while FDI has a negative impact. Inflation and carbon emissions have positive but insignificant effects, and the total trade balance negatively affects economic growth. These findings provide critical insights for policymakers in Nigeria.

Short-run impact of energy consumption on economic growth in Nigeria

Table 6: ARDL short-run ECM estimated results

Dependent variables: **GDP**			
Variables	**Coefficients**	***t*-ratio**	***P*-Value**
ΔGDP_{t-1}	-0.6285	-5.786	0.0007
ΔGDP_{t-2}	-0.1825	-3.16059	0.0159
ΔGDP_{t-3}	-0.455	-8.397	0.0001
ΔECG_{t}	2.5325	6.7602	0.0003
ΔECG_{t-1}	-3.2773	-7.2831	0.0002
ΔECG_{t-2}	-1.9899	-5.2289	0.0012
ΔPOP_{t}	-128.8237	-3.7827	0.0069
ΔPOP_{t-1}	-148.3398	-5.8128	0.0007
$\Delta INFL_{t}$	1.1143	8.0212	0.0001
$\Delta INFL_{t-1}$	-0.2512	-2.6237	0.0342
$\Delta INFL_{t-2}$	0.8499	6.9743	0.0002
$\Delta INFL_{t-3}$	0.1987	1.8938	0.1001
$\Delta C02_{t}$	-169.0625	-5.0687	0.0014
$\Delta C02_{t-1}$	-303.1879	-8.1168	0.0001
$\Delta C02_{t-2}$	-282.6769	-7.0601	0.0002
$\Delta C02_{t-3}$	-155.0932	-4.8239	0.0019
ΔFDI_{t}	-11.2345	-7.6015	0.0001
ΔFDI_{t-1}	3.5278	1.7269	0.1278
ΔTBL_{t}	-0.2935	-0.9723	0.3633
ΔTBL_{t-1}	3.8234	9.2573	0.0000
ΔTBL_{t-2}	3.0149	9.938	0.0000
ΔTBL_{t-3}	2.3551	8.913	0.0000
ECM_{t-1}	-0.8362	-10.4231	0.0000
R-squared	0.9715		
Adjusted *R*-squared	0.9268		

The p-value was significant at 1% and 5% levels.

From table 6 above, the error correction term ECMt-1 represents the speed at which equilibrium is restored after a disturbance, aligning with expectation by being negative and significant at the 1% level. The value of -0.8362 implies that 83.62% of the shock to economic growth will be adjusted in the next period.

The short-run coefficients of ΔGDP t-1, ΔGDP t-2, and ΔGDP t-3 are negative and significant at 1% and 5% levels, indicating that GDP from the previous three periods negatively affects current economic growth. The short-run coefficient of energy consumption (ΔECG t) is positive and significant at the 1% level, suggesting a 1% increase in energy consumption boosts current economic growth by 2.53%. However, energy consumption from the past one (ΔECG t-1) and two periods (ΔECG t-2) negatively affects current economic growth and is significant at 1%.

Contrary to the long-run results, the short-run population growth rate (ΔPOP t) and the previous year's population growth rate (ΔPOP t-1) negatively impact economic growth and are significant at 1%. The short-run coefficient for the current inflation rate (ΔINFL t) and the inflation rates from two (ΔINFL t-2) and three years ago (ΔINFL t-3) positively affect economic growth in conformity with long-run results. However, the inflation rate from the previous year (ΔINFL t-1) has a negative impact and is significant at 5%.

Short-run coefficients for current and lagged carbon emissions (ΔC02 t, ΔC02 t-1, ΔC02 t-2, ΔC02 t-3) negatively and significantly impact economic growth at the 1% level. This implies that increases in carbon emissions hinder growth. The current level of foreign direct investment (FDI) negatively impacts economic growth, aligning with long-run results. The previous year's FDI (ΔFDI t-1) showed a positive but insignificant effect.

The short-run coefficient for the total trade balance (TBL) in the current period negatively but insignificantly impacts economic growth, aligning with the long-run results. However, TBL coefficients from the past three years (ΔTBL t-1, ΔTBL t-2 and ΔTBL t-3) show a positive and significant relationship with economic growth, suggesting that changes in TBL significantly impact short-run economic growth in Nigeria.

Forecast for Nigeria (2023–2070)

Future forecast analysis was conducted on the dependent, independent, and control variables to project trends until 2070. This provides valuable insights for policymakers and stakeholders for early planning and policy design. The statistical model employs parameters like alpha, beta, gamma, Mean Absolute Scaled Error (MASE), Symmetric Mean Absolute Percentage Error (SMAPE), Mean Absolute Error (MAE), and Root Mean Squared Error (RMSE) to estimate the trend, seasonality, and errors. It also offers confidence bounds for the projection, suggesting uncertainty around the predicted value due to various factors. The forecast results are presented below.

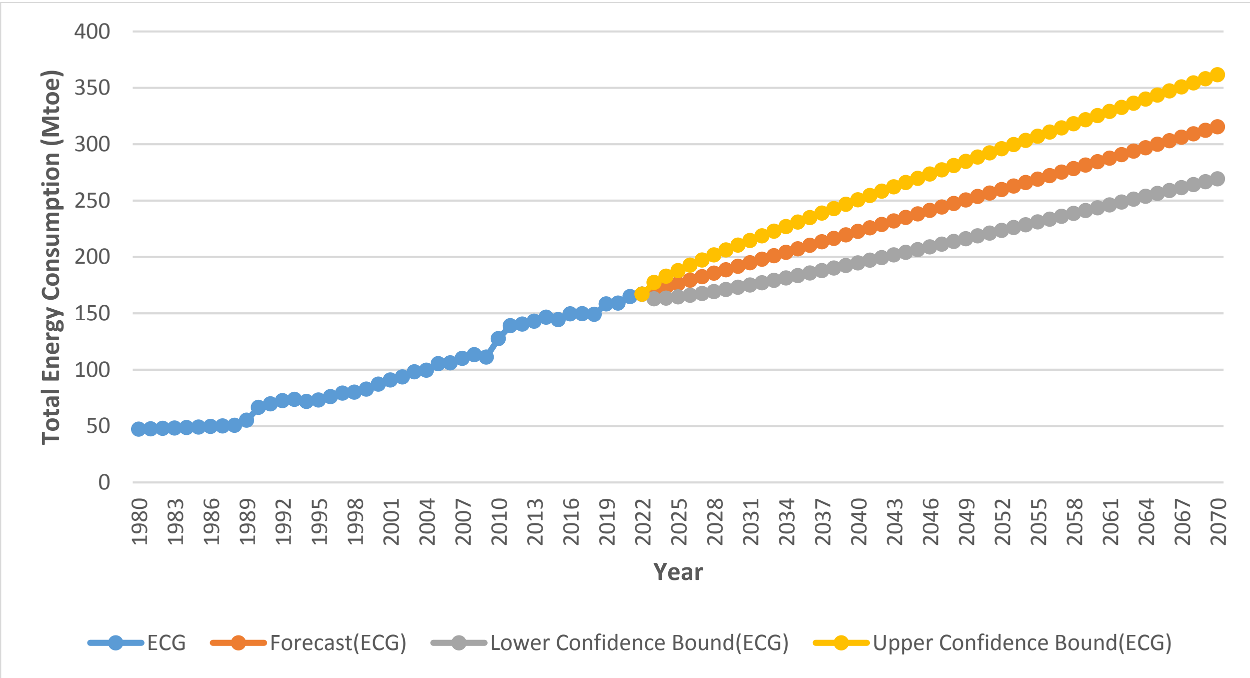

Figure 13: Total energy consumption growth forecast for Nigeria (2023–2070)

Figure 13 forecasts Nigeria's total energy consumption (in million or mega tonnes of oil equivalent or Mtoe) from 2023 to 2070, providing lower and upper confidence bounds. By 2070, consumption is projected to average 315.32 Mtoe, driven by population growth, economic development, and urbanization. The variability in confidence bounds suggests factors like energy prices, technological innovation, and climate change could impact actual consumption.

To boost energy supply and security, Nigeria should invest in modern infrastructure, diversify energy sources, and improve regional cooperation. Achieving sustainable development goals, improving energy efficiency, and implementing effective policies are crucial for balancing economic growth with environmental protection and climate action.

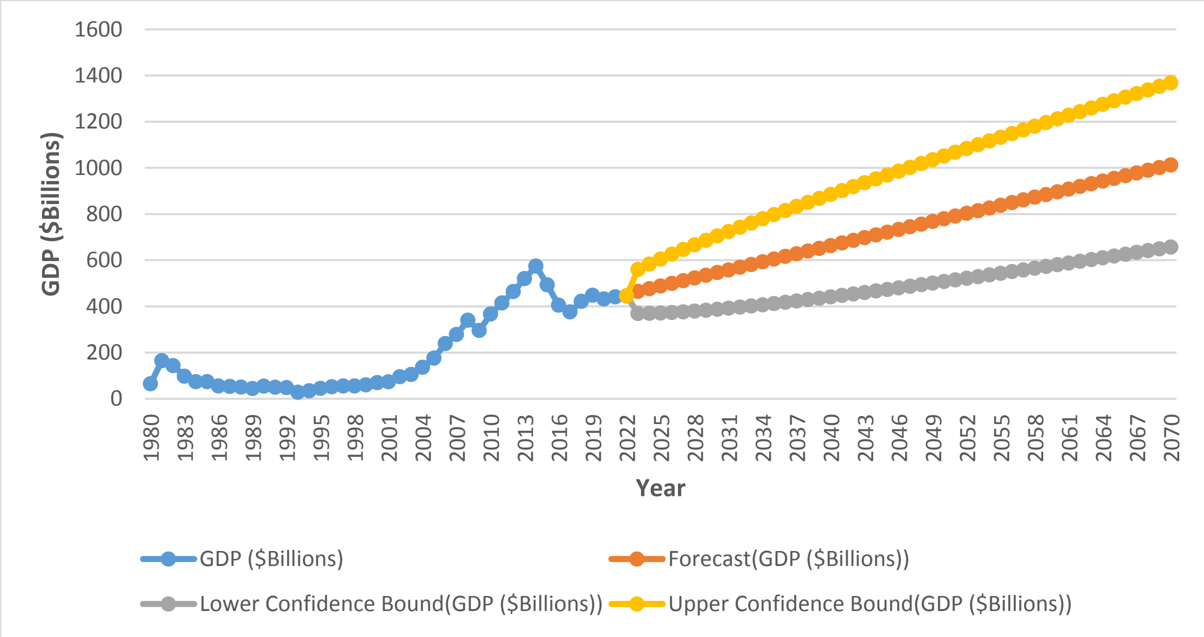

Figure 14: GDP growth forecast for Nigeria (2023–2070)

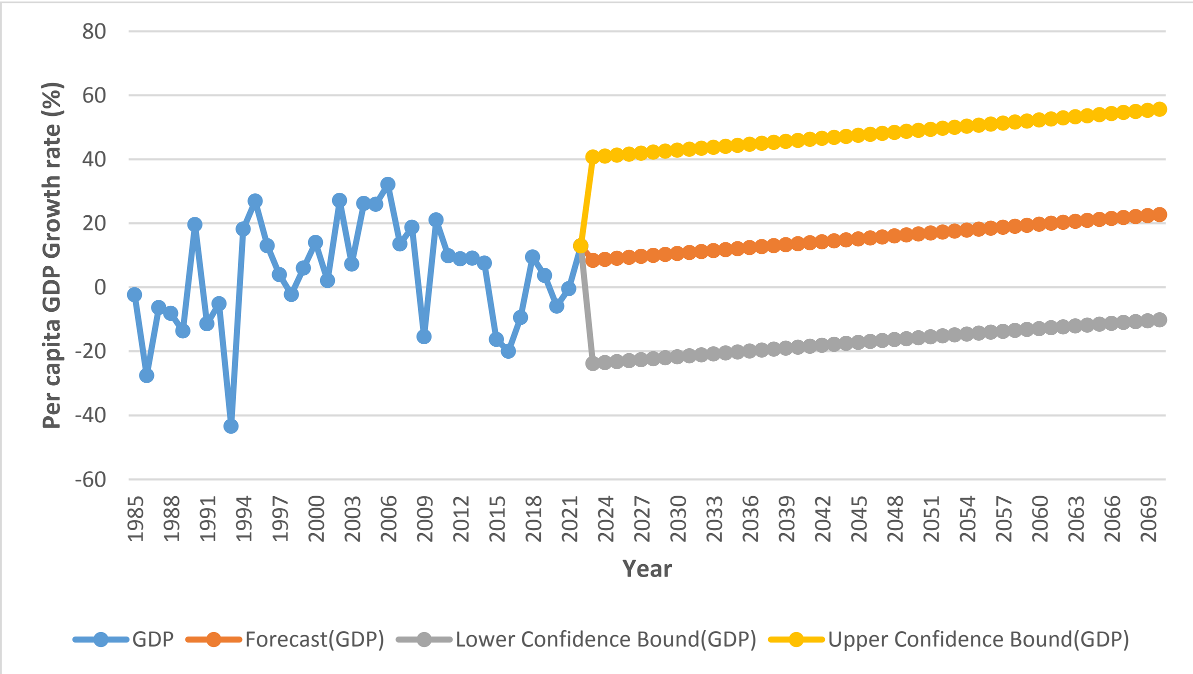

Figure 15: Per capita GDP growth rate forecast for Nigeria (2023–2070)

Figure 14 and 15 forecast Nigeria's GDP and per capita GDP growth rates from 2023 to 2070. By 2070, Nigeria's GDP is expected to average USD$1.012 trillion, making it a leading economy in Africa. Per capita GDP is forecast to grow steadily, averaging a 22.71% growth rate, implying improved living standards. However, variability in confidence bounds suggests factors such as security, inflation, political stability, and external shocks could affect these outcomes.

To sustain growth, Nigeria should diversify its economy, improve governance, enhance fiscal management, reduce debts, reduce dependence on oil, and address security issues for increased competitiveness and stability.

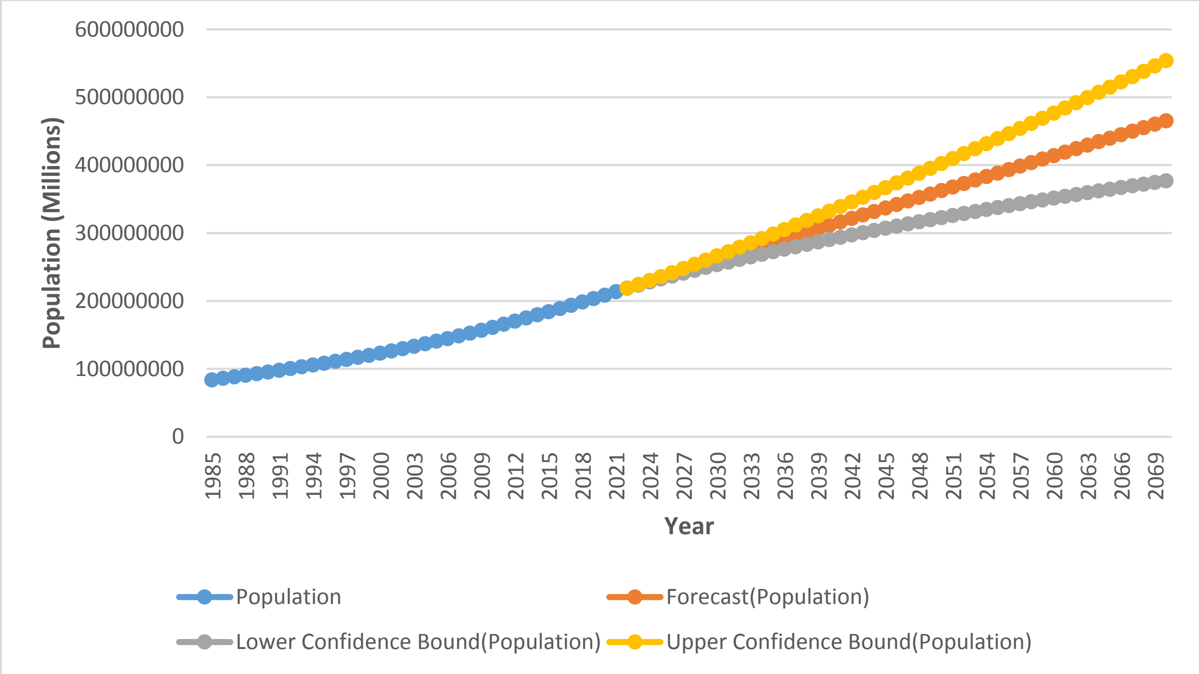

Figure 16: Population growth forecast for Nigeria (2023–2070)

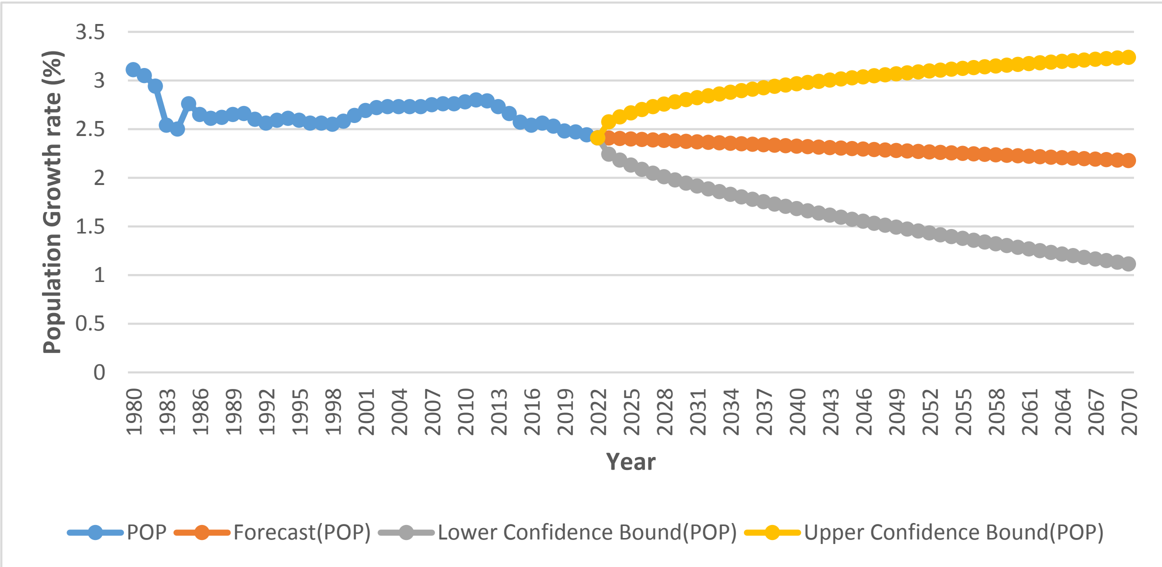

Figure 17: Population growth rate forecast for Nigeria (2023–2070)

Figure 16 and 17 forecast Nigeria's population growth and rate from 2023 to 2070, capturing minimum, average, and maximum projections. By 2070, Nigeria's population is expected to average 465.24 million people, with a growth rate of approximately 2.18%. The population is projected to range between 376.7 million and 553.7 million, with growth rates of around 2.40% in 2024 and 2.18% approximately by 2070. The variability in projections emphasizes the influence of factors like fertility, health, education, mitigation, and environmental conditions. Policymakers should manage growth through quality education, health services, family planning, poverty reduction, and leveraging demographic dividends for economic growth and innovation.

Policy implication

The significant and negative coefficient of ECMt-1 suggests a stable long-run relationship between GDP and the explanatory variables (ECG, POP, INFL, CO_2, FDI, and TBL), with deviations corrected over time. Policymakers can use the long-run coefficients to assess the impact of changes in these variables on economic growth. Attention to the adjustment process is key, requiring measures such as structural reforms, countercyclical policies, and efforts to maintain economic stability.

The short-run impacts of fluctuations in explanatory variables on GDP are shown by the significant coefficients of their first differences. Policymakers can use these to evaluate short-run GDP dynamics in response to shocks and interventions. The F-bounds test confirms a cointegration relationship among the variables, suggesting a long-term causal association with GDP. This information can help policymakers identify growth sources and potential instability in Nigeria's economic growth.

Efficient early policy interventions are critical for sustainable energy consumption and economic growth. Significant positive coefficients of current energy consumption underscore energy's role in economic development. Policies to attract investment in the energy sector are crucial to ensuring reliable, affordable energy, facilitating economic diversification, and enhancing productivity. The lagged GDP and FDI coefficients highlight the importance of economic growth and foreign investment. Policies that stimulate investment, improve the business environment, and foster growth should be implemented. Negative short-term coefficients of carbon emissions show the need for environmental policies to reduce emissions through sustainable energy, renewables, and efficiency.

Significant inflation rate coefficients underscore the need for effective inflation management. Prioritising price stability through prudent monetary, fiscal, and regulatory measures is key. The trade balance's significant negative impact on growth necessitates strategies to promote exports, reduce import dependence, and enhance competitiveness. Overall, early planning and policy designs are imperative for addressing present and future needs, ensuring sustainable growth, and responding to economic changes in Nigeria.

Conclusion

This study explored the long-run and short-run impacts of energy consumption on economic growth in Nigeria from 1980 to 2022, utilising ARDL and forecast analysis methods. An econometric model was specified, incorporating energy consumption and control variables such as population growth rate, inflation, carbon emissions, foreign direct investment, and trade balance. After ensuring stationarity, the ARDL cointegration method revealed that energy consumption positively impacts economic growth both in the short and long term. Population growth rate negatively affects long-term growth, while inflation curtails growth in the long term but exhibits opposite effects on growth in the short term. FDI and carbon emissions promote growth in both periods. The co-integrating equation suggests a 98.86% speed of adjustment to long-term equilibrium after a shock. Forecast analysis indicates future trends in GDP, per capita GDP growth, energy consumption, population growth, inflation, carbon emissions, and FDI, helping policymakers in early planning.

Recommendation

Policy recommendations include: (i) prioritising policies that stimulate sustainable economic growth and attract FDI by creating an enabling business environment, minimising bureaucratic impediments, providing investment incentives, and implementing reforms to enhance productivity and competitiveness; (ii) investing in a sustainable energy mix, especially renewables; modernising energy infrastructure; enhancing energy efficiency; and implementing environmental regulation to reduce carbon emissions; (iii) managing inflation through prudent monetary policies and fiscal measures to control government spending and maintain price stability; (iv) strengthening export competitiveness, diversifying export products, and attracting FDI into export-oriented industries and reducing import dependence; (v) snsuring policy consistency and stability across monetary, fiscal, trade, and energy sectors to avoid disruptions in adjustment processes. Lastly, implementing robust monitoring and evaluation mechanisms to assess the impacts and identify areas for improvement, fostering transparent and predictable frameworks to boost investor confidence, and promoting long-term economic stability.

Future Scope

Building on the findings of this study, future research will explore avenues to deepen understanding of the relationship between energy consumption and economic growth in Nigeria. That is, disaggregated analyses of energy types (renewable and non-renewable sources) to provide more targeted policy insights that will help to detect which energy sources have the most significant economic impact. Moreover, as recent data become available, additional variables may well be incorporated, such as technological innovation and digitalisation, to examine their interactive impacts on economic performance. Furthermore, trade-offs between economic performance and environmental degradation will be explored through advanced models. Besides, future research may look into applying dynamic modelling techniques like machine learning or system dynamics to augment the accuracy of the forecast and provide real-time policy guidance. Lastly, the impact of structural changes in global energy prices, financial markets, and trade policies on Nigeria's economy will be examined as more recent data become available.

Conflict of Interest

The authors affirm that there are no conflicting objectives.

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