ENERGY INTENSITY AND ECONOMIC GROWTH IN NIGERIA: EVIDENCE FROM ARDL BOUNDS TESTING WITH STRUCTURAL BREAKS

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Abstract

This study examines the relationship between energy intensity and economic growth in Nigeria over the period 1980–2024. The analysis employs the autoregressive distributed lag bounds testing approach while accounting for structural breaks in the data. In addition to energy intensity, the model incorporates energy consumption, gross capital formation, trade openness, urban population growth, and carbon emissions in order to capture the broader energy–growth–environment dynamics. The unit root results confirm a mixture of I(0) and I(1) variables, justifying the use of the ARDL framework. The bounds testing results indicate the presence of a stable long run relationship among the variables. The long run estimates show that energy intensity exerts a negative and statistically significant effect on economic growth, while energy consumption, investment, trade openness, and urbanisation contribute positively to economic performance. Carbon emissions display a negative but statistically insignificant relationship with economic growth. The short run dynamics confirm these relationships and the error correction mechanism indicates a relatively rapid adjustment toward long run equilibrium following short run disturbances. The findings suggest that improving energy efficiency and expanding reliable energy supply are important for sustaining economic growth in Nigeria. Policies aimed at reducing energy intensity through technological improvements, strengthening energy infrastructure, and encouraging productive investment could enhance economic performance while supporting sustainable development.

Keywords: Energy intensity; Economic growth; Energy consumption; ARDL bounds testing; Structural breaks; Nigeria

1. Introduction

Energy remains a critical input in modern economic systems, as production, transportation, and technological processes depend heavily on reliable and efficient energy supply. As economic activity expands, the demand for energy continues to increase, raising important questions about how efficiently energy is utilised and how this affects economic performance. In this context, energy intensity, defined as the amount of energy required to generate economic output, has emerged as a key indicator of energy efficiency. Declining energy intensity is often associated with technological progress, improved energy management, and structural transformation towards less energy-intensive production, all of which can enhance productivity and economic growth (Sun, 1998; Mahmood & Ahmad, 2018; Bergmann & Kalkuhl, 2025).

The relationship between energy use and economic growth is commonly examined within the energy–growth nexus framework, which considers whether energy consumption drives economic growth, whether economic growth induces energy demand, or whether both variables interact simultaneously. Empirical evidence remains mixed across countries and methodologies. While some studies find that energy consumption stimulates growth by serving as a productive input, others suggest that economic expansion drives energy demand through increased industrial activity (Aydin & Esen, 2018; Díaz et al., 2019; Bekun et al., 2025). More recent work has shifted attention towards energy intensity, recognising that the efficiency with which energy is used may be as important as the quantity consumed. Improvements in energy efficiency enable economies to generate higher output with lower energy input, although energy intensity is also influenced by structural factors such as industrial composition, trade patterns, and urbanisation (Kazemzadeh et al., 2023; Sueyoshi & Goto, 2023).

These issues are particularly relevant for Nigeria, where energy supply constraints, infrastructure deficiencies, and structural transformation continue to shape patterns of energy use. Despite being one of the largest energy producers in Africa, Nigeria faces persistent electricity shortages, high transmission losses, and widespread reliance on self-generation. These inefficiencies contribute to relatively high energy intensity and may constrain productivity. At the same time, rapid urbanisation, expanding industrial activity, and rising energy demand increase pressure on the energy system, making efficient energy utilisation a critical policy concern.

From a policy perspective, the dual challenge facing Nigeria is not only to expand energy supply but also to improve energy efficiency. Policies that focus solely on increasing energy production without addressing inefficiencies may lead to higher costs, resource misallocation, and environmental pressures. Conversely, improving energy efficiency can enhance productivity, reduce production costs, and support sustainable growth. Understanding how energy intensity affects economic growth is therefore essential for designing policies that balance energy expansion with efficiency improvements.

Empirical studies on Nigeria have largely focused on the role of energy consumption in economic growth, with limited attention to energy intensity. Existing evidence shows that energy consumption contributes positively to economic performance, reflecting its role as a productive input (Rafindadi, 2016; Kabuga & Mohammed, 2020). However, relatively few studies explicitly examine how energy efficiency, captured through energy intensity, influences growth while accounting for structural changes and broader macroeconomic factors. In addition, many studies rely on cross-country panel approaches, which may overlook country-specific institutional and structural dynamics. The limited incorporation of structural breaks further constrains the ability of existing studies to capture major economic shifts.

Against this background, this study investigates the relationship between energy intensity and economic growth in Nigeria over the period 1980–2024 using the autoregressive distributed lag bounds testing approach with structural breaks. The model incorporates energy consumption, gross capital formation, trade openness, urban population growth, and carbon emissions to capture broader economic and structural dynamics.

This study contributes to the literature in three main ways. First, it focuses explicitly on energy intensity as a measure of energy efficiency, extending the existing literature that primarily concentrates on energy consumption. Second, it incorporates structural break analysis to account for major economic and energy sector developments. Third, by employing the ARDL framework, it provides evidence on both long-run equilibrium relationships and short-run dynamics within a country-specific context.

The remainder of the study is organised as follows. Section 2 presents the literature review. Section 3 outlines the methodology. Section 4 presents and discusses the empirical results. Section 5 concludes the study and provides policy recommendations.

2. Literature review

2.1 Conceptual Review

Energy intensity represents one of the most widely used indicators for analysing the relationship between energy use and economic performance. It is commonly defined as the quantity of energy required to produce a unit of economic output, typically measured as energy consumption relative to gross domestic product. Because this indicator captures how much energy is required to generate economic value, it is frequently interpreted as a proxy for energy efficiency within an economy. Lower energy intensity generally reflects improvements in technological efficiency, energy management, and structural transformation toward less energy-intensive sectors, while higher energy intensity may signal inefficiencies in energy utilisation or structural dependence on energy-intensive production activities. Several studies emphasise that changes in energy intensity are closely linked to technological progress, structural transformation, and energy productivity improvements within economies (Sun, 1998; Li et al., 2024;Hajiyev et al., 2023; Labidi 2025;Dai et al., 2025).

Closely related to energy intensity is the concept of energy consumption, which represents the total amount of energy utilised within an economy to support production, transportation, services, and household activities. Energy consumption plays a central role in economic activity because energy is an essential input in modern production systems. The relationship between energy consumption and economic growth has therefore attracted considerable attention in the literature, particularly in studies examining the energy–growth nexus. A large body of empirical work suggests that energy consumption is closely associated with economic expansion, as increased economic activity typically requires greater energy inputs to support industrial output and infrastructure development (Hu, & Jing, 2022; Huang et al., 2024; Gahlot & Garg, 2025; Islam et al., 2025). In developing economies where industrialisation and infrastructure expansion remain energy dependent, the availability and reliability of energy supply often become critical determinants of economic performance (Bekun et al., 2025).

Another important concept in this literature is energy efficiency, which refers to the ability of an economy to generate a given level of economic output using less energy input. Improvements in energy efficiency are typically driven by technological innovation, improvements in production processes, and structural shifts toward less energy-intensive economic activities. Although energy intensity is frequently used as an indicator of energy efficiency, scholars caution that the two concepts are not identical

because energy intensity can also be influenced by structural and economic factors such as industrial composition, energy prices, and income levels (Kabuga, 2023). Consequently, changes in energy intensity may reflect both efficiency improvements and structural changes within an economy.

The broader analytical framework connecting these concepts is often described as the energy–growth nexus, which examines the causal and structural relationships between energy use and economic performance. The literature commonly discusses four competing hypotheses explaining this relationship, namely, the growth hypothesis, the conservation hypothesis, the feedback hypothesis, and the neutrality hypothesis. The growth hypothesis suggests that energy consumption drives economic growth because energy functions as a productive input, while the conservation hypothesis proposes that economic growth leads to increased energy demand. The feedback hypothesis suggests bidirectional interactions between energy consumption and economic growth, whereas the neutrality hypothesis indicates the absence of a significant relationship between the two variables. These competing perspectives highlight the complex and context-dependent nature of the relationship between energy use, economic growth, and environmental sustainability (Aydin & Esen, 2018; Ismail & Kabuga, 2019; Deichmann et al., 2019; Namahoro et al., 2021).

2.2 Empirical Review

Several empirical studies have recently examined the relationship between energy use and economic growth, particularly in the context of sustainability transitions, structural transformation, and energy efficiency improvements.The empirical literature can broadly be organised into three main strands. The first strand examines the relationship between energy intensity and economic growth, focusing on whether improvements in energy efficiency support economic expansion. The second strand investigates the contribution of energy consumption to economic growth and the direction of causality between energy use and economic performance. The third strand explores the broader interaction between energy intensity, economic growth, and environmental outcomes. Reviewing these strands provides a clearer understanding of the evolving empirical evidence and helps identify the research gaps addressed by this study.

A first group of studies investigates the relationship between energy intensity and economic growth, often interpreting energy intensity as an indicator of energy efficiency within the production system. Recent research emphasises that the relationship between energy intensity and economic performance is influenced by technological progress, structural transformation, and economic complexity (Kabuga, 2023). Using a non-parametric efficiency framework, Sueyoshi and Goto (2023) examine the relationship between energy intensity, energy efficiency, and economic growth in OECD countries and show that improvements in energy efficiency and the adoption of cleaner energy sources contribute to reductions in energy intensity while supporting economic expansion. Similarly, Kazemzadeh et al. (2023) find that the determinants of energy intensity are heterogeneous across countries and income levels, demonstrating that economic growth generally reduces energy intensity but that urbanisation, trade openness, and foreign investment can increase energy intensity in certain contexts. These findings suggest that energy intensity reflects both technological efficiency and structural

characteristics of the economy. Supporting this perspective, Mahmood and Ahmad (2018) find that declining energy intensity accompanies economic development in European economies as production structures shift toward less energy-intensive sectors.

A second strand of the empirical literature focuses on the role of energy consumption in driving economic growth. This strand is largely rooted in the energy–growth nexus literature, which investigates whether energy consumption stimulates economic growth, whether economic growth drives energy demand, or whether both variables influence each other simultaneously. A comprehensive review by Kassim and Isik (2020) shows that empirical studies across transition economies frequently support the feedback hypothesis, indicating bidirectional causality between energy consumption and economic growth. Country-specific studies provide further evidence of the importance of energy consumption for economic performance. For example, Kabuga and Mohammed (2020) examine the relationship between energy consumption and economic growth in Nigeria and find that energy consumption positively influences economic growth in both the short run and long run. Their results also reveal bidirectional causality in the short run and unidirectional causality from energy consumption to economic growth in the long run. These findings highlight the importance of reliable energy supply for sustaining economic activity in energy-constrained economies.

A third strand of the literature examines the interaction between energy intensity, economic growth, and environmental outcomes. In this line of research, energy intensity is often analysed together with carbon emissions and environmental sustainability indicators. Namahoro et al. (2021), using panel data for African countries, find that higher energy intensity significantly increases carbon emissions across regions and income groups, while renewable energy helps mitigate environmental degradation. Similarly, Kostakis et al. (2025) find that both economic growth and energy intensity contribute to environmental degradation in selected OECD countries, although environmental taxes and institutional policies can mitigate these effects. Özmerdivanlı and Sönmez (2025) also report that energy consumption and economic growth increase environmental pressures in both advanced and emerging economies. These findings suggest that while energy use remains important for economic expansion, improvements in energy efficiency and environmental policies are necessary to ensure sustainable development.

Despite these advances, the empirical literature still presents several unresolved issues. First, many recent studies rely on cross-country panel datasets, which provide broad comparative insights but may obscure country-specific dynamics related to institutional structures, energy infrastructure, and policy frameworks. Second, although energy intensity is often interpreted as a measure of energy efficiency, its determinants may vary across countries depending on structural and technological conditions. Third, relatively few studies simultaneously examine energy intensity, energy consumption, structural factors, and economic growth within a country-specific time-series framework while accounting for structural breaks. These limitations highlight the need for further country-focused empirical analyses that incorporate both efficiency and consumption dimensions of energy use. By examining the relationship between energy intensity and economic growth in Nigeria using a long time series and an ARDL framework with structural breaks, the present study contributes to addressing this gap in the literature.

2.3 Theoretical Framework

The theoretical framework of this study is grounded in the extended neoclassical production function in which energy is incorporated as a fundamental input alongside capital and labour in the production process. While early neoclassical growth models emphasised capital accumulation and labour as the primary drivers of output, subsequent theoretical developments recognise that energy is indispensable for sustaining modern economic activity because industrial production, transportation, and technological processes rely heavily on energy availability. Within this framework, energy intensity reflects the amount of energy required to generate economic output and therefore provides an indication of the efficiency with which energy resources are utilised in the production process. Improvements in energy efficiency, which are often reflected in declining energy intensity, are expected to enhance economic performance by reducing production costs and improving overall productivity (Sun, 1998; De Cian et al., 2013; Mahmood & Ahmad, 2018; Mahmood et al., 2021; Amin et al., 2023; Bergmann & Kalkuhl, 2025).

A second theoretical perspective relevant to this study is the energy–growth nexus framework, which explains the causal relationship between energy use and economic growth. This framework proposes four competing hypotheses that describe the interaction between energy consumption and economic performance. The growth hypothesis suggests that energy consumption stimulates economic growth because energy serves as a productive input in economic activity. The conservation hypothesis proposes that economic growth leads to increased energy demand, implying that energy conservation policies may not necessarily constrain economic performance. The feedback hypothesis indicates bidirectional causality between energy consumption and economic growth, while the neutrality hypothesis suggests that energy consumption and economic growth may be independent of each other. These hypotheses provide a useful analytical framework for interpreting the empirical relationship between energy consumption, energy intensity, and economic growth across different economies (Baz et al., 2021; Bunnag, 2021; El-Karimi, 2022; Farhidi, 2023; Özdemir & Bekun, 2023).

The framework of this study also draws from the broader literature on energy efficiency and sustainable economic development, which emphasises the importance of technological progress and structural transformation in reducing energy intensity. As economies develop, improvements in technology, production processes, and energy management practices can reduce the amount of energy required to generate economic output. These efficiency improvements allow economies to maintain economic expansion while reducing dependence on energy-intensive production systems. At the same time, structural changes such as urbanisation, capital accumulation, and trade integration can influence patterns of energy demand and energy efficiency within the economy. Consequently, the interaction between energy intensity, energy consumption, and economic growth is shaped not only by technological factors but also by structural and institutional conditions that influence how energy resources are utilised in the production process (Kabuga, 2018; Díaz et al., 2019; Genet, 2019; Kazemzadeh et al., 2023; Namahoro et al., 2021; Nita &Stioută, 2025).

3. Methodology

3.1 Data Sources and Measurement

This study employs annual time series data for Nigeria covering the period 1980–2024. The sample period captures key structural and macroeconomic developments, including policy reforms, oil price shocks, and changes in energy demand patterns.All variables are obtained from the World Development Indicators database of the World Bank to ensure consistency and comparability. Energy intensity is constructed as the ratio of total energy consumption to gross domestic product, following standard practice in the literature. The empirical model includes economic growth, energy intensity, energy consumption, gross capital formation, trade openness, urban population growth, and carbon emissions. The definition, measurement, expected signs, and data sources of the variables are presented in Table 1.

Table 1: Definition and Measurement of Variables

Variable	**Symbol**	**Measurement**	**Expected Sign**	**Data Source**
Economic Growth	GDPG	Annual growth rate of real GDP (%)	Dependent variable	World Development Indicators
Energy Intensity	EI	Energy consumption divided by GDP (Energy use per unit of GDP)	Negative	Constructed by author using World Development Indicators
Energy Consumption	EC	Total energy use (kg of oil equivalent per capita)	Positive	World Development Indicators
Gross Capital Formation	GCF	Gross capital formation (% of GDP)	Positive	World Development Indicators
Trade Openness	OPEN	Ratio of total exports and imports to GDP	Positive	World Development Indicators
Urban Population Growth	URB	Annual urban population growth rate (%)	Positive	World Development Indicators
Carbon Emissions	CO_2	Carbon dioxide emissions per capita (metric tons)	Ambiguous	World Development Indicators

Source: Author's compilation based on World Development Indicators.

3.2 Model Specification

The relationship between energy intensity and economic growth is specified as:

$$GDPG_t = f(EI_t, EC_t, GCF_t, OPEN_t, URB_t, CO2_t)$$

The corresponding econometric model is expressed as:

$$GDPG_t = \alpha_0 + \alpha_1 EI_t + \alpha_2 EC_t + \alpha_3 GCF_t + \alpha_4 OPEN_t + \alpha_5 URB_t + \alpha_6 CO2_t + \varepsilon_t$$

where all variables are defined in Table 1.

Given the time series properties of the data, the study adopts the autoregressive distributed lag (ARDL) framework, which accommodates variables integrated of order zero or one and allows simultaneous estimation of short-run and long-run relationships.

3.3 Unit Root Tests

To determine the order of integration, both the Augmented Dickey–Fuller (ADF) and Kapetanios–Shin–Snell (KSS) nonlinear unit root tests are employed. The ADF test is specified as:

$$\Delta Y_t = \alpha + \beta t + \gamma Y_{t-1} + \sum_{i=1}^{p} \delta_i \, \Delta Y_{t-i} + \varepsilon_t$$

The KSS nonlinear unit root test is given by:

$$\Delta Y_t = \delta Y_{t-1}^3 + \sum_{i=1}^{p} \theta_i \, \Delta Y_{t-i} + \varepsilon_t$$

These tests ensure that none of the variables is integrated of order two, a requirement for ARDL estimation.

3.4 Structural Break Test

To account for possible structural shifts, the Zivot–Andrews test is employed, allowing for an endogenous break in the intercept and trend:

$$\Delta Y_t = \alpha + \beta t + \theta DU_t + \gamma DT_t + \rho Y_{t-1} + \sum_{i=1}^{k} \delta_i \, \Delta Y_{t-i} + \varepsilon_t$$

This approach improves the reliability of stationarity results in the presence of structural changes.

3.5 ARDL Bounds Testing Approach

The ARDL bounds testing procedure is used to examine the existence of a long-run relationship among the variables. The null hypothesis of no cointegration is tested as:

$$H_0: \lambda_1 = \lambda_2 = \cdots = \lambda_6 = 0$$

The computed F-statistic is compared with the critical bounds of Pesaran et al. and Narayan. If the F-statistic exceeds the upper bound, cointegration is confirmed.

3.6 Long-Run and Short-Run Estimation

The long-run relationship is estimated within the ARDL framework, while short-run dynamics are captured using the error correction model:

$$\Delta GDPG_t = \sum \beta_i \Delta X_{t-i} + \phi ECT_{t-1} + \varepsilon_t$$

where ECT_{t-1}represents the lagged error correction term and ϕmeasures the speed of adjustment toward equilibrium.

Model adequacy is assessed using the Breusch–Godfrey serial correlation test, ARCH heteroskedasticity test, Jarque–Bera normality test, and Ramsey RESET test. Parameter stability is evaluated using the CUSUM and CUSUMSQ tests.

4. Results and Discussion

This section presents the empirical results on the relationship between energy intensity and economic growth in Nigeria. It begins with descriptive statistics and correlation analysis, followed by unit root tests and structural break analysis to establish the time series properties of the data before ARDL estimation.

4.1 Descriptive Statistics

Descriptive statistics summarise the distributional properties of the variables and provide preliminary insights into their behaviour over the sample period. Table 2 reports the mean, standard deviation, minimum, and maximum values.

Table 2: Descriptive Statistics

Variable	Mean	Std. Dev.	Minimum	Maximum
GDPG	3.62	2.84	-4.15	8.74
EI	5.11	0.83	3.74	6.58
EC	68.42	9.63	49.21	84.37
GCF	18.76	5.92	8.42	34.65
OPEN	41.33	12.17	18.54	72.46
URB	3.94	0.71	2.51	5.16
CO2	0.62	0.17	0.31	0.96

Source: Author's compilation

Real GDP growth (GDPG) records an average of 3.62 per cent with considerable variability, reflecting periods of expansion and contraction associated with macroeconomic shocks. Energy intensity (EI) shows moderate dispersion, indicating changes in energy efficiency over time. Energy consumption (EC) exhibits steady

variation consistent with rising demand linked to population growth and economic activity.Gross capital formation (GCF) displays notable volatility, suggesting fluctuations in investment cycles. Trade openness (OPEN) also varies widely, reflecting external sector instability driven by oil price movements. Urban population growth (URB) remains relatively stable, indicating sustained urban expansion. Carbon emissions (CO_2) show gradual increases over time, consistent with expanding energy use.

4.2 Correlation Matrix

The correlation matrix provides preliminary evidence on the direction and strength of linear relationships among the variables and helps assess potential multicollinearity issues.

Table 3: Correlation Matrix

Variable	GDPG	EI	EC	GCF	OPEN	URB	CO2
GDPG	1						
EI	-0.43	1					
EC	0.48	0.55	1				
GCF	0.52	-0.21	0.41	1			
OPEN	0.37	-0.18	0.44	0.29	1		
URB	0.33	0.16	0.51	0.24	0.27	1	
CO2	0.29	0.46	0.63	0.31	0.35	0.49	1

Source: Author's computation.

Economic growth (GDPG) is negatively correlated with energy intensity (EI), suggesting that higher energy inefficiency is associated with weaker growth. In contrast, GDPG is positively correlated with energy consumption (EC), gross capital formation (GCF), trade openness (OPEN), and urban population growth (URB), indicating that these factors are associated with improved economic performance.Among the explanatory variables, energy consumption shows a strong positive association with carbon emissions, reflecting fossil fuel dependence. Overall, the correlation coefficients remain moderate, suggesting that multicollinearity is unlikely to affect subsequent estimations.

4.3 Linear and Nonlinear Unit Root Tests (Without Structural Breaks)

Unit root tests are conducted to determine the order of integration of the variables and ensure the suitability of the ARDL framework. Both the Augmented Dickey–Fuller (ADF) and Kapetanios–Shin–Snell (KSS) tests are employed.

Table 4: ADF Unit Root Test Results

Variable	Level t-stat	First Difference t-stat	Order of Integration
GDPG	-2.04	-5.88***	I(1)
EI	-1.92	-5.67***	I(1)
EC	-2.11	-6.02***	I(1)
GCF	-2.34	-5.51***	I(1)
OPEN	-1.76	-5.83***	I(1)
URB	-3.54**	—	I(0)
CO_2	-1.88	-5.46***	I(1)

Source: Author's computation. ***Notes: **, ** and * denote significance at the 1%, 5% and 10% levels respectively.*

The ADF results indicate that GDP growth (GDPG), energy intensity (EI), energy consumption (EC), gross capital formation (GCF), trade openness (OPEN), and carbon emissions (CO_2) are non-stationary at levels but become stationary after first differencing, implying I(1) behaviour. Urban population growth (URB) is stationary at level, indicating an I(0) process.

Table 5: KSS Nonlinear Unit Root Test Results

Variable	Level Statistic	First Difference Statistic	Order of Integration
GDPG	-2.21	-5.31***	I(1)
EI	-2.04	-5.13***	I(1)
EC	-2.11	-5.47***	I(1)
GCF	-2.36	-5.01***	I(1)
OPEN	-2.08	-5.22***	I(1)
URB	-3.45**	—	I(0)
CO_2	-2.15	-5.09***	I(1)

Source: Author's computation. ***, ** and * denote significance at the 1%, 5% and 10% levels respectively.

The KSS results confirm the ADF findings, indicating that all variables except URB are integrated of order one. The consistency across both tests strengthens confidence in the integration properties of the data. The presence of a mixture of I(0) and I(1) variables justifies the use of the ARDL approach.

4.4 Structural Break Test (Zivot–Andrews Test)

To account for possible structural changes, the Zivot–Andrew's test is employed, allowing for an endogenous break in the series.

Table 6: Zivot–Andrews Structural Break Unit Root Test

Variable	Break Year	Test Statistic	5% Critical Value	Order of Integration
GDPG	2016	-5.02**	-4.8	I(1)
EI	1999	-4.92**	-4.8	I(1)
EC	2008	-4.87**	-4.8	I(1)
GCF	1986	-4.94**	-4.8	I(1)
OPEN	2014	-4.85**	-4.8	I(1)
URB	1991	-5.21***	-4.8	I(0)
CO_2	2005	-4.90**	-4.8	I(1)

Source: Author's computation. ***, ** and * denote significance at the 1%, 5% and 10% levels respectively.

The results indicate the presence of structural breaks across several variables. The identified break dates align with key economic events, including the 2016 recession, the 1999 democratic transition, the 2008 global financial crisis, and the 1986 structural adjustment reforms.Despite these structural shifts, the integration properties of the variables remain unchanged, with urban population growth (URB) stationary at level and other variables integrated of order one. These findings support the inclusion of structural break dummies and confirm the suitability of the ARDL bounds testing framework.

4.5 ARDL Bounds Test for Cointegration

The ARDL bounds testing approach is used to examine the existence of a long-run relationship among the variables. The computed F-statistics are compared with the critical bounds of Pesaran et al. and Narayan.

Table 7: ARDL Bounds Test for Cointegration (Without Structural Break)

Panel A: Bounds Test Results						
Model Specification	**Optimal Lag**	**F-Statistic**	**χ^2 Serial**	**χ^2 Normal**	**χ^2 ARCH**	**χ^2 RESET**
ARDL: GDPG (EI, EC, GCF, OPEN, URB, CO_2)	(2,1,1,1,1,1,1)	5.67*	1.72	2.05	1.44	1.21

Panel B: Asymptotic and Finite Sample Critical Values (k = 6)				
Significance	**Pesaran I(0)**	**Pesaran I(1)**	**Narayan I(0)**	**Narayan I(1)**
1%	3.15	4.43	3.68	5.12
5%	2.45	3.61	2.98	4.05
10%	2.12	3.23	2.57	3.66

Source: Author's computation. ***, ** and * denote significance at the 1%, 5% and 10% levels respectively. Optimal lag length is selected using the Akaike Information Criterion (AIC). Diagnostic statistics correspond to Breusch–Godfrey serial correlation test, Jarque–Bera normality test, ARCH heteroskedasticity test, and Ramsey RESET specification test.

The estimated F-statistic exceeds the upper bound critical values at conventional significance levels, indicating the presence of a long-run relationship among the variables.

Table 8: ARDL Bounds Test for Cointegration (With Structural Break)

Panel A: Bounds Test Results							
Model Specification	Optimal Lag	Break Dummy	F-Statistic	χ^2 Serial	χ^2 Normal	χ^2 ARCH	χ^2 RESET
ARDL: GDPG (EI, EC, GCF, OPEN, URB, CO_2) + D2016	(2,1,1,1,1,1,1)	Yes	6.21*	1.63	1.94	1.38	1.18
Panel B: Asymptotic and Finite Sample Critical Values (k = 6)							
Significance	Pesaran I(0)	Pesaran I(1)	Narayan I(0)	Narayan I(1)			
1%	3.15	4.43	3.68	5.12			
5%	2.45	3.61	2.98	4.05			
10%	2.12	3.23	2.57	3.66			

Source: Author's computation.

Structural break dummy corresponds to the 2016 economic recession associated with the global oil price collapse. The dummy variable takes the value 1 for 2016 onwards and 0 otherwise. Diagnostic statistics correspond to Breusch–Godfrey serial correlation test, Jarque–Bera normality test, ARCH heteroskedasticity test, and Ramsey RESET specification test.

The results remain robust after incorporating structural break dummies, with the F-statistic still exceeding the upper bound. This confirms that cointegration persists even after accounting for structural shifts in the Nigerian economy. In summary, the results provide strong evidence of a stable long-run relationship between economic growth and its determinants.

4.6 Long-Run ARDL Estimates

The long-run estimates from the ARDL model are presented in Table 9.

Table 9: Long-Run ARDL Estimates

Variable	Model 1: Without Structural Break	Model 2: With Structural Break
EI	-0.742***	-0.694***
	(0.214)	(0.198)
EC	0.318***	0.336***
	(0.102)	(0.098)
GCF	0.154**	0.167***
	(0.061)	(0.059)
OPEN	0.089**	0.094***
	(0.034)	(0.031)
URB	0.207**	0.221**
	(0.095)	(0.089)
CO_2	-0.061	-0.074
	(0.048)	(0.045)
D2016	-	-1.384***
		(0.452)
Constant	1.482**	1.734***
	(0.604)	(0.581)

Source: Author's computation. Note: Standard errors are reported in parentheses. ***, ** and * denote statistical significance at the 1%, 5% and 10% levels, respectively. Model 2 includes the structural break dummy for 2016.

Energy intensity (EI) exhibits a negative and statistically significant effect on economic growth in both Model 1 and Model 2, confirming that energy inefficiency constrains output. The magnitude of the coefficient becomes slightly smaller in Model 2, suggesting that accounting for structural breaks moderates, but does not alter, the adverse effect of energy intensity on growth. This consistency indicates that the efficiency–growth relationship is structurally stable over time.Energy consumption (EC) remains positive and highly significant across both models, with a marginal increase in its coefficient in Model 2. This suggests that after accounting for structural shifts, the growth-enhancing role of energy use becomes slightly stronger, reinforcing the importance of reliable energy supply in supporting economic activity.

Gross capital formation (GCF) and trade openness (OPEN) maintain positive and significant effects in both specifications, with higher coefficients and stronger significance levels in Model 2. This indicates that investment and external sector integration play more pronounced roles in driving growth when structural changes are explicitly considered.Urban population growth (URB) is also positive and significant in both models, with a slight increase in magnitude in Model 2. This suggests that urbanisation contributes consistently to economic performance, and its effect is not driven by structural breaks.

Carbon emissions (CO_2) remain negative but statistically insignificant across both models, indicating that environmental pressures do not exert an independent long-run influence on economic growth within the model specification.The inclusion of the structural break dummy (D2016) in Model 2 reveals a negative and statistically significant effect, confirming that the 2016 economic recession had a substantial adverse impact on growth. Importantly, the overall similarity in coefficient signs and significance levels across both models suggests that the long-run relationships are robust and not sensitive to structural shifts, although accounting for such breaks slightly strengthens the estimated effects of key growth drivers.

4.7 Short-Run Dynamics and Error Correction Model

The short-run dynamics are captured through the error correction model presented in Table 10.

Table 10: Short-Run ARDL Error Correction Estimates

Variable	Model 1: Without Structural Break	Model 2: With Structural Break
ΔGDPG(-1)	-0.184**	-0.176**
	(0.089)	(0.084)
ΔEI	-0.291**	-0.276**
	(0.118)	(0.111)
ΔEC	0.146**	0.153***
	(0.061)	(0.058)
ΔGCF	0.084***	0.089***
	(0.031)	(0.029)
ΔOPEN	0.041**	0.044**
	(0.018)	(0.017)
ΔURB	0.096**	0.102**
	(0.044)	(0.041)
ΔCO_2	-0.028	-0.031
	(0.022)	(0.021)
D2016	-	-0.842***
		(0.296)
ECT(-1)	-0.612***	-0.658***
	(0.109)	(0.101)
Constant	0.734**	0.781***
	(0.281)	(0.266)

Source: Author's computation. Note: Standard errors are in parentheses. ***, ** and * denote significance at 1%, 5% and 10% levels. Model 2 includes the 2016 structural break dummy.

The short-run estimates reveal a high degree of consistency across both specifications, indicating that the core relationships are robust to the inclusion of structural breaks.Energy intensity (ΔEI) maintains a negative and statistically significant effect on economic growth in both Model 1 and Model 2. The magnitude declines slightly in Model 2, suggesting that accounting for structural shifts moderates the immediate adverse effect of energy inefficiency, although the overall negative relationship remains unchanged.

Energy consumption (ΔEC) exhibits a positive and significant effect in both models, with a slightly stronger coefficient and higher significance in Model 2. This indicates that short-run growth responds positively to increases in energy use, and this effect becomes more pronounced when structural disruptions are considered.Gross capital formation (ΔGCF), trade openness (ΔOPEN), and urban population growth (ΔURB) all retain positive and statistically significant coefficients across both models, with marginal increases in magnitude in Model 2. This suggests that investment, external sector activity, and urbanisation consistently support short-run economic performance, and their effects are not driven by structural breaks.Carbon emissions (ΔCO_2) remain negative and statistically insignificant in both specifications, indicating that environmental factors do not exert an independent short-run influence on growth.The structural break dummy (D2016) in Model 2 is negative and significant, confirming that the 2016 economic recession had an immediate contractionary effect on economic activity.

The error correction term (ECT (-1)) is negative and highly significant in both models, confirming the existence of a stable long-run relationship. The magnitude increases in Model 2 from -0.612 to -0.658, indicating a faster speed of adjustment when structural breaks are accounted for. This suggests that approximately 61 to 66 per cent of short-run disequilibrium is corrected within one year. In summary, the close similarity of coefficients across both models indicates that the short-run dynamics are stable, while the inclusion of structural breaks slightly strengthens the adjustment process and the estimated effects of key variables.

4.8 Diagnostic Tests and Model Stability

Diagnostic tests are conducted to assess the validity of the estimated model.

Table 11: Diagnostic Test Results

Test	Statistic	p-value
Breusch–Godfrey Serial Correlation (χ^2)	1.63	0.201
ARCH Heteroskedasticity Test (χ^2)	1.38	0.24
Ramsey RESET Test (χ^2)	1.18	0.284
Jarque–Bera Normality Test (χ^2)	1.94	0.379

Source: Author's computation.

The results indicate no evidence of serial correlation or heteroskedasticity, and the model satisfies the normality assumption. The Ramsey RESET test confirms correct functional specification.The CUSUM and CUSUMSQ plots remain within the critical bounds, indicating parameter stability over the sample period. In summary, the diagnostic and stability tests confirm that the estimated ARDL model is robust and reliable for inference.

4.9 Discussion of Findings

This subsection interprets the empirical results in relation to the existing literature on the energy–growth nexus, with emphasis on energy intensity as an indicator of energy efficiency and its implications for economic performance.

The findings indicate that energy intensity exerts a negative and statistically significant effect on economic growth in the long run, suggesting that inefficient energy utilisation constrains productivity. This aligns with studies that associate lower energy intensity with improved efficiency, technological progress, and structural transformation (Sun, 1998; Mahmood & Ahmad, 2018; Bergmann & Kalkuhl, 2025). The result supports the view that improvements in energy efficiency enhance growth by reducing production costs and enabling more efficient resource allocation.Energy consumption is found to have a positive and significant effect on economic growth, confirming its role as a productive input. This is consistent with evidence that energy availability remains central to economic expansion, particularly in developing economies where infrastructure constraints limit productive capacity (Díaz et al., 2019; Bekun et al., 2025). The result also reflects the dependence of key sectors such as industry, transport, and services on reliable energy supply.

The positive and significant effects of gross capital formation and trade openness highlight the importance of investment and external sector integration in driving growth. These findings are consistent with growth theory and empirical evidence that investment supports productive capacity, while openness facilitates technological diffusion and efficiency gains (Kazemzadeh et al., 2023). Similarly, urban population growth contributes positively to economic performance, reflecting agglomeration effects and improved access to markets and infrastructure.Carbon emissions are found to be statistically insignificant, suggesting that environmental pressures do not exert an independent effect on economic growth within the model. This is consistent with mixed evidence in the literature, where the growth–environment relationship varies depending on structural conditions and energy composition (Namahoro et al., 2021).

In the short run, the results broadly mirror the long-run findings. Energy intensity continues to exert a negative effect, while energy consumption, investment, trade openness, and urbanisation remain positive drivers of growth. The error correction term confirms a relatively fast adjustment toward equilibrium, indicating that deviations from the long-run path are not persistent. In summary, the findings highlight the dual role of energy in economic performance: while energy consumption supports growth, inefficient energy use constrains it. This underscores the importance of improving energy efficiency alongside expanding energy supply in order to sustain economic growth.

5. Conclusion and Policy Recommendations

This study examines the relationship between energy intensity and economic growth in Nigeria over the period 1980–2024 using the ARDL bounds testing approach with structural breaks. The results provide evidence of a stable long-run relationship among the variables.The findings show that energy intensity exerts a negative and statistically significant effect on economic growth, indicating that inefficient energy utilisation constrains economic performance. In contrast, energy consumption, gross capital formation, trade openness, and urban population growth positively influence growth. The short-run results confirm these relationships, while the error correction mechanism indicates a relatively fast adjustment toward long-run equilibrium.

These findings carry important policy implications. First, improving energy efficiency should be a central component of Nigeria's energy strategy. Reducing energy intensity through investment in modern technologies, upgrading energy infrastructure, and promoting efficient production processes can enhance productivity and support economic growth. Policies that encourage energy-efficient practices in industry, transportation, and services are particularly important.Second, expanding and stabilising energy supply remains critical. Persistent energy shortages continue to constrain economic activity in Nigeria. Strengthening electricity generation capacity, improving transmission infrastructure, and diversifying energy sources can enhance energy reliability and support sustained economic expansion.

Third, strengthening investment in productive sectors is essential for long-term growth. Increased capital formation in infrastructure, manufacturing, and technology can improve productive capacity and facilitate structural transformation. Policies that promote private sector investment and improve the business environment are therefore important.Fourth, trade policies that enhance integration into global markets can support economic growth through technological diffusion and improved efficiency. Reducing trade barriers and strengthening export capacity can contribute to productivity improvements and economic resilience.

Finally, although carbon emissions do not exert a significant direct effect on economic growth in this study, environmental sustainability remains important for long-term development. Policies that promote cleaner energy technologies and reduce dependence on carbon-intensive energy sources can support sustainable growth without compromising economic performance.In summary, achieving sustainable economic growth in Nigeria requires a balanced approach that combines improvements in energy efficiency, expansion of energy supply, and strengthening of investment and structural transformation.

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