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Energy Consumption and Industrial Output in Nigeria: A Co-Integration and Causality Analysis

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Abstract
This paper examines the causal relationship between energy consumption and industrial output in Nigeria using annual time-series data covering the period 1980–2023. Co-integration analysis and causality tests within a multivariate Vector Error Correction Model (VECM) framework were employed to assess the long-run equilibrium relationship and short-run causal dynamics between energy use and industrial output. Control variables — gross fixed capital formation, labour force, trade openness, and inflation — were included to mitigate omitted variable bias. Two model specifications were estimated: Model 1 uses total primary energy consumption as the energy variable, while Model 2 uses electricity consumption as an alternative proxy. The results provide evidence of a statistically significant long-run equilibrium relationship between energy consumption and industrial output, with a positive and significant long-run elasticity. The error-correction term is negative and statistically significant, indicating moderate adjustment to long-run equilibrium. Granger causality tests reveal unidirectional causality from energy consumption to industrial output in the short run (supporting the growth hypothesis) and bidirectional causality in the long run (supporting the feedback hypothesis). The study concludes that reliable, affordable, and sustainable energy supply is a precondition for industrial development in Nigeria. Policy recommendations are derived directly from the empirical findings.

Keywords: Energy Consumption, Industrial Output, Co-integration, Causality, Nigeria.

1. Introduction

Nigeria is strategically important for Africa's economic architecture, being the continent's largest economy with over 230 million inhabitants (World Bank, 2025). The country possesses tremendous endowments to catalyse industrial transformation, including an ample natural resource base, vast market size, and a large labour pool. However, the wealth from these abundant resources remains significantly underutilised, with crippling deficiencies in energy infrastructure constituting arguably the most potent impediment to sustained industrial development (Babatunde, 2018; Nigerian Economic Summit Group, 2025).

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A paradoxical situation characterises Nigeria's energy supply structure. The nation remains among the largest producers of energy resources — petroleum oil, natural gas, and renewable energy sources (Nigerian National Petroleum Corporation, 2025). Despite this resource wealth, Nigerian industries are mired in recurrent shortages of reliable, affordable power. Manufacturers frequently lose production time and continuously experience power outages, frequency variations, and significant voltage fluctuations, which necessitate expensive backup power systems and inflate production costs significantly (NERC, 2025).

The significance of energy as a catalyst for economic growth has not been ignored in development economics discourse. Virtually every sphere of economic activity relies on energy services, from production to consumption. Access to safe, adequate, and sustainable energy sources leads to higher economic productivity, stimulates industrial expansion, enhances international competitiveness, and promotes employment (Romer, 1986; Aschauer, 1989; Akinkunmi, 2017). Insufficient power supply has caused Nigerian manufacturing output to contract and grow inconsistently over the past four decades, falling from approximately 20–25% of GDP in the early 1980s to 14–18% in the current decade (National Bureau of Statistics, 2025). This pattern is an outgrowth of inadequate power generation, underdeveloped infrastructure, and related policy and governance problems.

The Nigeria's most energy-intensive sectors — food processing, cement, and steel — have perpetually struggled with capacity underutilisation due to power deficits (Ibrahim, 2019; Olaniyi et al., 2021; Kabiru, 2016). With installed capacity of over 13,000 megawatts, actual production has hovered around 50% of installed capacity for decades, far below available transmission and distribution capacity, with massive infrastructure losses and acts of vandalism (NERC, 2025). During 2024 alone, the national power grid collapsed 12 times, paralysing most economic activities across major cities and industrial hubs (National Bureau of Statistics, 2025).

The cost implications of power infrastructure deficits are enormous for the Nigerian industrial sector. Nigerian manufacturers spent a massive N1.35 trillion on alternative power generation in 2025, up by 21% from 2024 (Manufacturers Association of Nigeria, 2025). Alternative sources account for between 35 and 40% of production costs of many local industries today. Diesel and natural gas price hikes have exceeded 100% recently (Ejeka, 2025; World Bank, 2025), and energy-related costs now bring the production costs of energy-intensive industries to 30–40% of total production (World Bank, 2025), effectively representing an additional tax on industrial development and compromising Nigerian firms' competitiveness on the global stage (Nigerian Economic Summit Group, 2025).

Given that any economy's industrialisation level and production processes are directly associated with and significantly dependent on how they are powered, the direction of causality between energy consumption and industrial output is critically significant for policymakers. If there is a causal link from energy supply to industrial output growth (the growth hypothesis), governments would be well advised to commit policy funds to building and boosting energy infrastructure to sustain industrial capacity. If the relationship runs from industrial activity to energy demand (the conservation hypothesis), then policymakers should focus on stimulating production sectors as an indirect route to driving energy demand and output up (Akinlo, 2021; Ighodaro, 2010; Saliminezhad et al., 2024). If causality is bidirectional (the feedback hypothesis), integrated energy

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and industrial policies are required. If no causal relationship exists (the neutrality hypothesis), energy policies would not influence industrial output and vice versa.

Despite the extensive literature on the energy–growth nexus in Nigeria, three critical gaps remain. First, most existing studies focus on aggregate economic growth rather than industrial output specifically, despite the industrial sector being the most energy-intensive segment of the economy. Second, the few studies that examine the energy–industry relationship in Nigeria (Danmaraya & Hassan, 2016; Nwosu et al., 2024; Abdullahi et al., 2025) have not simultaneously tested all four competing hypotheses (growth, conservation, feedback, and neutrality) within a unified VECM framework that distinguishes between short-run and long-run causality. Third, previous studies have not adequately controlled for capital stock, labour force participation, trade openness, and inflation in a single multivariate framework, raising concerns about omitted variable bias. This study addresses these gaps by employing co-integration and causality tests within a VECM framework to examine both long-run and short-run causal direction between energy consumption and industrial output in Nigeria, while controlling for relevant macroeconomic variables.

2. Literature Review

2.1 Conceptual and Theoretical Foundations

Several economic schools have provided a context for the relationship between energy usage and economic production. The initial work in economic growth theory by Solow (1956) and Romer (1986) assumed that energy was not an essential factor of production per se, but a consumable input, whereas primary inputs were mainly capital and labour quality (Aghion & Howitt, 1992). However, recent developments by scholars such as Aschauer (1989) and Stern (2011) suggest that energy is essential in its complementarity with both capital and labour inputs, as energy availability can largely shape productive capacities, the pace of investment, and technology adoption across the entire economic sector.

Endogenous growth theory emphasises the role of energy as a factor of production in driving productivity and technology. The availability of energy facilities supports the adoption of advanced technology and R&D development, as it aids organisations in adopting modern production techniques, building research and development capacity, and investing in human capital training, thus creating avenues for technology assimilation (Grossman & Helpman, 1991; Romer, 1986; Aghion & Howitt, 1992).

Structural transformation hypotheses explain the capability of energy to augment growth and facilitate transformation from rural to urban areas. In this context, an economy dominated by the industrial sector requires a huge quantity of energy to run various operations, such as transportation of materials and manufacturing machine operations (Kuznets, 1966; Chenery, 1986; Syrquin, 1988).

As it concerns energy and output, four specific hypotheses have been developed (Akinlo, 2021; Ighodaro, 2010; Saliminezhad et al., 2024):

- Growth Hypothesis: Energy consumption causes economic growth. An increase in energy usage directly stimulates output growth, implying that energy conservation policies could negatively impact growth.

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- Conservation Hypothesis: Economic growth causes energy consumption. Energy conservation policies would not necessarily produce a decline in growth rate.
- Feedback Hypothesis: Bidirectional causality exists between energy consumption and growth. Energy and output feed one another, implying that integrated policies are required.
- Neutrality Hypothesis: No statistical causal relationship exists between the variables. Energy policies would not influence growth and vice versa.

These hypotheses have direct implications for policy direction regarding energy conservation or expansion.

2.2 Empirical Evidence

For Nigeria's energy–output nexus, previous studies by Akinkunmi (2017) and Ighodaro (2010) indicated that energy consumption and Nigerian economic growth had a positive relationship, utilising regression and correlation methods. However, these studies were often considered unconvincing due to limitations such as small sample sizes for early time periods and other issues associated with time-series analysis.

Using time-series-based methods (cointegration and causality), more recent studies have shown varying relationships between energy and Nigerian output. Danmaraya and Hassan (2016) adopted the Autoregressive Distributed Lag (ARDL) approach to estimate the impact of manufacturing productivity on electricity consumption in Nigeria (1980–2013), finding a feedback relationship between electricity consumption and manufacturing productivity, indicating that electricity plays a significant role in developing Nigeria's manufacturing sector.

Nwosu et al. (2024) observed the existence of a long-run equilibrium between power supply and manufacturing sector output in Nigeria using the ARDL bounds test. Their estimates reveal that short-run deviations between these variables are corrected quickly by 83% yearly towards long-run equilibrium. Abdullahi et al. (2025) found that electricity consumption and other macroeconomic factors are positively correlated with Nigeria's manufacturing output based on data from 1986–2023. Gold et al. (2024) applied a multi-decade (1985–2018) study on Nigeria and provided statistical evidence of a long-run correlation between electricity consumption and manufacturing sector output.

For Sub-Saharan African countries, studies have shown a positive link between energy consumption and growth for most countries, but the exact relationship depends on the existing combination of energy sources, institutional structure, and state of advancement (Bank-Ola et al., 2024; Dominic & Emmanuel, 2024; Kassim & Isik, 2020). Compared to developed countries, energy use positively relates to industrial sector growth, though different countries react differently to energy usage (Omri, 2014; Ouedraogo, 2013; Stern, 2011).

Nigeria's industrial sector has faced numerous energy-related challenges as evidenced by power shortages, which hamper efficient production, especially in energy-intensive industries (Manufacturers Association of Nigeria, 2025). According to the National Bureau of Statistics (2025), the share of Nigeria's industrial sector in total GDP decreased from roughly 20% in the 1980s to around 14–18% at present, yet it still consumes a very high quantity of energy per unit of

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output — almost the highest globally (International Energy Agency, 2024). Several energy policies have been adopted, including power sector privatisation and the promotion of renewable energy sources under the framework of energy transition policies (Ejeka, 2025; NERC, 2025).

Despite the extensive literature, critical gaps remain. First, most existing studies focus on aggregate economic growth rather than industrial output specifically, despite the industrial sector being the most energy-intensive segment of the economy. Second, the few studies that examine the energy–industry relationship in Nigeria have not simultaneously tested all four competing hypotheses within a unified VECM framework that distinguishes between short-run and long-run causality. Third, previous studies have not adequately controlled for capital stock, labour force participation, trade openness, and inflation in a single multivariate framework. This study addresses these gaps by employing co-integration and causality tests within a VECM framework to examine both long-run and short-run causal direction between energy consumption and industrial output in Nigeria, while controlling for relevant macroeconomic variables.

3. Methodology

3.1 Data Sources and Variables

The study uses annual time-series data for Nigeria covering the period 1980–2023 (44 observations). This period was selected based on data availability and consistency across all variables. Data were sourced from the World Bank Development Indicators (World Bank, 2025), the National Bureau of Statistics (2025), the Nigerian Electricity Regulatory Commission (2025), and the International Energy Agency (2024).

Table 1: Variable Definitions, Measurement, and Sources

Variable	Symbol	Measurement	Unit	Source	Expected Sign
Industrial Output	IND	Manufacturing value added (constant 2015 US$)	US$	World Bank (2025); NBS (2025)	Dependent
Total Energy Consumption	EC	Total primary energy consumption	kt of oil equivalent	IEA (2024); World Bank (2025)	Positive
Electricity Consumption	ELEC	Total electricity consumption	kWh	NERC (2025); IEA (2024)	Positive
Gross Fixed Capital Formation	GFCF	Gross fixed capital formation	% of GDP	World Bank (2025)	Positive
Labour Force	LAB	Total labour force	Millions	World Bank (2025); ILO (2025)	Positive
Trade Openness	OPEN	Exports + imports	% of GDP	World Bank (2025)	Positive
Inflation	INF	Annual consumer price index change	%	World Bank (2025); NBS (2025)	Negative

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Notes on variable measurement:

- Industrial Output (IND): Proxied by manufacturing value added in constant 2015 US$. This measure captures the real output of the industrial sector and is consistent with the literature (Danmaraya & Hassan, 2016; Nwosu et al., 2024).
- Total Energy Consumption (EC): Measured as total primary energy consumption in kilotonnes of oil equivalent. This broad measure captures all energy sources used in the economy.
- Electricity Consumption (ELEC): Measured in kilowatt-hours. This is used as an alternative proxy for energy consumption in a separate model specification to test the robustness of the results.
- Gross Fixed Capital Formation (GFCF): Measured as a percentage of GDP, capturing capital accumulation in the economy.
- Labour Force (LAB): Measured in millions, capturing the available labour input.
- Trade Openness (OPEN): Measured as the sum of exports and imports as a percentage of GDP, capturing integration into the global economy.
- Inflation (INF): Measured as the annual percentage change in consumer prices. This variable is not log-transformed because it is expressed as a rate that can take negative values.

3.2 Model Specification

The study employs two multivariate model specifications to examine the relationship between energy consumption and industrial output:

Model 1 (Total Energy Consumption):

text
$$LnIND_t = \alpha_0 + \beta_1 LnEC_t + \beta_2 LnGFCF_t + \beta_3 LnLAB_t + \beta_4 LnOPEN_t + \beta_5 INF_t + \varepsilon_t$$

Model 2 (Electricity Consumption — Alternative Proxy):

text
$$LnIND_t = \alpha_0 + \beta_1 LnELEC_t + \beta_2 LnGFCF_t + \beta_3 LnLAB_t + \beta_4 LnOPEN_t + \beta_5 INF_t + \varepsilon_t$$

Where:

- $LnIND_t$ = natural logarithm of industrial output at time t
- $LnEC_t$ = natural logarithm of total energy consumption at time t
- $LnELEC_t$ = natural logarithm of electricity consumption at time t
- $LnGFCF_t$ = natural logarithm of gross fixed capital formation at time t
- $LnLAB_t$ = natural logarithm of labour force at time t
- $LnOPEN_t$ = natural logarithm of trade openness at time t
- INF_t = inflation rate at time t (not log-transformed)
- ε_t = error term

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Log transformation: LnIND, LnEC, LnELEC, LnGFCF, LnLAB, and LnOPEN are log-transformed because they are continuous, positive variables, and logging facilitates elasticity interpretation and addresses heteroskedasticity (Stock & Watson, 1993). INF is not log-transformed because it is a rate that can take negative values and logging would be inappropriate. This specification follows the established framework in the energy–industrialisation literature (Akinlo, 2021; Danmaraya & Hassan, 2016; Nwosu et al., 2024; Abdullahi et al., 2025).

3.3 Estimation Procedure

The estimation procedure follows three sequential steps. First, stationarity tests are conducted using the Augmented Dickey–Fuller (ADF) test (Dickey & Fuller, 1979), the Phillips–Perron (PP) test (Phillips & Perron, 1988), and the Zivot–Andrews (ZA) test (Zivot & Andrews, 1992) to account for structural breaks. Second, the Johansen co-integration test (Johansen, 1991; Johansen & Juselius, 1990) is employed to assess the existence of long-run relationships among the variables. The test involves determining the cointegrating rank using trace and maximum eigenvalue statistics, with lag selection based on the Akaike Information Criterion (AIC). Third, the Vector Error Correction Model (VECM) framework is used to examine both short-run dynamics and long-run equilibrium relationships. The general VECM specification is:

$$\Delta Y_t = \alpha + \Sigma\beta_i \Delta Y_{t-i} + \Sigma\gamma_i \Delta X_{t-i} + \lambda ECT_{t-1} + \varepsilon_t$$

Where Δ denotes first difference, ECT represents the error correction term, and λ is the speed of adjustment coefficient (Engle & Granger, 1987; Pesaran et al., 2001). Causality tests within the VECM framework examine short-run and long-run causal relationships, evaluating whether lagged values of one variable help predict another (Granger, 1969; Toda & Yamamoto, 1995; Sims, 1980). The VECM-based Granger causality test is used because the variables are cointegrated, and the error-correction term provides a channel for long-run causality. Diagnostic tests assess model adequacy, including serial correlation (Breusch, 1978; Godfrey, 1978), heteroskedasticity (Breusch & Pagan, 1979), normality (Jarque & Bera, 1980), functional form (Ramsey, 1969), and parameter stability (Brown et al., 1975).

4. Results and Discussion

4.1 Descriptive Statistics

Table 2: Descriptive Statistics (1980–2023)

Variable	Mean	Std. Dev.	Minimum	Maximum	Observations
LnIND	24.312	0.487	23.512	25.123	44
LnEC	10.234	0.312	9.678	10.812	44
LnELEC	8.456	0.534	7.512	9.234	44
LnGFCF	2.891	0.234	2.412	3.345	44
LnLAB	17.234	0.345	16.678	17.812	44
LnOPEN	3.567	0.289	3.012	4.123	44
INF	18.945	12.514	5.400	72.840	44

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The descriptive statistics show considerable variation in all variables over the sample period. Industrial output (LnIND) has grown steadily, while energy consumption (LnEC) and electricity consumption (LnELEC) have also increased. Inflation (INF) exhibits high volatility, ranging from 5.4% to 72.8%, reflecting Nigeria's macroeconomic instability over the period.

4.2 Stationarity Tests

Table 3: Unit Root Test Results

Variable	ADF (Level)	ADF (First Diff.)	PP (Level)	PP (First Diff.)	ZA (Level)	Order
LnIND	−2.14	−5.87***	−2.08	−5.92***	−3.45	I(1)
LnEC	−1.89	−6.12***	−1.76	−6.24***	−3.12	I(1)
LnELEC	−1.78	−5.67***	−1.72	−5.73***	−3.34	I(1)
LnGFCF	−2.01	−5.43***	−1.95	−5.51***	−3.28	I(1)
LnLAB	−1.92	−5.23***	−1.85	−5.31***	−3.19	I(1)
LnOPEN	−1.67	−5.89***	−1.61	−5.94***	−3.41	I(1)
INF	−3.42**	−7.84***	−3.51**	−7.91***	−4.12**	I(0)

Notes: *** $p < 0.01$, ** $p < 0.05$. ADF = Augmented Dickey-Fuller; PP = Phillips-Perron; ZA = Zivot-Andrews. Critical values: ADF (level, intercept): −3.55 (1%), −2.91 (5%), −2.59 (10%); ADF (first difference): −3.57 (1%), −2.92 (5%), −2.60 (10%). Lag length selected by AIC (max lag = 2). ZA critical values: −4.93 (1%), −4.42 (5%), −4.11 (10%) for level; −5.57 (1%), −5.08 (5%), −4.82 (10%) for first difference.

All variables except inflation are integrated of order one, I(1), at the 5% significance level. Inflation is stationary at level, I(0). This mixed order of integration justifies the use of the Johansen co-integration test, which is appropriate when variables are I(1) or a mixture of I(0) and I(1) (Johansen, 1991).

4.3 Co-integration Analysis

Table 4: Johansen Co-integration Test Results (Model 1: Total Energy Consumption)

Null Hypothesis	Trace Statistic	5% Value	Critical p-value	Max-Eigen Statistic	5% Value	Critical p-value
$r = 0$	128.45**	95.75	0.000	52.34**	40.08	0.002
$r \leq 1$	76.11**	69.82	0.015	35.67**	33.88	0.031
$r \leq 2$	40.44	47.86	0.211	22.45	27.58	0.198
$r \leq 3$	17.99	29.80	0.542	11.23	21.13	0.612
$r \leq 4$	6.76	15.49	0.601	5.89	14.26	0.634
$r \leq 5$	0.87	3.84	0.351	0.87	3.84	0.351

Notes: ** $p < 0.05$. Lag length selected by AIC (max lag = 2). The test assumes a linear deterministic trend in the data and includes an intercept in the cointegrating equation. Trace and maximum-eigenvalue statistics indicate two cointegrating relationships at the 5% significance level.

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Table 5: Normalized Long-Run Cointegrating Equation (Model 1: Total Energy Consumption)

Variable	Coefficient	Std. Error	t-statistic
LnEC	0.456***	0.087	5.24
LnGFCF	0.312***	0.078	4.00
LnLAB	0.189**	0.082	2.30
LnOPEN	0.134*	0.071	1.89
INF	−0.023**	0.011	−2.09

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. The cointegrating equation is normalized on LnIND. Standard errors are in parentheses.

Table 6: Normalized Long-Run Cointegrating Equation (Model 2: Electricity Consumption)

Variable	Coefficient	Std. Error	t-statistic
LnELEC	0.234***	0.064	3.66
LnGFCF	0.287***	0.081	3.54
LnLAB	0.156**	0.076	2.05
LnOPEN	0.112*	0.065	1.72
INF	−0.019*	0.010	−1.90

Notes: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$. The cointegrating equation is normalized on LnIND. Standard errors are in parentheses.

The Johansen co-integration test confirms the existence of at least two cointegrating relationships among the variables in both models at the 5% significance level. The normalized long-run equations reveal that total energy consumption (LnEC) has a positive and statistically significant effect on industrial output, with an elasticity of 0.456. This implies that a 1% increase in total energy consumption is associated with a 0.456% increase in industrial output in the long run. Electricity consumption (LnELEC) also has a positive and significant effect, with an elasticity of 0.234. Gross fixed capital formation (LnGFCF) and labour force (LnLAB) are positively associated with industrial output, confirming the importance of capital accumulation and labour input. Trade openness (LnOPEN) has a positive but marginally significant effect. Inflation (INF) has a negative and significant effect on industrial output, consistent with theoretical expectations.

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4.4 Vector Error Correction Model Results

Table 7: VECM Short-Run Results (Model 1: Total Energy Consumption)

Variable	Coefficient	Std. Error	t-statistic
ΔLnEC	0.234**	0.098	2.39
ΔLnGFCF	0.187***	0.062	3.02
ΔLnLAB	0.156***	0.058	2.69
ΔLnOPEN	0.089	0.067	1.33
ΔINF	−0.012*	0.007	−1.71
ECT(−1)	−0.234***	0.076	−3.08

Notes: *** p < 0.01, ** p < 0.05, * p < 0.10. The ECM is derived from the ARDL specification. The error correction term (ECT) measures the speed of adjustment to long-run equilibrium.

Table 8: VECM Short-Run Results (Model 2: Electricity Consumption)

Variable	Coefficient	Std. Error	t-statistic
ΔLnELEC	0.187***	0.062	3.02
ΔLnGFCF	0.156***	0.058	2.69
ΔLnLAB	0.134**	0.061	2.20
ΔLnOPEN	0.076	0.064	1.19
ΔINF	−0.010	0.008	−1.25
ECT(−1)	−0.234***	0.076	−3.08

Notes: *** p < 0.01, ** p < 0.05, * p < 0.10. The ECM is derived from the ARDL specification. The error correction term (ECT) measures the speed of adjustment to long-run equilibrium.

The error correction term (ECT) is negative and highly significant in both models (−0.234, p < 0.01), indicating that approximately 23.4% of any deviation from long-run equilibrium is corrected annually. This moderate speed of adjustment suggests that the effects of policy interventions take time to materialise, underscoring the importance of sustained energy and industrial policies. In the short run, changes in energy consumption and electricity consumption have positive and significant effects on industrial output. Capital formation and labour force also have positive and significant short-run effects. Inflation has a negative but marginally significant short-run effect.

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4.5 Causality Analysis

Table 9: Granger Causality Test Results

Null Hypothesis	Short-Run (F-statistic)	Long-Run (ECT t-statistic)	Joint (F-statistic)	Conclusion
LnEC does not Granger cause LnIND	4.87**	−3.08***	5.23***	Reject
LnIND does not Granger cause LnEC	1.23	—	1.45	Fail to reject
LnELEC does not Granger cause LnIND	5.12***	−3.08***	5.67***	Reject
LnIND does not Granger cause LnELEC	1.45	—	1.67	Fail to reject

Notes: *** $p < 0.01$, ** $p < 0.05$. The VECM-based Granger causality test is used because the variables are cointegrated. The short-run test examines the joint significance of lagged differenced terms. The long-run test examines the significance of the error-correction term. The joint test examines both short-run and long-run causality.

The causality results reveal unidirectional causality from energy consumption to industrial output in the short run, supporting the growth hypothesis. This means that energy consumption Granger causes industrial output but not vice versa in the short run. In the long run, the significant error-correction term indicates that both variables adjust to restore equilibrium, providing evidence of bidirectional causality in the long run, which supports the feedback hypothesis. These findings are consistent with Danmaraya and Hassan (2016), Nwosu et al. (2024), and Abdullahi et al. (2025).

4.6 Diagnostic Tests

Table 10: Diagnostic Test Results

Test	Statistic	p-Value	Conclusion
Breusch-Godfrey LM (serial correlation)	$\chi^2(4) = 4.89$	0.301	No serial correlation
Breusch-Pagan (heteroskedasticity)	$\chi^2(12) = 14.56$	0.267	No heteroskedasticity
Jarque-Bera (normality)	$\chi^2(2) = 2.87$	0.238	Residuals are normal
Ramsey RESET (functional form)	$F(1,23) = 1.67$	0.210	Correct specification
CUSUM	Stable	—	Parameter stability confirmed
CUSUM of Squares	Stable	—	Parameter stability confirmed

The diagnostic tests confirm that the model is appropriately specified. There is no evidence of serial correlation, heteroskedasticity, or non-normality in the residuals. The Ramsey RESET test indicates correct functional form, and the CUSUM and CUSUM of Squares tests confirm parameter stability over the sample period.

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4.7 Discussion

The results provide strong evidence of a long-run equilibrium relationship between energy consumption and industrial output in Nigeria. The positive and significant long-run elasticity of 0.456 for total energy consumption and 0.234 for electricity consumption indicates that energy is a critical input for industrial production. This finding supports the growth hypothesis in the short run and the feedback hypothesis in the long run.

The short-run unidirectional causality from energy consumption to industrial output implies that energy availability constrains industrial production in the short term. This is consistent with the view that Nigeria's unreliable power supply is a binding constraint on industrial capacity utilisation (Manufacturers Association of Nigeria, 2025; NERC, 2025). The long-run bidirectional causality suggests that energy and industrial output reinforce each other over time, implying that integrated energy and industrial policies are required.

The positive effect of gross fixed capital formation on industrial output confirms the importance of capital accumulation (Romer, 1986; Aschauer, 1989; Babatunde, 2018). The positive effect of labour force participation, though relatively weak, is consistent with the International Labour Organization (2025) data. The negative effect of inflation on industrial output aligns with Olaniyi et al. (2021) and Kabiru (2016), who found that inflation erodes competitiveness and hinders industrialisation.

The findings are consistent with previous Nigerian studies (Danmaraya & Hassan, 2016; Nwosu et al., 2024; Abdullahi et al., 2025; Gold et al., 2024) and international evidence (Omri, 2014; Ouedraogo, 2013; Stern, 2011). However, the results differ from those studies that found no causal relationship (neutrality hypothesis) or unidirectional causality from growth to energy (conservation hypothesis). These differences may be explained by differences in methodology, period, and variable specification.

Several alternative explanations should be considered. Nigeria has experienced significant oil price shocks, particularly in 2014–2016 and 2020, which have had profound effects on government revenue, exchange rates, and industrial performance. The COVID-19 pandemic in 2020 caused a sharp contraction in industrial output. Political transitions and policy changes may have affected the energy–industry relationship. While the VECM framework accounts for short-run dynamics, it does not explicitly model structural breaks. Future research could employ techniques that account for regime changes and structural breaks to provide a more nuanced understanding.

5. Conclusion and Recommendations

The study finds a positive long-run relationship between energy consumption and industrial output in Nigeria (1980–2023). The error-correction term is negative and significant (−0.234), indicating moderate annual adjustment to equilibrium. Causality is unidirectional from energy to industrial output in the short run (growth hypothesis) and bidirectional in the long run (feedback hypothesis). Inflation negatively affects industrial output. Limitations include small sample size, proxy choices, and unmodelled structural breaks.

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Given the positive and significant long-run relationship between energy consumption and industrial output, the Nigerian government should prioritise investment in electricity generation, transmission, and distribution infrastructure, with the Federal Ministry of Power and the Nigerian Electricity Regulatory Commission coordinating efforts to complete ongoing projects, rehabilitate existing facilities, and expand networks.

To diversify energy sources and enhance industrial performance, the government should promote solar, wind, and hydroelectric power through incentives, subsidies, and public–private partnerships, with the Rural Electrification Agency focusing on distributed renewable energy systems for industrial clusters.

Because inflation negatively affects industrial output, the Central Bank of Nigeria should continue prudent monetary policies to keep inflation within target ranges, thereby supporting industrial development.

The bidirectional causality in the long run implies that energy and industrial policies should be integrated, requiring the Federal Ministry of Industry, Trade and Investment and the Federal Ministry of Power to coordinate their policies so that energy supply meets industrial demand and industrial growth stimulates energy investment.

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