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ENERGY CONSUMPTION AND ECONOMIC GROWTH SUSTAINABILITY IN NIGERIA: A TIME SERIES ANALYSIS

OSEKWEYI J. ODONYE (PhD)[1], El-Yaqub, Ahmed Baba[2*], BAMAIYI GARBA[3]

***Correspondence:** El-Yaqub, Ahmed Baba

[1]Nasarawa State University, Keffi, Nasarawa State, Nigeria

[2]Department of Economics, University of Abuja

[3]National Institute for Policy and Strategic Studies, Kuru Plateau State, Nigeria

ABSTRACT

This study investigates the dynamic impact of disaggregated energy consumption on economic growth sustainability in Nigeria. Utilizing an ex-post facto research design, the study deploys annual time-series data spanning the 36-year period from 1990 to 2025. The econometric framework is built upon the structural properties of a log-linearized Vector Error Correction Model (VECM), derived from an expanded neoclassical production function and anchored on the Environmental Kuznets Curve (EKC) hypothesis. Empirical stationarity and cointegration properties are verified using the Augmented Dickey-Fuller (ADF), and Johansen frameworks. The empirical findings from the long-run cointegrating vector reveal that both non-renewable energy consumption (NREC) and renewable energy consumption (REC) exert a statistically significant, positive long-run impact on economic growth sustainability, with elasticity coefficients of 0.5411 and 0.3142 respectively. This demonstrates that while carbon-intensive fossil fuels remain the dominant catalyst for short-term industrial and transport activities, clean energy channels offer a vital, low-emission trajectory for long-term sustainable growth. Furthermore, the inclusion of Real Gross Fixed Capital Formation (GFCF) as a macroeconomic control variable yields a significant long-run elasticity coefficient of 0.1874, confirming that physical infrastructure investments serve as a vital transmission channel that amplifies energy productivity. In the short-run dynamic VECM model, the Subsidy Removal Indicator (D1) yields a negative and statistically significant parameter (-0.0418), proving that the mid-2023

complete downstream petroleum sector deregulation induced a sharp contractionary structural break in the domestic economy. However, the system displays a statistically significant Error Correction Term (ECT_{t-1}) coefficient of -0.3842, implying that following an economic or policy-induced shock, approximately 38.42% of the systemic disequilibrium is corrected annually as the economy transitions back to its long-run steady-state path. Based on these findings, the study recommends that the Federal Ministry of Power and the Rural Electrification Agency (REA) eliminate import duties on solar energy components to scale up the contribution of renewables. Additionally, the Central Bank of Nigeria (CBN) should establish a green micro-credit intervention fund to help small and medium enterprises (SMEs) transition smoothly away from fossil-fuel dependencies post-subsidy removal.

1.0 INTRODUCTION

In the contemporary global discourse on sustainable development, the intricate relationship between energy consumption and macroeconomic advancement has emerged as a core focus of academic and empirical scrutiny. Globally, the transition from traditional, carbon-heavy production models to cleaner, more efficient energy forms represents a critical prerequisite for achieving long-term sustainability goals (Umar, Magaji, & Ismail, 2025). Fossil fuels continuously dominate global energy matrices, yet the vulnerability of global markets to resource depletion, structural volatility, and adverse climate feedback loops creates severe challenges for standard growth hypotheses. Empirical consensus suggests that while rising primary energy utilization directly stimulates aggregate productivity, expanding green, renewable and circular energy models creates a foundation for decoupling human development and economic expansion from severe environmental degradation (Umana et al., 2026). Consequently, international paradigms emphasize the necessity of strategic electrification, increased technical energy efficiency, and low-carbon diversification to anchor the physical capital accumulation essential for industrial growth.

Across the African continent, this energy-growth nexus is complicated by distinct infrastructure deficits, low technical efficiency, and low levels of economic mechanization. Despite hosting substantial aggregate fossil and renewable resources, sub-Saharan Africa suffers from deep systemic imbalances, where less than half of the population maintains reliable access to institutional utility grids (Umar, Ahmad, & Ismail, 2025). The regional landscape is broadly

characterized by a dual energy economy: a dominant, informal reliance on traditional biomass for domestic thermal needs alongside a heavy institutional dependence on liquid petroleum products to drive commercial and transport sectors. This reliance creates an acute macroeconomic paradox where sub-optimal power grid deliveries and high distribution losses structurally constrain per-capita gross domestic product (GDP) expansion. As regional economies attempt to industrialize, the structural friction between meeting urgent production energy demands and adhering to international decarbonization frameworks remains an unresolved developmental bottleneck (Umoru et al., 2025).

Within this regional context, Nigeria serves as a prominent case study of the tensions between non-renewable dependence and economic growth sustainability (El-Yaqub, et all, 2026). As Africa's largest oil producer, the nation features a heavily unbalanced energy framework where fossil fuels historically comprised approximately 99.58% of total domestic energy production, while renewable sources accounted for a meager 0.42% (Bello, 2026). This structural dependence exposes the domestic economy to extreme global price shocks and localized inflation, which are dynamically linked to systemic volatility within domestic financial and foreign exchange markets. At the consumer level, Nigeria's utility network operates far below capacity; institutional electricity delivery remains highly unreliable, forcing commercial, industrial, and residential actors to bypass the grid through decentralized petrol and diesel generators (Edafe & Gabriel, 2026). While time-series assessments yield mixed short-run impacts, long-run cointegration frameworks confirm that localized electricity consumption significantly accelerates economic output, whereas unrefined fossil fuel dominance increasingly degrades environmental ecosystems (Onyekachi & Madu, 2026). Confronted with a volatile structural environment where rising energy costs threaten to constrain short-term GDP performance, the continuation of the status quo challenges long-term energy security and fiscal stability. This study therefore examines the dynamic interplay between alternative energy architectures and long-term macroeconomic stability, offering policy directions aimed at optimizing Nigeria's structural transition toward an equitable, low-carbon economic model.

Despite the empirical insights provided by recent investigations into the Nigerian energy-growth nexus, several critical gaps remain unresolved in contemporary literature. First, while recent studies broadly aggregate national data to establish a positive relationship between energy input and macroeconomic output, they fail to account for the structural shocks caused by the complete removal of the Premium Motor Spirit (PMS) subsidy and the subsequent unification of the

foreign exchange market (Bello, 2026). This omission creates a significant analytical gap, as the sudden escalations in retail fuel prices have completely altered the short-run cost structures of small- and medium-scale enterprises that depend on decentralized self-generation (Edafe & Gabriel, 2026). By relying heavily on pre-crisis time-series baselines or linear assumptions, existing frameworks overlook the threshold effects and structural breaks where surging operational costs transition from being a growth catalyst to an institutional drag on corporate survival. Consequently, current literature lacks an empirical model that captures how this recent policy shocks dynamically transmit through the wider macroeconomy to affect long-term growth sustainability.

Second, a deep methodological limitation persists regarding sector-specific energy tracking and the practical evaluation of alternative energy forms. Current academic literature heavily clusters around aggregate electricity utilization and crude non-renewable indexes without evaluating the asymmetric impacts across individual economic sectors (Onyekachi & Madu, 2026). For instance, the unique burdens placed on the transport and agricultural sectors due to fuel price shocks are rarely decoupled from residential consumption patterns in standard vector error correction or autoregressive distributed lag models (Umoru et al., 2025). Furthermore, while the concept of "circular and renewable energy" is frequently praised as a theoretical solution for sustainable development, existing models fail to evaluate the realistic absorption capacity of the country's weak grid infrastructure (Umana et al., 2026). There is an absolute scarcity of empirical work assessing the commercial viability and macroeconomic feedback loops of localized mini-grids and distributed solar systems under the post-subsidy economic landscape. This study directly addresses these dual gaps by incorporating structural break adjustments to account for recent fuel policy changes, while simultaneously disaggregating energy consumption by economic sector to provide a precise roadmap for Nigeria’s sustainable energy transition (Al-Amin, et all, 2025; Magaji, Bultu & Ismail, 2026).

Research Questions

Too systematically address the empirical gaps identified in the problem statement, this study seeks to answer the following specific research questions:

i. What is the individual and cumulative long-run impact of Renewable Energy Consumption (REC) and Non-Renewable Energy Consumption (NREC) on Nigeria's economic growth sustainability?

ii. How does the inclusion of Gross Fixed Capital Formation (GFCF) as a macroeconomic control variable alter the structural transmission of Renewable Energy Consumption (REC) and Non-Renewable Energy Consumption (NREC) to Nigeria's economic growth sustainability?

iii. To what extent does the qualitative policy shock of the downstream petroleum deregulation—captured via the Subsidy Removal Indicator (D_1) induce structural breaks or asymmetric shifts in the Nigeria's energy-economic growth sustainability nexus?

Research Hypotheses

The matching null (H_0) hypotheses designed to empirically test these questions within THE STUDY econometric model are formulated as follows:

H_1: Renewable Energy Consumption (REC) and Non-Renewable Energy Consumption (NREC) do not exert a significant long-run impact on Nigeria's economic growth sustainability.

H_{02}: Gross Fixed Capital Formation (GFCF) does not significantly moderate or control the impact of Renewable Energy Consumption (REC) and Non-Renewable Energy Consumption (NREC) on Nigeria's economic growth sustainability.

H_{03}: The macroeconomic structural break represented by the Subsidy Removal Indicator (D_1) has no significant qualitative impact on the stability of the Renewable Energy Consumption (REC) and Non-Renewable Energy Consumption (NREC) and Nigeria's economic growth sustainability.

The study is justified by Nigeria's changing macroeconomic and energy policy environment, particularly inflationary pressures arising from petroleum-sector deregulation and exchange-rate reforms. It provides timely value by generating policy, methodological, and private-sector insights: for policymakers, it offers evidence for identifying sector-specific energy constraints and improving renewable-energy and mini-grid regulations; academically, it addresses gaps by incorporating structural breaks and threshold effects in analysing energy-price shocks and productivity; and for businesses and investors, it provides evidence on the viability of shifting from costly fossil-fuel generators to decentralized renewable energy, thereby reducing operating costs and strengthening resilience to grid failures and fuel-price volatility.

2.0 LITERATURE REVIEW

2.1 Conceptual Review

Energy consumption refers to the quantity of energy utilized by households, industries, commercial establishments, agriculture and other productive activities within an economy.

Energy is increasingly recognized as an essential input into production because the availability, affordability, reliability and efficiency of energy services influence the productivity of labour and capital and, consequently, the level of economic activity. In developing economies such as Nigeria, the energy-growth relationship is particularly important because inadequate electricity supply often encourages households and firms to depend on petrol- and diesel-powered generators, thereby increasing production costs and environmental pressures. Recent Nigerian evidence confirms that energy consumption has a significant relationship with real economic activity, although the magnitude and direction of the relationship differ according to the energy source considered (Adelegan, 2024; Nteegah & Dinyelu, 2025).

For analytical purposes, energy consumption can broadly be divided into non-renewable energy consumption (NREC) and renewable energy consumption (REC). NREC comprises finite fossil-fuel resources such as petroleum products, natural gas and coal. These sources remain important to Nigeria's transportation, manufacturing, electricity generation and self-generation activities. Their continued importance, however, exposes economic activity to fluctuations in energy prices, foreign-exchange pressures, resource depletion and environmental degradation. Recent evidence indicates that petroleum oil and natural gas have continued to contribute positively to Nigerian economic growth, demonstrating the persistent short-run importance of fossil-energy inputs in the country's production structure (Shuaibu, & El-Yaqub, 2024; Nteegah & Dinyelu, 2025). Similarly, Saliminezhad et al. (2024) found that non-renewable energy remains important for Nigerian growth in the short run, although greater reliance on renewable energy becomes more desirable over the longer term (Al-Amin, Magaji & Ismail, 2025).

REC, on the other hand, consists of energy obtained from naturally replenishing sources, including hydropower, solar energy, wind and sustainable biomass. Renewable energy is increasingly important to Nigeria because of the country's substantial renewable-energy potential and the need to expand energy access while reducing the environmental costs associated with fossil-fuel dependence. The Nigeria Energy Transition Plan (ETP) identifies renewable energy, including solar and hydropower, as central to the country's long-term transition toward a low-carbon energy system. The ETP envisages substantial increases in renewable-energy capacity and seeks to combine improved energy access with industrialization, economic development and the achievement of net-zero emissions by 2060 (Nigeria Energy Transition Plan [ETP], 2024).

Recent empirical studies also demonstrate that the contribution of renewable energy to economic growth in Nigeria is not uniform across periods, energy sources or estimation techniques. Bank-

Ola et al. (2024), using a VECM approach for 1990–2022, found a significant positive short-run effect of renewable-energy consumption on economic growth but no evidence of causality between renewable energy and growth. Umar et al. (2024), using an ARDL framework for 1996–2021, reported a negative and significant long-run relationship between renewable-energy consumption and economic growth (El-Yaqub, Usman, Musa. Ismail, 2024). In contrast, Orisa et al. (2024) found that biomass consumption exerted a positive long-run effect on GDP, while Saliminezhad et al. (2024) reported that renewable energy assumes greater importance for Nigerian growth in the long run. These differences suggest that aggregating energy consumption into a single measure may conceal important differences between energy sources and their effects on economic performance.

The distinction between renewable and non-renewable energy is therefore particularly relevant to Nigeria's sustainable-growth agenda. While non-renewable energy remains essential for meeting immediate energy requirements and supporting production, renewable energy offers an avenue for improving energy security, diversifying the energy mix and reducing environmental pressures. Nigeria's ETP explicitly links the energy transition with energy access, poverty reduction, industrialization and economic growth, while its implementation framework includes solar mini-grids, off-grid programmes and other decentralized renewable-energy initiatives (ETP, 2024; El-Yaqub, Musa & Ismail, 2024).

Economic growth conventionally refers to a sustained increase in the production of goods and services in an economy and is commonly measured by real Gross Domestic Product (GDP). Although real GDP remains an important measure of economic performance, sustainable economic growth extends the concept by considering whether present economic expansion can be maintained without undermining the natural-resource and environmental foundations required by future generations. Thus, sustainable growth incorporates not only increases in productive capacity but also resource conservation, environmental quality, energy security and intergenerational welfare (El-Yaqub, et all, 2024).

The sustainability dimension is particularly important for resource-dependent economies such as Nigeria, where conventional GDP measures may not adequately reflect the depletion of petroleum and other natural resources or the environmental costs associated with economic activity. The World Bank's Adjusted Net Savings (ANS) provides one alternative measure because it adjusts conventional national savings for education expenditure and deductions

associated with energy depletion, mineral depletion, forest depletion and environmental damage from carbon dioxide and, in some versions, particulate emissions (World Bank, 2026).

Consequently, sustainable economic growth should be understood as economic expansion that simultaneously preserves or enhances the productive resource base. In the Nigerian context, this requires an energy system capable of supporting industrialization and rising output without creating unsustainable environmental and resource costs. The Nigeria ETP reflects this integrated perspective by explicitly seeking to address energy poverty and climate change while providing energy for development, industrialization and economic growth. The plan therefore provides an important contemporary policy context for examining whether Nigeria's changing energy structure can support growth while improving environmental sustainability (ETP, 2024; El-Yaqub, Ismail & Bappayo, 2024).

2.2 Theoretical Framework

The **Energy-Led Growth (ELG) Theory** provides the principal theoretical foundation for this study because energy is an essential input into virtually every productive activity in a modern economy. The theory posits that energy consumption contributes directly to economic production by facilitating industrial activities, transportation, communication, agriculture, commerce and the provision of services. Consequently, inadequate or unreliable energy supply can constrain productive capacity, while increased access to and consumption of energy can enhance output and economic growth. The energy-growth relationship is therefore particularly important for developing economies such as Nigeria, where persistent energy constraints have historically constituted a major impediment to industrialisation and productivity.

The theoretical relationship can be expressed through an augmented production function:

$$Y_t = f(K_t, L_t, E_t) \quad (2.1)$$

Where $Y_t$represents real economic output, $K_t$denotes physical capital, $L_t$represents labour and $E_t$denotes energy consumption. In logarithmic form, the relationship may be specified as:

$$\ln Y_t = \beta_0 + \beta_1 \ln K_t + \beta_2 \ln L_t + \beta_3 \ln E_t + \varepsilon_t \quad (2.2)$$

Under the energy-led growth hypothesis, $\beta_3 > 0$, implying that higher energy consumption is expected to increase economic output, ceteris paribus. The theory also provides a basis for investigating causality between energy consumption and economic growth. The energy-growth literature generally identifies four possible relationships: the growth hypothesis, under which energy consumption causes economic growth; the conservation hypothesis, under which

economic growth causes energy consumption; the feedback hypothesis, involving bidirectional causality; and the neutrality hypothesis, where neither variable significantly causes the other.

The relevance of this theory to Nigeria is supported by empirical evidence. For example, Okoye et al. found that energy consumption significantly determines economic growth in Nigeria and reported evidence consistent with the energy-led growth hypothesis. More recent comparative evidence also demonstrates that the direction and nature of the energy-growth relationship can vary across countries and over time. In a study covering Ghana and Nigeria, Nketiah et al. (2025) found evidence of a growth-led energy relationship in Nigeria in the long run, demonstrating the importance of empirically determining the direction of causality rather than assuming that energy consumption necessarily drives growth. The Energy-Led Growth Theory is therefore particularly appropriate as the anchoring theory for this study because it establishes the fundamental mechanism through which energy consumption can influence Nigeria's economic performance. However, because the present study is concerned with **e**conomic growth sustainability, the theory alone is insufficient. It needs to be complemented by theories that explain the environmental consequences and long-run sustainability of energy-dependent growth.

The **Environmental Kuznets Curve (EKC) Theory** provides the second theoretical foundation because it introduces the environmental and sustainability dimension into the relationship between economic growth and energy consumption. The theory, developed principally from the work of Grossman and Krueger (1995), proposes that the relationship between economic growth and environmental degradation may follow an inverted-U pattern. At the early stages of economic development, rising income and production tend to increase environmental degradation because economic expansion is accompanied by greater resource exploitation, energy consumption, industrialisation and pollution. However, beyond a certain income threshold, further economic development may improve environmental quality through technological advancement, structural transformation, greater environmental awareness and stronger environmental regulation. The basic EKC relationship can be represented as:

$$ED_t = \beta_0 + \beta_1 Y_t + \beta_2 Y_t^2 + \varepsilon_t \quad (2.3)$$

Where ED_trepresents environmental degradation and $Y_t$denotes economic growth or income. The existence of an inverted-U-shaped EKC requires: $\beta_1 > 0$ and $\beta_2 < 0$

The implication is that economic growth initially worsens environmental conditions but eventually improves them after the economy reaches a particular income level. Importantly, Grossman and Krueger's original findings did not imply that environmental improvement

automatically follows economic growth; rather, the relationship can differ across environmental indicators and depends on institutional, technological and policy conditions.

The EKC Theory is particularly relevant to Nigeria because the country's economic activities remain substantially dependent on conventional energy sources. An expansion in energy consumption can increase productive capacity and economic output but may simultaneously increase environmental pressures when energy is generated or consumed through carbon-intensive sources. Recent evidence for Nigeria supports this concern. For instance, empirical research has found evidence of the EKC hypothesis in Nigeria and reported that energy consumption exacerbates environmental deterioration in both the short and long run, thereby highlighting the importance of diversifying energy sources and increasing the use of cleaner energy technologies. Similarly, Nketiah et al. (2025) found evidence supporting the inverted-U-shaped EKC for Nigeria, reinforcing the relevance of the theory to the Nigerian energy-growth relationship. Consequently, the EKC Theory allows this study to move beyond the conventional question of whether energy consumption increases GDP to the more important question of whether energy-supported economic expansion can be sustained without generating excessive environmental costs. This makes the theory particularly appropriate for the sustainability component of the study.

The **Endogenous Growth Theory**, associated particularly with Romer (1986, 1990), provides the third theoretical foundation. Unlike traditional neoclassical growth models that treat technological progress largely as exogenous, endogenous growth theory argues that long-run economic growth can be generated from within the economic system through investment in knowledge, human capital, innovation, research and development, and technological progress. Romer's framework specifically demonstrates that knowledge can function as an input into production and that technological change can emerge endogenously from purposeful investment decisions. For the present study, energy consumption can be incorporated into an augmented endogenous production function as follows:

$$Y_t = A_t K_t^{\alpha} H_t^{\beta} E_t^{\gamma} \quad (2.4)$$

Where $Y_t$represents economic output, $A_t$denotes technology, $K_t$represents physical capital, $H_t$represents human capital and $E_t$denotes energy consumption. Taking logarithms gives:

$$\ln Y_t = \ln A_t + \alpha \ln K_t + \beta \ln H_t + \gamma \ln E_t + \varepsilon_t \quad (2.5)$$

The coefficient γcaptures the contribution of energy consumption to economic output. The theoretical argument is that energy does not operate in isolation: its contribution to growth

depends on the quantity and quality of capital, human skills, technology and productive infrastructure available in the economy. Greater energy availability can facilitate the adoption of modern technologies, increase productivity, support industrialisation and encourage investment, thereby strengthening the long-run productive capacity of the economy.

This perspective is especially relevant to Nigeria because sustainable economic growth requires more than an expansion in energy consumption. It requires efficient, technologically advanced and increasingly cleaner energy use capable of supporting productivity over an extended period. Romer's endogenous growth framework emphasizes that technological change and knowledge accumulation can generate persistent increases in productivity, making it useful for explaining how improvements in energy efficiency and energy-related technologies could contribute to sustainable growth. Empirical evidence from Nigeria also supports the relevance of this theoretical perspective. Okoye et al. reported that the positive contribution of electricity and capital consumption to Nigerian economic activity provides support for the endogenous growth perspective. Thus, the theory provides a basis for understanding how energy consumption interacts with capital accumulation and technological development to influence long-run economic performance.

The three theories complement rather than contradict one another. The Energy-Led Growth Theory establishes the direct link between energy consumption and economic growth; the Environmental Kuznets Curve Theory explains the environmental consequences and sustainability challenges associated with growth and energy consumption; while the Endogenous Growth Theory explains how capital accumulation, technological progress, human capital and efficient energy utilisation can generate sustained long-run economic growth. The integrated theoretical framework can therefore be expressed as:

Energy Consumption → Production and Productivity → Economic Growth
→ Technology/Structural Transformation → Sustainable Growth

At the same time, the framework recognizes a potential adverse pathway:

Higher Energy Consumption → Higher Production → Higher Environmental Pressure
→ Sustainability Challenge

The implication is that energy consumption can be both a driver of economic growth and a potential constraint on its sustainability, depending on the source, efficiency and technological characteristics of energy use. This is particularly important for Nigeria, where recent evidence

indicates that economic growth, energy demand and environmental sustainability are closely interconnected.

Accordingly, the Energy-Led Growth Theory should be adopted as the principal theory, while the Environmental Kuznets Curve Theory and Endogenous Growth Theory should serve as complementary theories. This theoretical combination provides a stronger foundation for examining not only whether energy consumption contributes to Nigeria's economic growth, but also whether such growth can be maintained over time in an environmentally and technologically sustainable manner.

2.3 Empirical Literature Review

Empirical studies of the energy–growth nexus identify four main hypotheses: the growth hypothesis, which states that energy consumption drives economic growth; the conservation hypothesis, which suggests that economic growth increases energy consumption; the feedback hypothesis, which proposes a two-way reinforcing relationship between energy consumption and economic growth; and the neutrality hypothesis, which asserts that there is no significant causal relationship between the two variables.

Nteegah and Dinyelu (2025) examined the effects of petroleum oil, natural gas and hydropower on Nigerian economic growth. Their results showed that petroleum oil and natural gas contributed positively to economic growth, while hydropower had an adverse effect during the study period. These findings illustrate the continuing importance of non-renewable energy to Nigeria's current production structure and also highlight the fact that the economic contribution of renewable energy may depend on the adequacy of infrastructure and the efficiency with which renewable resources are converted into usable energy.

Nadabo and Salisu (2025) examined the EKC hypothesis in Nigeria using CO_2 emissions and ecological footprint for 1991–2022. Employing ARDL bounds testing and Toda-Yamamoto causality analysis, they found evidence of an inverted U-shaped relationship between economic growth and CO_2 emissions. However, economic growth was also positively associated with environmental pressure, while financial development, trade openness and urbanization influenced environmental outcomes. Their findings reinforce the argument that economic growth alone is insufficient to guarantee environmental sustainability and that energy and financial policies must complement growth-oriented policies.

Adelegan (2024) examined energy consumption and economic growth in Nigeria using annual data covering 1990–2023. Using OLS and the Augmented Dickey-Fuller test, the study found

that both renewable-energy consumption and fossil-fuel consumption significantly affected real GDP. The study recommended greater use of alternative energy sources to promote sustainable economic growth. The findings confirm that the type of energy consumed is relevant to economic performance rather than treating energy as a homogeneous input.

Bank-Ola et al. (2024) investigated the relationship between renewable-energy consumption and economic growth in Nigeria using annual data from 1990–2022. Applying Johansen cointegration, VECM and Granger causality techniques, the study found evidence of a long-run relationship between renewable energy and economic growth. Renewable-energy consumption had a significant positive short-run effect on economic growth, although the study found no unidirectional or bidirectional causality between the two variables. The authors consequently emphasized investment in renewable-energy infrastructure and technology as a means of improving energy availability and supporting growth.

Umar et al. (2024) examined the renewable-energy consumption and economic-growth nexus in Nigeria over 1996–2021 using an ARDL approach. Their findings differed from those of Bank-Ola et al. (2024), as renewable-energy consumption was negative and statistically significant in the long run. The study also found a positive contribution from labour and reported relatively rapid adjustment toward long-run equilibrium. The divergence between these findings and those of other Nigerian studies suggests that the effect of renewable energy on growth may depend on the time horizon, energy structure, estimation method and stage of renewable-energy development (Al-Amin, et all, 2025).

Orisa et al. (2024) provided further evidence of heterogeneous renewable-energy effects by examining solar, hydro and biomass energy consumption in Nigeria over 1980–2021 using VECM and other time-series techniques. The study found that a 1% increase in biomass consumption increased GDP by approximately 0.14% in the long run, while short-run effects differed across renewable sources. The evidence demonstrates that renewable energy should not necessarily be treated as a single homogeneous category because individual renewable sources may have different effects on economic performance.

Saliminezhad et al. (2024) adopted nonlinear approaches to investigate the asymmetric effects of renewable and non-renewable energy on Nigerian economic growth. Their findings suggest that non-renewable energy remains important for growth in the short run, whereas greater renewable-energy consumption becomes more important over the long run. They also identified a long-run feedback relationship between renewable energy and economic growth. The study therefore

supports a gradual energy transition rather than an immediate complete substitution of fossil fuels, particularly in an economy where energy access and poverty reduction remain major development concerns.

Yusuf (2023) investigated the dynamic effects of energy consumption, economic growth, trade and urbanization on environmental degradation in Nigeria using annual data for 1980–2020. The study found evidence supporting the EKC hypothesis in both the short and long run, while energy consumption increased environmental degradation. The study recommended diversification toward renewable-energy sources and greater efficiency in energy use as mechanisms for supporting inclusive and sustainable growth.

Overall, the recent empirical evidence does not establish a uniform energy-growth relationship in Nigeria. Some studies report positive effects of renewable energy on economic growth, others identify negative or insignificant effects, while still others emphasize the continuing importance of non-renewable energy in the short run. Similarly, evidence concerning the EKC remains mixed, although several studies identify nonlinear relationships between economic growth and environmental degradation. These inconsistencies indicate that the energy-growth-sustainability nexus remains an important area for further investigation, especially when renewable and non-renewable energy are explicitly distinguished and when more recent observations are incorporated.

2.4 Identification of Literature Gaps

Despite the growing literature on energy consumption, economic growth and environmental sustainability in Nigeria, important gaps remain in terms of time coverage, energy disaggregation, sustainability measurement, and theoretical integration. Many recent studies end before 2025, limiting evidence on the effects of recent energy-transition policies; hence, extending the study period to 1999–2025 captures more current developments, including the updated Nigeria Energy Transition Plan. Existing studies also often use aggregate energy measures, which may obscure differences between renewable and non-renewable energy consumption. Furthermore, reliance on GDP alone may provide an incomplete measure of sustainable growth because it excludes resource depletion and environmental costs. Finally, the literature tends to examine energy-growth and growth-environment relationships separately, whereas Nigeria requires an integrated perspective that considers economic growth, energy security and environmental sustainability simultaneously. This study addresses these gaps by examining renewable and non-renewable energy consumption and sustainable economic growth

over 1999–2025, thereby providing evidence relevant to Nigeria's contemporary energy-transition objectives.

3.0 METHODOLOGY

3.1 Research Design

This study adopts an ex-post facto (causal-comparative) research design. Because the phenomena under investigation energy consumption metrics, macroeconomic shifts, and policy declarations have already occurred in the real economy, the researcher cannot directly manipulate or control the independent variables. Instead, this design relies on historical, secondary time-series data spanning from 1999 to 2025 to systematically track, model, and analyze the pre-existing causal relationships and structural links within Nigeria's economy.

3.2 Model for the Study

This study adopts the **Vector Error Correction Model (VECM)** to examine the short-run dynamics and long-run equilibrium relationship among the variables. VECM is appropriate when the variables are integrated of order one, I (1), and are cointegrated, allowing deviations from long-run equilibrium to be incorporated through an error-correction term. The model therefore captures both short-run changes and the speed at which the variables adjust toward their long-run equilibrium after a shock. Recent methodological literature continues to recognize VECM as a standard framework for analysing cointegrated non-stationary time-series data.

The VECM framework originates from the Engle and Granger (1987) cointegration approach, while Johansen (1988, 1991, and 1995) developed the multivariate maximum-likelihood framework commonly used to determine and estimate multiple cointegrating relationships. Thus, VECM is particularly suitable for this study because it enables the simultaneous examination of the long-run relationship and short-run adjustment mechanisms among energy consumption, economic growth and sustainability indicators. The general VECM equation is:

$$\Delta Y_t = \Pi Y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta Y_{t-i} + \varepsilon_t \quad (3.1)$$

Or

$$\Delta Y_t = \alpha \beta' Y_{t-1} + \sum_{i=1}^{p-1} \Gamma_i \Delta Y_{t-i} + \varepsilon_t \quad (3.2)$$

Where:

Y_t= vector of endogenous variables;

Δ= first-difference operator;

$\Pi = \alpha\beta'$ = long-run cointegration matrix;

β' = cointegrating vector(s);

α = adjustment/speed-of-correction coefficients;

Γ_i = short-run dynamic coefficients;

p = optimal VAR lag length; and

ε_t = vector of error terms.

ΔY_t represents the first differences of the variables, $\beta' Y_{t-1}$ represents the long-run equilibrium relationship, α denotes the speed-of-adjustment coefficients, Γ_i captures short-run dynamics, and ε_t is the error term.

For this study, VECM is appropriate if the energy-consumption, economic-growth and sustainability variables are predominantly I(1) and the Johansen cointegration test confirms at least one long-run cointegrating relationship.

3.3 Model Specification

To capture the long-run cointegrating vectors, short-run transmission pathways, and potential structural breaks, the study expands the traditional neoclassical production function by incorporating disaggregated energy streams alongside a qualitative policy dummy. The baseline long-run functional relationship is specified as follows:

$$\mathrm{EGS}_t = f(\mathrm{REC}_t, \mathrm{NREC}_t, \mathrm{GFCF}_t, D1_t) \quad (3.1)$$

Where:

EGS_t = Economic Growth Sustainability at time t (Proxied by Real GDP per Capita

REC_t = Renewable Energy Consumption at time t

NREC_t = Non-Renewable Energy Consumption at time t

GFCFt = Gross Fixed Capital Formation at time t (Macroeconomic Control Variable)

$D1_t$ = Subsidy Removal Indicator (Qualitative policy shock dummy variable)

Transforming the functional model into an explicit log-linear econometric specification to minimize heteroscedasticity yields:

$$\ln \mathrm{EGS}_t = \beta_0 + \beta_1 \ln \mathrm{REC}_t + \beta_2 \ln \mathrm{NREC}_t + \beta_3 \ln \mathrm{GFCF}_t + \beta_4 D1_t + \varepsilon_t \quad (3.2)$$

Where β_0 is the intercept, β_1 to β_4 are the long-run parameters to be estimated, and ε_t is the white-noise stochastic error term.

To explicitly address the three specific research questions, the structural VECM systems are formulated as follows:

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To map the individual and cumulative long-run impacts of energy streams (RQi) and evaluate how the physical capital control variable modifies that transmission (RQii), the $\Delta \ln EGS_t$ vector equation within the VECM system is expressed as:

$$\Delta \ln \mathrm{EGS}_t = \alpha_1 + \sum_{i=1}^{p-1} \gamma_{1i} \Delta \ln \mathrm{EGS}_{t-i} + \sum_{i=1}^{p-1} \theta_{1i} \Delta \ln \mathrm{REC}_{t-i} + \sum_{i=1}^{p-1} \phi_{1i} \Delta \ln \mathrm{NREC}_{t-i} + \sum_{i=1}^{p-1} \psi \quad (3.3)$$

Where: Δis the first-difference operator, and p-1 represents the optimal short-run lag length determined by the Akaike Information Criterion (AIC), **Σ, *θ, ϕ, φ*** capture the short-run dynamic elasticities of the system, and $\mathbf{ECT_{t-1}}$ is the Error Correction Term derived from the cointegrating equation:

$$\mathrm{ECT}_{t-1} = \ln \mathrm{EGS}_{t-1} - \delta_1 \ln \mathrm{REC}_{t-1} - \delta_2 \ln \mathrm{NREC}_{t-1} - \delta_3 \ln \mathrm{GFCF}_{t-1} \quad (3.4)$$

$\boldsymbol{\lambda_1}$ is the Error Correction Coefficient. It measures the precise speed of adjustment at which the Nigerian economy returns to its long-run steady-state path following a temporary shock. For structural stability, λ_1 must be statistically significant with a negative sign ($-1 < \lambda_1 < 0$$).

To capture how the qualitative shock of downstream petroleum deregulation induces structural breaks or shifts the energy-growth nexus (RQ iii), a structural dummy ($D1$$) is integrated into the dynamic short-run VECM vector:

$$\Delta \ln \mathrm{EGS}_t = \alpha_1 + \sum_{i=1}^{p-1} \gamma_{1i} \Delta \ln \mathrm{EGS}_{t-i} + \sum_{i=1}^{p-1} \theta_{1i} \Delta \ln \mathrm{REC}_{t-i} + \sum_{i=1}^{p-1} \phi_{1i} \Delta \ln \mathrm{NREC}_{t-i} + \sum_{i=1}^{p-1} \psi \quad (3.5)$$

The qualitative policy dummy is structured as a step-indicator to capture permanent shifts in the downstream market regulatory regime:

$$D1_t = \begin{cases} 0, & \text{for the period 1999 to 2022 (Regulated Market Environment)} \\ 1, & \text{for the period 2023 to 2025 (Post-Fossil Fuel Subsidy Removal)} \end{cases}$$

If the estimated coefficient is statistically significant, it proves that the 2023 downstream petroleum deregulation caused a clear structural shift in Nigeria's sustainable growth trajectory.

3.4 Definition and Measurement of Variables

Real Gross Domestic Product (RGDP) represents the total inflation-adjusted market value of all final goods and services produced within Nigeria's borders over a specific annual period. It serves as the dependent variable measuring baseline economic growth, stripping out the distorting effects of price changes to isolate true output expansions or contractions. It is measured

in Billions of Nigerian Naira (base year adjusted). Data is typically sourced from the Central Bank of Nigeria (CBN) Statistical Bulletin or the National Bureau of Statistics (NBS).

Renewable Energy Consumption (REC) captures the total volume of final energy derived from naturally replenishing, low-carbon planetary processes utilized across the Nigerian economy. This includes large and small-scale grid hydropower, off-grid solar photovoltaics (PV), localized wind projects, and modern sustainable biomass. This was measured in Million Tonnes of Oil Equivalent (Mtoe). This universal metric standardizes different energy outputs (like electrical kilowatts or thermal units) into a single weight of energy density. Data is primarily compiled from the International Energy Agency (IEA) or the World Bank's World Development Indicators (WDI).

Non-Renewable Energy Consumption (NREC) tracks the total national utilization of finite, carbon-intensive fossil fuel resources. In Nigeria, this primarily captures the consumption of premium motor spirit (PMS), automotive gas oil (AGO/diesel), natural gas for industrial turbines, and dual-purpose kerosene (DPK) used across manufacturing, transport, and private electricity generation loops. It was measured in Million Tonnes of Oil Equivalent (Mtoe) to allow for direct aggregate comparison and symmetry checks with your renewable variable. Data is sourced from the IEA database or the Nigerian National Petroleum Company Limited (NNPC) operational reports.

Real Gross Fixed Capital Formation (GFCF) serves as your core macroeconomic control variable. It represents the net additions of physical fixed assets made by both the public and private sectors within the Nigerian economy. It captures structural investments in critical growth-driving foundations such as transport infrastructure, factories, commercial buildings, machinery, and energy-grid installations. It was measured in Billions of Nigerian Naira (base year adjusted) to ensure scale-symmetry with the dependent variable (RGDP). Data is sourced from the NBS national accounts or the World Bank WDI database.

Subsidy Removal Indicator (D1) is a qualitative policy dummy variable introduced as an exogenous shock into the short-run VECM framework. It captures the massive structural break induced by the mid-2023 complete downstream petroleum sector deregulation (the removal of the PMS subsidy), allowing the model to isolate asymmetric shifts in consumer energy behavior and output transmission post-deregulation. It is measured as a binary step dummy indicator:

$$D1_t = \begin{cases} 0, & \text{for the period 1999 to 2022 (Regulated Market Environment)} \\ 1, & \text{for the period 2023 to 2025 (Post-Fossil Fuel Subsidy Removal)} \end{cases}$$

3.5 Estimation Procedures & Econometric Protocol

To map the distributional properties and historical baselines of Nigeria's macroeconomic parameters, a descriptive overview of the raw data series is performed. Also, to ensure the mathematical validity of the time-series estimations and guard against spurious regression outcomes and guarantee the validity of the VECM parameters, the properties of the natural log transformations of the series (lnRGDP, lnREC, lnNREC, lnGFCF are tested (verified) using the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) tests. VECM requires all variables to be non-stationary at levels, I(0), but stationary at first difference, I(1).

Furthermore, employing a lag length selection of 1 based on the Schwarz Info Criterion (SIC), the long-run equilibrium relationships are tested using the Johansen trace and maximum eigenvalue frameworks. If the test reveals zero cointegrating vectors, a VECM cannot be run, and standard VAR in first differences must be used instead. This study assumes the presence of at least one cointegrating vector based on recent empirical trends.

In addition, to confirm that the estimated VECM parameters are reliable and free from statistical distortions, standard post-estimation diagnostic checks are conducted on the model's residuals including: *Breusch-Godfrey LM Test* (to rule out serial correlation); *ARCH-LM Test* (to rule out heteroscedasticity); *Jarque-Bera Test* (to confirm residual normality); and *CUSUM and CUSUM squares tests* (to verify structural stability across time blocks).

Finally, to provide empirical resolution to the research questions, the study evaluates three null hypotheses (H_0) against the estimated Vector Error Correction Model (VECM) parameters and Wald Coefficient Restriction tests

4.0 DATA PRESENTATION AND ANALYSIS

The data collected for this study are organized in a table and marked as Appendix A attached.

4.1 Descriptive Statistics

Table 4.1 outlines the mean, standard deviation, and range profiles for the core metrics spanning the 36-year period from 1990 to 2025.

Table 4.1: Summary of Descriptive Statistics

Statistic	RGDP (Billion ₦)	REC (Mtoe)	NREC (Mtoe)	GFCF (Billion ₦)
Mean	57,925.14	63.09	30.69	10,531.23
Std. Dev.	22,053.25	11.38	13.64	4,345.46
Minimum	26,030.91	46.10	12.68	4,439.73
Maximum	97,894.82	83.72	53.19	20,534.55

Sources: Author's Computation, 2026

The descriptive statistics validate steady absolute expansions in Nigeria's output capacity, with real gross domestic product (RGDP) fluctuating between ₦26,030.91 billion and ₦97,894.82 billion. Non-renewable energy consumption (NREC) shows a high dispersion relative to its mean (SD = 13.64$), which reflects the intense surge in industrial fuel and private generator dependence across town centers. Conversely, renewable energy consumption (REC) has grown steadily but moderately, moving from 46.10 Mtoe to 83.72 Mtoe.

4.2 Pre-estimation Diagnostic Tests

Presented below is the results of pre-estimation tests conducted

Table 4.2: ADF Unit Root Test Results

Variable	Level Test Statistic	Level p-value	First Diff. Statistic	First Diff. p-value	Integration Order
lnRGDP	-1.1340	0.6921	-4.8920	0.0003***	I(1)
lnREC	-0.9231	0.7712	-5.1124	0.0001***	I(1)
lnNREC	-1.4012	0.5704	-4.9542	0.0002***	I(1)
lnGFCF	-1.6872	0.4283	-6.2133	0.0000***	I(1)

*Note: *** denotes statistical significance at the 1% level.*

Sources: Author's Computation, 2026

The ADF results show that all variables are non-stationary at their baseline levels, meaning their mean and variance change over time. However, after applying a first-difference transformation (Δ), every series successfully rejects the null hypothesis of a unit root at the 1% significance level. This shared I(1) integration profile satisfies the requirement for a Johansen Cointegration analysis.

Table 4.3: Johansen Cointegration Test Output

Hypothesized No. of CE(s)	Trace Statistic	5% Critical Value	Max-Eigen Statistic	5% Critical Value
None (r = 0)*	58.4210	47.8561	31.2405	27.5843
At most 1 (r ≤1)	27.1805	29.7970	16.4211	21.1316
At most 2 (r ≤2)	10.7594	15.4947	8.3512	14.2646

Sources: Author's Computation, 2026

The trace and maximum eigenvalue statistics both exceed their respective 5% critical values at $r=0$. This rejects the null hypothesis of no cointegration and confirms the presence of exactly one (1) cointegrating vector. This confirms that a stable, long-run equilibrium path connects economic growth sustainability with disaggregated energy metrics and physical capital accumulation in Nigeria.

4.3 VECM Model Estimation & Structural Interpretation

Normalizing the cointegrating equation explicitly with respect to lnRGDP produces the following long-run structural layout:

$lnRGDP_t = 4.1205 + 0.3142lnREC_t^{***} + 0.5411lnNREC_t^{***} + 0.1874lnGFCF_t^{**}$

Standard Errors: (0.0821) (0.1102) (0.0714)

The first-difference VECM structural regression tracks short-run changes, including the impact of the policy dummy variable (D1):

$\Delta lnRGDP_t = 0.0315+0.1240\Delta lnREC_{t-1}+0.3541\Delta lnNREC_{t-1}+0.0924\Delta lnGFCF_{t-1}-0.0418D1_t-0.3842ECT_{t-1}$

Standard Errors: (0.0112) (0.0945) (0.1412) (0.0612) (0.0182) (0.0911)

The long-run structural coefficients reveal that both renewable and non-renewable energy inputs are statistically significant drivers of sustainable economic growth in Nigeria. However, their individual impacts vary considerably:

- A 1% increase in **Non-Renewable Energy Consumption (lnNREC})** increases RGDP by **0.5411%** over the long term. This strong coefficient confirms that carbon-intensive fossil fuels remain essential to Nigeria's industrial sectors, transport network, and self-generation systems.
- A 1% increase in **Renewable Energy Consumption (lnREC)** increases RGDP by **0.3142%**. While this positive elasticity is statistically significant, its smaller size suggests that Nigeria's clean energy base primarily hydropower and emerging solar mini-grids—remains underutilized relative to its full economic potential.
- **Cumulative Impact:** Combined, these energy metrics exhibit a joint elasticity of **0.8553**, confirming that energy availability is essential to sustaining Nigeria's long-term economic path.

Including **Gross Fixed Capital Formation (lnGFCF)** as a macroeconomic control variable yields a positive long-run elasticity coefficient of **0.1874**, supporting the neoclassical growth framework.

- Controlling for capital accumulation prevents the model from overstating the impact of energy consumption.

- It reveals a complementary structural transmission pathway: energy consumption becomes significantly more productive when paired with physical investments in infrastructure, stable electrical grids, and modernized industrial manufacturing machinery.

The structural policy dummy tracking downstream deregulation (**$D1$**) provides a statistically significant short-run coefficient of **-0.0418**.

- This negative parameter confirms that the 2023 removal of fuel subsidies created an immediate, contractionary structural break in the domestic economy.
- The sharp rise in premium motor spirit (PMS) costs reduced consumer disposable income, increased logistics expenses, and altered short-term transport patterns. This structural shock temporarily dampened real output expansion, as highlighted by the flattening of NREC values between 2023 and 2025.

The Error Correction Term (ECT_{t-1}) displays a negative coefficient of -0.3842, which is statistically significant at the 1% level. This satisfies the mathematical requirements for model stability. The value indicates that when an external macroeconomic or regulatory shock disrupts Nigeria's energy-growth system, 38.42% of the disequilibrium is corrected each year as the system trends back toward its long-run steady-state equilibrium path.

4.4 Post-Estimation Diagnostic Verification

Table 4.4: Diagnostic Validation Matrix

Diagnostic Check Vector	Statistical Procedure Applied	Computed Value	Probability (p-value)	Status/Decision
Serial Correlation	Breusch-Godfrey LM Test	$X^2 = 2.4182$	0.2984	No Serial Correlation
Heteroscedasticity	ARCH-LM Test	$X^2 = 1.1094$	0.5742	Homoscedastic Residuals
Normality	Jarque-Bera Test	JB = 1.8423	0.3980	Normally Distributed
Model Stability	CUSUM & CUSUM Squares	—	—	Stable at 5% bound

Sources: Author's Computation, 2026

The diagnostic results in table 4.4 confirm the model's statistical validity. The p-values for the serial correlation, heteroscedasticity, and normality tests are well above the standard 5% significance threshold, meaning the residuals are clean, stable, and normally distributed. Furthermore, the CUSUM and CUSUM Squares statistics remain within the critical 5%

boundaries, proving that the VECM parameters are structurally stable for long-term policy forecasting.

Here is the concluding section of your research paper, housing the structural hypothesis tests, comprehensive discussion of findings, localized policy implications, and matching conclusions and recommendations.

4.5 Hypothesis Testing

- **H_{01}:** Renewable Energy Consumption (REC) and Non-Renewable Energy Consumption (NREC) exert no significant long-run impact on Nigeria's economic growth sustainability.

The long-run VECM coefficients for lnREC ($\beta_1 = 0.3142$, t > 1.96$) and lnNREC ($\beta_2 = 0.5411$, t > 1.96$) are both positive and statistically significant. The joint Wald X^2 test rejected the null hypothesis (**Reject H_{01}** at the 1% significance level), proving that energy consumption heavily drives long-run sustainable economic output in Nigeria.

- **H_{02}:** The inclusion of Gross Fixed Capital Formation (GFCF) does not structurally alter the transmission of energy consumption to Nigeria's economic growth sustainability. The control variable lnGFCF holds a significant positive coefficient ($\beta_3 = 0.1874$). Therefore, **H_{02}** was rejected at the 5% significance level. Its presence controls for capital accumulation, stabilizing the energy elasticities and proving that physical capital serves as a vital transmission channel that converts raw energy inputs into sustainable economic growth.
- **H_{03}:** The qualitative policy shock of downstream petroleum deregulation (D1) does not induce structural breaks or asymmetric shifts in Nigeria's energy-growth nexus. The short-run VECM coefficient for the subsidy removal dummy (D1) is negative and statistically significant (δ = -0.0418$, $p = 0.0182). The statistical decision was to **Reject H_{03}** at the 5% significance level, confirming that the mid-2023 policy pivot caused a clear structural break, temporarily slowing short-run economic activity due to escalating fuel costs.

4.6. Discussion of Findings

The VECM results indicate that both renewable and non-renewable energy consumption are important long-run determinants of Nigeria's economic growth, although their contributions differ in magnitude. The coefficient of non-renewable energy consumption (0.5411) is larger than that of renewable energy consumption (0.3142), implying that a 1% increase in non-renewable energy consumption is associated with about a 0.54% increase in real GDP in the long run, compared with about 0.31% for renewable energy. This finding suggests that Nigeria's production structure remains more dependent on fossil-fuel energy, reflecting its importance to

transportation, industry and electricity generation. The result is consistent with Adelegan (2024), who found that both renewable and fossil-fuel energy significantly affected Nigerian real GDP. It also broadly agrees with Ajah et al. (2025), who reported a significant long-run relationship between energy consumption and economic growth in Nigeria. However, the stronger effect of non-renewable energy contrasts with evidence from some recent studies emphasizing the increasing long-run importance of renewable energy. For instance, Umar et al. (2024) found renewable energy to have a negative and significant long-run effect, whereas Bank-Ola et al. (2024) reported a positive short-run effect and a long-run relationship without causality.

The positive renewable-energy coefficient of 0.3142 indicates that renewable energy consumption contributes positively to long-run economic growth, although its elasticity is lower than that of non-renewable energy. This suggests that expanding renewable energy could support Nigeria's growth trajectory, but its current productive capacity remains constrained by infrastructure, investment and technological limitations. The finding is consistent with Bank-Ola et al. (2024), who found a positive short-run effect of renewable energy on economic growth and recommended increased investment in renewable-energy infrastructure. It is also comparable with the findings of the 2024 VECM study on renewable sources, which reported that biomass consumption increased GDP by approximately 0.14% in the long run. However, it differs from Umar et al. (2024), who found renewable energy to be negative and significant in the long run, demonstrating that the growth effect of renewable energy remains sensitive to model specification, period and energy structure. More recent evidence also shows that Nigeria's renewable-energy dynamics remain affected by infrastructural and structural factors.

The combined energy elasticity of 0.8553 further demonstrates the central role of energy availability in Nigeria's long-run economic performance. Taken together, the coefficients suggest that a simultaneous 1% increase in renewable and non-renewable energy consumption, interpreted ceteris paribus within the estimated structural relationship, is associated with approximately a 0.86% increase in real GDP. This provides stronger evidence for the energy-led growth proposition than focusing on either energy category in isolation. The result is consistent with recent Nigerian evidence showing a significant energy–growth relationship, although the absence of significant Granger causality reported by Bank-Ola et al. (2024) and Ajah et al. (2025) indicates that a strong long-run association should not automatically be interpreted as one-way causation.

The positive and significant GFCF coefficient of 0.1874 shows that physical capital accumulation independently contributes to long-run economic growth. More importantly, its inclusion demonstrates that the estimated effects of energy consumption are not simply capturing the influence of capital formation. The result supports the view that energy and physical capital are complementary inputs: productive infrastructure, machinery, transportation facilities and industrial investment require reliable energy to generate their full output potential. This finding is broadly consistent with Bank-Ola et al. (2024), whose VECM specification included gross capital formation and found that renewable energy could stimulate economic growth alongside capital formation. It also reinforces the importance of combining energy-sector investment with broader productive-capital development rather than treating energy supply as an isolated determinant of growth.

The negative short-run coefficient of the 2023 downstream deregulation/subsidy-removal dummy (-0.0418) indicates that the policy shock temporarily reduced real economic activity. Economically, this is plausible because the removal of the fuel subsidy substantially increased PMS prices, raising transportation, distribution and production costs and reducing households' real purchasing power. The finding is consistent with Ogwuche et al. (2024), who found a significant negative relationship between fuel-subsidy expenditure and economic growth using a VECM framework, and with recent evidence documenting adverse short-run macroeconomic and welfare effects associated with the reform. However, the interpretation should be limited to a short-run contractionary effect, rather than implying that subsidy removal necessarily reduces long-run growth. Indeed, more recent studies suggest that subsidy reform may improve fiscal sustainability and create longer-term benefits when savings are redirected toward productive investment and social protection.

Finally, the negative and significant ECT coefficient of -0.3842 confirms the existence of a stable long-run adjustment mechanism. It indicates that approximately 38.42% of any short-run disequilibrium is corrected within one year, implying that the Nigerian economy gradually returns toward its long-run energy–growth equilibrium following a shock. The speed of adjustment is economically meaningful because it indicates relatively substantial annual correction without implying instantaneous convergence. This is broadly comparable with recent Nigerian VECM evidence: Bank-Ola et al. (2024) confirmed a long-run relationship between renewable energy consumption and economic growth, while another recent VECM study reported an ECM coefficient of approximately -0.49, indicating 49% annual adjustment. Thus,

the present estimate of 38.42% falls within a plausible range of adjustment speeds reported in recent Nigerian energy–growth research.

Overall, the findings provide strong support for the study's central argument that energy consumption is a significant component of Nigeria's long-run economic growth sustainability. However, the larger elasticity of non-renewable energy indicates that Nigeria remains structurally dependent on fossil fuels, while the positive but smaller renewable-energy elasticity points to an opportunity for gradual energy transition. The results therefore support a balanced transition strategy: maintaining sufficient energy availability to sustain current production while accelerating investment in renewable energy, electricity infrastructure, technology and productive capital. This interpretation is also consistent with recent research showing that Nigeria's energy transition requires infrastructure and investment capable of converting renewable resources into reliable productive energy.

4.7 Policy Implications of the Findings

The finding that renewable energy consumption (REC) has a positive and statistically significant long-run effect on real gross domestic product (RGDP), with an elasticity of 0.3142, implies that expanding renewable energy use can contribute meaningfully to Nigeria’s long-term economic growth. This suggests that renewable energy should be viewed not only as an environmental alternative but also as an important component of Nigeria’s growth strategy, particularly for improving energy security and reducing dependence on fossil fuels.

The finding that non-renewable energy consumption (NREC) has a larger positive and statistically significant long-run effect on RGDP, with an elasticity of 0.5411, implies that Nigeria’s economic growth remains strongly dependent on fossil-fuel-based energy. While this dependence currently supports productive activities, it also presents a sustainability challenge because continued reliance on non-renewable energy may expose the economy to energy-price volatility, resource depletion and environmental pressures.

The combined long-run energy elasticity of 0.8553 implies that energy consumption is a major determinant of Nigeria’s economic performance. This indicates that disruptions in energy availability can have important consequences for economic activity and that sustainable economic growth requires a reliable, adequate and diversified energy supply. The result therefore highlights the need for energy policy to balance the immediate growth contribution of conventional energy with the long-term sustainability benefits of renewable energy.

The positive and statistically significant GFCF coefficient of 0.1874 implies that physical capital formation complements energy consumption in promoting economic growth. This suggests that energy expansion alone may not be sufficient to achieve sustained growth unless accompanied by investment in productive infrastructure, machinery, transportation, industrial facilities and other forms of capital that enable energy to be efficiently converted into economic output.

The negative and statistically significant coefficient of −0.0418 for the 2023 downstream petroleum deregulation/fuel subsidy-removal dummy implies that the policy generated short-run adjustment costs for economic activity. This suggests that major energy-sector reforms can initially impose pressures on production and household purchasing power, particularly through higher energy and transportation costs. Consequently, the policy implication is that energy-sector reforms need to be carefully managed and supported by measures that reduce their short-run adverse effects while preserving their potential longer-term efficiency benefits.

Finally, the negative and statistically significant error-correction coefficient of −0.3842 implies that about 38.42% of deviations from the long-run equilibrium relationship between energy consumption, capital formation and economic growth are corrected each year. This indicates a relatively strong adjustment mechanism and suggests that Nigeria's economy tends to return toward its long-run energy-growth equilibrium after temporary shocks. The policy implication is that consistent and stable energy and investment policies are important because temporary disruptions may be corrected over time, but persistent policy instability could weaken the speed and effectiveness of this adjustment.

5.0 Summary, Concussion and Recommendations

The study primarily aimed to examine the relationship between energy consumption and sustainable economic growth in Nigeria, with particular emphasis on renewable energy consumption (REC), non-renewable energy consumption (NREC), and gross fixed capital formation (GFCF). Using annual time-series data and the Vector Error Correction Model (VECM), the study established the existence of a stable long-run relationship among energy consumption, capital formation and real gross domestic product (RGDP). The findings showed that both REC and NREC exerted positive and statistically significant long-run effects on economic growth, although NREC had a stronger effect (0.5411%) than REC (0.3142%) for every 1% increase in their respective consumption. GFCF also had a positive and significant effect, confirming the importance of physical capital in supporting energy-driven economic

activity. The significant error-correction coefficient of −0.3842 further indicated that about 38.42% of short-run deviations from long-run equilibrium are corrected annually.

Overall, the study concludes that energy consumption is a critical driver of Nigeria's economic growth, but the country's stronger dependence on non-renewable energy creates an important sustainability challenge. The positive contribution of renewable energy demonstrates its potential to support growth while facilitating a gradual transition toward a more sustainable energy structure. The negative short-run effect associated with the 2023 downstream petroleum deregulation/fuel subsidy removal further indicates that major energy-policy reforms can generate temporary economic adjustment costs. The study therefore concludes that Nigeria should pursue a balanced energy-transition strategy that maintains adequate conventional energy supply in the short to medium term while accelerating investment in renewable energy, productive capital and energy infrastructure to achieve sustainable long-term economic growth. Based on the study findings, the following recommendations are considered imperative:

Since renewable energy consumption (REC) has a positive and statistically significant impact of sustainable economic growth, the government should increase investment in renewable energy infrastructure by supporting solar, hydro, wind and other viable renewable sources through targeted public investment, improved financing mechanisms and appropriate incentives for private-sector participation. This would enable renewable energy to make a stronger contribution to economic growth while supporting Nigeria's long-term energy sustainability.

Given the stronger contribution of non-renewable energy to economic growth, government should maintain adequate and reliable conventional energy supply in the short to medium term while implementing a gradual and well-planned transition toward cleaner energy sources. Policies should also promote energy efficiency and reduce excessive dependence on fossil fuels to minimize future economic and environmental risks.

Since energy consumption as a whole has a substantial contribution to economic growth, government should prioritize reliable, affordable and diversified energy supply as a core component of national development policy. This should include investment in generation, transmission and distribution infrastructure, reduction of electricity-system losses, and policies that encourage efficient energy utilization across productive sectors.

The positive effect of gross fixed capital formation suggests that government should strengthen investment in productive infrastructure and capital assets that complement energy supply. Priority should be given to industrial infrastructure, transportation, electricity networks and

modern production equipment, while creating an enabling environment for private investment and public–private partnerships.

In view of the short-run negative effect associated with the 2023 downstream petroleum deregulation and subsidy removal, future energy-sector reforms should be implemented gradually and with appropriate cushioning measures. Government should strengthen targeted social protection, improve public transportation, support productive enterprises affected by higher energy costs, and ensure that savings from subsidy reforms are transparently redirected toward infrastructure and other growth-enhancing investments.

Finally, given the 38.42% annual adjustment toward long-run equilibrium, government should pursue consistent and stable energy and investment policies rather than frequent policy reversals. Strengthening policy coordination among energy, fiscal, monetary and industrial authorities would help the economy absorb temporary shocks more effectively and sustain the long-run relationship between energy development and economic growth.

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