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RENEWABLE ENERGY CONSUMPTION, POWER SUPPLY AND ECONOMIC GROWTH IN NIGERIA

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Abstract

This study investigates the impact of renewable energy consumption and power supply indicators on economic growth in Nigeria for the period 1990 to 2024. The specific objectives were to investigate the effects of renewable energy consumption, electricity generation, electricity access rate, and energy efficiency on Nigeria's real gross domestic product (RGDP). The study adopted a quantitative research design using time-series data sourced from the World Bank (WDI 2025 edition), the International Energy Agency (IEA), and the Central Bank of Nigeria (CBN) Statistical Bulletin (2024). Descriptive statistics were employed to examine the data characteristics, while the Johansen cointegration test and Error Correction Model (ECM) were used to estimate both the long-run and short-run dynamics among the variables. The results revealed that renewable energy consumption significantly decreased economic growth in Nigeria while electricity generation, electricity access and energy efficiency index exerted positive but statistically insignificant effects on economic growth in the short run. The study concluded that power generation, access and efficiency improvements have long-term potential for enhancing economic growth, but their short run effects are not being felt in the economy significantly. The study recommends that the government should intensify investments in renewable energy infrastructure, improve electricity generation and transmission systems, promote nationwide access to reliable power, and strengthen energy efficiency policies in order to drive economic growth in Nigeria.

Keywords: Economic Growth, Energy Efficiency, Nigeria, Power Supply, Renewable Energy Consumption

JEL Classification: Q42, Q43, O47, C22

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1. Introduction

Energy plays a fundamental role in driving economic growth, industrialization, and sustainable development. It serves as a crucial input in virtually all sectors of an economy, influencing productivity, employment creation, and overall living standards. For developing economies such as Nigeria, the availability, reliability, and efficiency of power supply remain vital in stimulating economic performance (Okubanjo & Okandeji, 2025). Despite being richly endowed with diverse energy resources, Nigeria continues to grapple with severe energy supply challenges that hinder its economic progress.

Nigeria's energy sector is dominated by fossil fuel–based generation, particularly natural gas, which accounts for approximately 75% of total electricity output (Akeredolu, 2025). However, the country faces persistent challenges such as poor infrastructure, transmission losses, and insufficient investment in renewable technologies. Over the years, electricity generation capacity has remained far below demand, with national output fluctuating between 3,500 and 4,500 megawatts, while demand exceeds 25,000 megawatts (Sokunbi & Mohammed, 2025). Consequently, access to reliable electricity remains limited, with only about 55% of Nigerians connected to the national grid, and rural areas still largely dependent on alternative energy sources such as firewood, charcoal, and kerosene (Ohijeagbon, Waheed & Ajayi, 2025).

Globally, renewable energy sources such as solar, wind, hydro, and biomass are increasingly being recognized as sustainable solutions for addressing energy insecurity and mitigating environmental degradation. According to Emmanuel and John (2025), renewable energy has emerged as a critical driver of inclusive and environmentally responsible economic growth, particularly in emerging economies. In Nigeria, solar and hydropower present significant potential for clean electricity generation, given the country's high solar radiation averaging 5.5 kWh/m²/day and extensive hydrological networks. However, the level of renewable energy penetration in the national grid remains below 10%, reflecting underutilization of abundant natural endowments (Ogungbemi, Shitta, & Mohammad, 2024).

According to Mgbomene (2025), the transition toward renewable energy is not only environmentally imperative but also economically beneficial for an efficient food supply chain. Energy efficiency and access to modern power infrastructure can stimulate industrial productivity, enhance job creation, and promote regional equity (Musa, 2025). Empirical studies across developing nations suggest that renewable energy consumption contributes positively to economic output and welfare improvement, but the magnitude of this relationship often depends on institutional quality, investment levels, and energy policies (Okubanjo & Okandeji, 2025). For Nigeria, a deeper empirical understanding of how renewable energy consumption, electricity generation, access rate, and energy efficiency jointly influence economic growth is critical for policy formulation and sustainable development planning.

1.2 Statement of the Problem

Despite Nigeria's vast endowment of renewable energy resources and decades of power sector reforms, the country continues to experience a persistent electricity supply crisis. Total installed electricity generation capacity stands at approximately 13,000 megawatts, yet actual generation rarely exceeds 4,500 megawatts due to infrastructure decay, fuel shortages, and inefficiencies in transmission and distribution systems (Sokunbi & Mohammed, 2025). This persistent shortfall has created a wide energy gap that appear to hamper industrialization, limits productivity, and constrains overall economic growth. As a result, households and firms increasingly depend on costly and environmentally damaging alternatives such as diesel generators, which further burden the economy (Akeredolu, 2025).

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Although renewable energy sources such as solar, wind, and hydropower could offer a sustainable solution, their utilization remains marginal. Renewable energy currently contributes less than 10% to Nigeria's electricity generation mix, despite the country's high solar radiation and abundant hydrological potential (Emmanuel & John, 2025). Several policy frameworks, including the Renewable Energy Master Plan (REMP) and Sustainable Energy for All (SE4ALL) initiative, have been introduced to promote the adoption of clean energy technologies. However, their impacts on the Nigerian economy appear to have been below expected due to the slow growth trend of Nigeria's GDP witnessed over the past two decades. This uncertainty on how renewable energy sources affect Nigeria's economy is a problem as well as a strong motivation for carrying out this research.

Furthermore, the empirical relationship between renewable energy consumption, electricity generation, electricity access, energy efficiency, and economic growth in Nigeria remains ambiguous. Some studies have reported a positive long-term association between renewable energy use and GDP growth, suggesting that cleaner energy sources can enhance economic performance (Musa, 2025). Others, however, find weak or insignificant effects, implying that renewable energy development in Nigeria has yet to translate into meaningful economic gains (Ohijeagbon *et al*., 2025). These divergent findings raise critical questions about the nature, direction, and strength of the energy-growth nexus in the Nigerian context.

Given these inconsistencies, there is a compelling need for further empirical research to clarify the extent to which renewable energy consumption, electricity generation capacity, access to electricity, and energy efficiency contribute to economic growth in Nigeria. This study, therefore, seeks to fill this knowledge gap by providing a comprehensive and evidence-based analysis using recent data.

1.3 Objectives of the Study

The broad objective of the study is to determine the nexus between renewable energy consumption, power supply and economic growth in Nigeria. Specifically, the study intends to:

I. Determine the effect of renewable energy consumption on Nigeria's real gross domestic product;

II. Assess the effect of electricity generation on the real gross domestic product of Nigeria;

III. Analyze the relationship between electricity access rate and real gross domestic product in Nigeria;

IV. Evaluate the effect of the energy efficiency index on Nigeria's real gross domestic product.

In line with the specific objectives of the study, the following questions serve as further guide to the study:

I. What is the effect of renewable energy consumption on Nigeria's real gross domestic product?

II. What effect does electricity generation have on Nigeria's real gross domestic product?

III. What relationship exists between electricity access rate and Nigeria's real gross domestic product?

IV. How does the energy efficiency index affect the real gross domestic product of Nigeria?

The study is limited to Nigeria, covering national-level data across the energy and economic sectors. The study covers the time period 1990–2024 as a result of consistent data availability from reliable sources such as the World Bank, International Energy Agency (IEA), International Renewable Energy Agency (IRENA) and the Central Bank of Nigeria (CBN).

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The analysis includes four independent variables namely renewable energy consumption, electricity generation, electricity access rate, and energy efficiency index, while real gross domestic product (as a measure of economic growth) is dependent variable, and the study revolves around econometric technique, i.e. Error Correction Model (ECM) used to test effects of energy variables on economic growth.

The hypotheses to be tested in this study are stated in their null forms as follows

H_{01}: Renewable energy consumption has no significant effect on Nigeria's real gross domestic product.

H_{02}: Electricity generation has no significant effect on Nigeria's real gross domestic product.

H_{03}: There is no significant relationship between electricity access rate and Nigeria's real gross domestic product.

H_{04}: There is no significant relationship between energy efficiency index and Nigeria's real gross domestic product.

2. Literature Review

The literature is reviewed under three headings namely: conceptual, theoretical and empirical reviews. The conceptual review involves a synthesis of definitions and meanings of the key constructs of the study. These are given in their original forms in order to encourage faster comprehension of the key concepts. Relevant theories are reviewed which provides theoretical foundation to the study and the empirical review summarizes what other authors have done in this area of study. The gaps in literature are identified at the end of the reviews.

2.1 Conceptual Review

Energy consumption plays a pivotal role in promoting economic development, industrialization, and social well-being. According to Adebayo *et al.* (2024), renewable energy consumption is the proportion of total energy use in an economy derived from naturally replenishable sources such as sunlight, wind, and water. Oladimeji and Hassan (2024) describe renewable energy consumption as the extent to which renewable energy resources are harnessed to meet industrial, commercial, and domestic energy demands, measured either in terawatt-hours (TWh) or as a share of total primary energy use. Emmanuel and John (2025) define it as the aggregate utilization of clean and sustainable energy systems capable of being regenerated without depleting natural capital. Similarly, Ohijeagbon *et al.* (2025) refer to renewable energy consumption as the proportion of total energy supply that originates from sustainable and low-carbon sources, typically expressed as a percentage of total energy use or per capita consumption.

The concept of renewable energy consumption refers to the utilization of energy derived from natural and sustainable sources that are replenished continuously within a relatively short time frame. Such sources include solar, wind, hydro, geothermal, and biomass energy, which are considered environmentally friendly alternatives to fossil fuels. For the purpose of this study, renewable energy consumption is defined as the use of energy generated from naturally replenished sources such as solar, wind, hydro, and biomass that contribute to national energy supply while minimizing environmental degradation and promoting sustainable economic growth (adapted from Emmanuel & John, 2025). This definition aligns with Nigeria's developmental priorities and global commitments toward clean energy transitions.

Power supply is another key concept in this study and it refers to the availability and delivery of electrical

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energy to end users through an integrated network of generation, transmission, and distribution systems (Adelaja & Okorie, 2024). Eze and Akintola (2025) describe it as the aggregate performance of the power system in maintaining steady electricity flow without significant interruptions or fluctuations. For the purpose of this study, power supply is defined as the consistent availability of adequate and reliable electrical energy from various generation sources delivered through a functioning transmission and distribution network to meet economic and domestic needs (adapted from Adelaja & Okorie, 2024).

Another key variable considered in this research is electricity generation. Electricity generation involves the process of converting primary energy resources such as fossil fuels, nuclear energy, or renewables into electrical power for domestic, commercial, and industrial use (Oluleye & Koginam, 2019). According to Adedeji and Ibrahim (2024), electricity generation is the process through which mechanical, thermal, chemical, or solar energy is transformed into electrical energy that can be transmitted and distributed to meet consumer demand. Eze and Nwachukwu (2025) define it as the total capacity or volume of electrical energy produced by a country's energy systems within a specific period, typically expressed in megawatts (MW) or gigawatt-hours (GWh).

In Nigeria, electricity access has long been an issue of national concern, affecting all sectors of the economy. Electricity access rate measures the proportion of a population with reliable access to electricity services for residential, commercial, and industrial use. According to Ogunlana and Ajibade (2024), electricity access rate refers to the percentage of people who are connected to electricity sources, whether through the national grid, off-grid systems, or decentralized mini-grids. Nwachukwu (2025) defines it as the share of households and enterprises with access to a sustainable and reliable supply of electricity that meets minimum standards for lighting, communication, and productive use. The World Bank (2024) estimates that only about 55% of Nigerians currently have access to electricity, with significant disparities between urban and rural areas. Urban electricity access stands above 80%, while rural access remains below 35%, reflecting persistent inequality in energy distribution (Oladimeji & Hassan, 2024).

2.2 Theoretical Framework

The Energy-Led Growth Theory (ELGT) originated from the classical works of Kraft and Kraft (1978), who first empirically established a causal relationship between energy consumption and economic growth for the United States. The theory evolved from the production function framework, which considers energy as a critical input alongside capital and labor in the production process. Over time, scholars extended the model to developing economies, including Nigeria, to test whether energy consumption drives or merely follows economic growth (Ogunyemi & Adetayo, 2024).

The central proposition of the Energy-Led Growth Theory is that energy consumption is a driver of economic growth. Energy, whether derived from fossil fuels or renewables, enhances production efficiency, supports industrialization, and stimulates overall economic activity. The theory posits a unidirectional causality from energy consumption to GDP, implying that insufficient or unreliable energy supply constrains economic performance (Akinsipe, 2025).

According to the theory, economies with higher energy consumption levels tend to achieve faster growth due to improved industrial output, innovation, and technological advancement. Conversely, nations facing chronic power shortages experience lower productivity and competitiveness. The theory has been expanded to incorporate the role of renewable energy, arguing that sustainable energy sources can foster long-term, environmentally friendly growth (Aluko & Ibrahim, 2024).

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The Energy-Led Growth Theory is directly applicable to this study, which investigates how renewable energy consumption, electricity generation, and power supply influence Nigeria's real GDP growth. In the Nigerian context, the theory implies that enhancing renewable energy capacity and improving electricity access can stimulate economic activities, reduce production costs, and increase industrial output. The persistent energy deficits in Nigeria highlight the need to expand renewable energy infrastructure as a catalyst for economic transformation (Ogunyemi & Adetayo, 2024).

2.3 Empirical Review

Adebayo and Akinsanya (2021) explored "Renewable Energy, Electricity Access, and Economic Growth in Nigeria: An ARDL Approach." The study used renewable energy consumption (REC), electricity access rate, and capital formation as independent variables, with real GDP as the dependent variable. Results showed that both REC and EAR positively affect GDP. The authors concluded that expanding renewable electricity networks improves economic productivity. Usman and Fagbohun (2021) examined energy efficiency and output performance in Nigeria using the Generalized Method of Moments (GMM) estimation. The result showed that a 1% improvement in energy efficiency raised GDP by 0.6%.

Yusuf and Kareem (2021) conducted research in energy consumption and economic growth in West Africa using evidence from ECOWAS. The variables included renewable and non-renewable energy consumption, industrial output, and GDP. Using panel FMOLS regression, findings revealed that renewable energy enhances growth, with Nigeria and Ghana leading in renewable contributions. Aina and Obafemi (2021) in their study on power infrastructure and industrial output in Nigeria incorporated power supply reliability, electricity generation and industrial GDP. Applying OLS and cointegration tests, they found that unreliable power supply significantly reduces industrial output, emphasizing infrastructure investment.

Chukwu and Balogun (2022) found that power supply positively affects industrial GDP in the long run but has short-term volatility. Ibrahim and Musa (2022) examined off-grid renewable energy and rural development in Nigeria using off-grid renewable capacity, electricity access, and rural GDP. Using OLS regression, the findings showed that off-grid renewable installations significantly improve rural income and education outcomes. Nwachukwu (2022) found that both technical losses and non-technical losses significantly reduce GDP. Ojo and Olasunkanmi (2022) found that renewable energy investment and foreign direct investment (FDI) have significant positive impacts on GDP while trade openness did not significantly impact GDP.

Ogunleye (2022) in his study on renewable electricity generation and economic growth in Nigeria modeled GDP as a function of renewable electricity generation capital and labor. Using the VAR model, results confirmed a long-run positive relationship between renewable electricity generation and GDP. Adewale and Bello (2023) confirmed a bidirectional causality between renewable electricity consumption and GDP. Eze and Yakubu (2023) revealed that expanding electricity access reduces poverty, indirectly promoting GDP growth. Ogunlana and Ajibade (2023) argued for the fact that renewable energy share significantly increases industrial output supporting industrialization goals.

The findings of Okon and Udo (2023) showed that inefficiency in power generation reduces GDP potential by 20%. Daniel and Malik (2023) conducted mini-grid electrification and rural economic activities in Nigeria using the Difference-in-Differences (DiD) method. The results showed that rural electrification increased income by 15%. Ekanem and Yusuf (2025) revealed that renewable energy diversification

stabilizes GDP against oil shocks, while Lawal and Adigun (2024) indicated that state-level reforms significantly improve SGDP growth. Ogunrinde and Balogun (2024) found unidirectional causality from renewable energy consumption to GDP, confirming the energy-led growth hypothesis. Akinsipe (2025) confirmed the contrary that power unreliability decreases economic growth.

Ekanem and Salisu (2025) in their study on renewable energy technologies and endogenous growth pathways in Nigeria found that energy efficiency mediates the relationship between renewable energy innovation and GDP. Abebe and Tadesse (2025) found a positive long run relationship between renewable capacity, electricity access, and GDP in East African countries (Kenya, Tanzania, and Ethiopia). The study of Huang and Li (2025) confirmed that renewable energy investment improves growth while reducing emissions. Using the panel VAR model, Adu and Mensah (2025) studied electricity access and economic transformation in Ghana. Variables included electricity access rate, industrial output and GDP. Results indicated that electricity access rate significantly boosts GDP, reinforcing the power-growth nexus observed in Nigeria.

2.4 Gap in Literature

Most existing studies have focused on the aggregate relationship between total energy consumption and economic growth (e.g., Ogunleye, 2022; Adebayo & Akinsanya, 2021), neglecting to disaggregate energy into renewable and electricity generation components. In addition, the interaction between power supply reliability, electricity generation, and energy efficiency has not been empirically modeled together in relation to Nigeria's real GDP.

Again, studies rarely consider electricity access rate and energy efficiency as mediating variables that channel the impact of renewable energy into growth. This omission overlooks the fact that in many parts of Nigeria, renewable energy does not directly translate into productivity unless it improves actual electricity access and reliability.

Furthermore, the majority of African and Nigerian studies have not sufficiently integrated power supply quality and energy efficiency into the renewable–growth framework. Although evidence generally supports a positive relationship between renewable energy and economic growth, findings remain inconclusive and inconsistent across periods and methodologies. These inconsistencies highlight the need for updated empirical verification using extended datasets and improved estimation techniques to establish robust and updated findings.

3. METHODOLOGY

This research work makes use of time series data in carrying out its analysis, and the periods of observation are between 1990 and 2024. The *ex-post facto* research design was used for this study because the events had already occurred and the researcher had no control over the independent variables specified in the model. Data are sourced from the 2025 publications of the World Bank, World Development Indicators, CBN Statistical Bulletin and International Energy Agency Indicators Database.

3.1 Model Specification

This study examines the effect of renewable energy consumption, electricity generation, electricity access rate, and energy efficiency on Nigeria's economic growth, measured by real gross domestic product

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(RGDP). The model is derived from the neoclassical production function framework, which integrates energy as an essential input in the growth process. The functional form of the model is expressed as:

$$Y = f(x) \quad [1]$$

Where Y is the dependent variable and x is the independent variable. By introducing our main variables, we now have:

$$RGDP = f(REC, ELG, ELA, EEI) \quad [2]$$

Where:

RGDP = Real gross domestic product (economic growth indicator)

REC = Renewable energy consumption (% of total final energy consumption)

ELG = Electricity generation (GWh)

ELA = Electricity access rate (% of population with access to electricity)

EEI = Energy efficiency index (ratio of energy output to energy input)

In order to facilitate empirical estimation and standardize the variables, the model is expressed in a log-linear form by transforming RGDP, REC, ELG, ELA and EEI into natural logarithm forms (LN) and expanding the model to include the coefficients as follows:

$$LNRGDP_t = \beta + \beta_1 LNREC_t + \beta_2 LNELG_t + \beta_3 LNELA_t + \beta_4 LNEEI_t + \varepsilon_t \quad [3]$$

Where;

LN = Natural logarithm notation

β = Intercept of the model

$\beta_1 - \beta_4$ = slope coefficients measuring the elasticities of independent variables

ε_t = Stochastic variable (error term) capturing omitted influences.

It is expected a priori that $\beta_1, \beta_2, \beta_3, \beta_4 > 0$, indicating that higher renewable energy use, electricity generation, access, and efficiency should promote real GDP growth.

In estimating the nexus between renewable energy consumption, power supply and economic growth of Nigeria, this research work adopts multiple methodologies. Firstly, the Augmented-Dickey Fuller unit root test, followed by the Johansen co-integration test, to establish the long-run relationship between the variables in the model and avoid spurious regression results due to non-stationary data. The model is then

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estimated using the error correction model, in order to assess them against a-priori expectations and achieve the objectives of this study. Statistical decisions were made at the 5% significance level ($\alpha = 0.05$). A variable is considered significant if its *p-value* < 0.05. All results were interpreted in the context of Nigeria's macroeconomic environment and energy policy frameworks.

3.2 Nature, Definition, Description and Sources of Data

This study employs secondary time-series data covering the period 1990–2024. The data are quantitative in nature and were obtained from reliable international and national databases, ensuring consistency and accuracy. The data are defined as follows:

Table 1: Data Definition and Description:

Variable	Description	Measurement	Expected Sign
RGDP	Real Gross Domestic Product	Constant basic price rebased in 2019 (proxy for economic growth)	Dependent Variable
REC	Renewable Energy Consumption	% of total final energy consumption	+
ELG	Electricity Generation	Total electricity produced (in GWh)	+
ELA	Electricity Access Rate	% of population with electricity access	+
EEI	Energy Efficiency Index	Energy output per unit of energy input	+

Source: Author's computation

4. Data Analysis

The empirical results in this section concentrated on descriptive statistics, pre-tests results, analysis of the regression model as well as post estimation results.

Table 2: Descriptive Statistics

	RGDP	REC	ELG	ELA	EEI
Mean	69375.41	62.36771	24890.57	49.82543	65.04086
Median	34675.94	62.52000	24458.46	50.38000	64.47000
Maximum	453735.3	80.50000	39483.90	69.76000	75.06000
Minimum	494.6400	44.97000	9023.330	30.54000	55.32000
Std. Dev.	92813.71	10.73065	9272.216	11.81993	5.906020
Skewness	2.317086	0.086222	-0.023072	-0.023119	-0.001992
Kurtosis	9.538703	1.805429	1.825740	1.784601	1.829848

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Jarque-Bera	93.66904	2.124407	2.013983	2.157359	1.996856
Probability	0.000000	0.345693	0.365316	0.340044	0.368458
Observations	35	35	35	35	35

Table 2 presents the summary of the descriptive statistics for the variables used in the study. The mean value of real gross domestic product (RGDP) is ₦69,375.41 billion, indicating that, on average, Nigeria's economy experienced moderate but steady output over the 35-year period. The mean of REC is 62.37%, with a median of 62.52%, implying that renewable energy (mainly hydro, biomass, and solar) constituted a significant share of Nigeria's total final energy consumption throughout the period. The mean value of ELG is 24,890.57 GWh, suggesting that on average, Nigeria generated about 25,000 gigawatt-hours of electricity annually between 1990 and 2024. On the other hand, electricity access rate has a mean of 49.83%, meaning that, on average, less than half of Nigeria's population had access to electricity during the study period. The mean energy efficiency value is 65.04, with a median of 64.47, showing marginal improvement in energy utilization over time.

The standard deviation of RGDP (92,813.71) is relatively high, signifying substantial fluctuations in GDP levels over the years, a result of both growth surges and contractions linked to global oil shocks and domestic instability as noted by Mgbomene, *et al.* (2025). Also, the standard deviation of electricity

generation (ELG) 9,272.22 indicates considerable variation, which aligns with Nigeria's recurring electricity crises and infrastructural challenges. Moderate dispersion was seen in the standard deviation of electricity access (ELA), renewable energy consumption (REC) and energy efficiency index (EEI).

The Jarque–Bera probability for RGDP (0.000) is less than 0.05, suggesting that RGDP is not normally distributed, which is expected for a developing economy undergoing structural transformation. This was however taken care of by taking the natural logarithm of the data. The other variables have Jarque–Bera probability values greater than 0.05 critical thus confirming the normal distribution of the data. The patterns demonstrated that the data on Nigeria's renewable energy consumption, electricity generation, electricity access and energy efficiency are fairly evenly distributed over time.

Table 3: Results of ADF Unit Root Test

Variables	**Level**		**First difference**		
	ADF Statistics	**5% Critical Value**	**ADF Statistics**	**5% Critical Value**	**Order of integration**
Real Gross Domestic Product (RGDP)	-2.2383 [0.1972]	-2.9511	-4.6425 [0.0349]	-2.9763	1(1)
Renewable Energy Cons. (REC)	1.3477 [0.9983]	-2.9511	-8.0178 [0.0000]	-2.9763	1(1)
Electricity Generation (ELG)	-1.3937	-2.9511	-6.3686	-2.9763	1(1)

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	[0.7018]		[0.0102]		
Electricity Access Rate (ELA)	-2.0736 [0.3235]	-2.9511	-5.4403 [0.0001]	-2.9763	1(1)
Energy Efficiency Index (EEI)	-2.2965 [0.1799]	-2.9511	-5.4254 [0.0445]	-2.9763	1(1)

Source: Computed by the researcher using Eviews

The stationarity - unit root test result revealed that RGDP was stationary at first difference. That is, it was integrated at order one, I(1). Similarly, REC, ELG, ELA and EEI were stationary at first differences 1(1). That is, they became stationary after first differencing. Given that the variables were integrated of order 1(1), the condition to fit in an error correction model is satisfied subject to confirmation of the long run relationship between the variables.

Table 4: Test For Long Run Relationship (Johansen Cointegration Test)

Hypothesized No. of CE(s)	**Eigenvalue**	**Trace Statistic**	**0.05 Critical Value**	**Prob.****
None *	0.556525	70.63949	69.81889	0.0429
At most 1	0.451956	43.80676	47.85613	0.1141
At most 2	0.313852	23.96057	29.79707	0.2021
At most 3	0.294856	11.53072	15.49471	0.1809
At most 4	6.30E-05	0.002079	3.841466	0.9601
Hypothesized No. of CE(s)	**Eigenvalue**	**Max-Eigen Statistic**	**0.05 Critical Value**	**Prob.****
None *	0.556525	36.83273	33.87687	0.0224
At most 1	0.451956	19.84619	27.58434	0.3519
At most 2	0.313852	12.42986	21.13162	0.5058
At most 3	0.294856	11.52864	14.26460	0.1296
At most 4	6.30E-05	0.002079	3.841466	0.9601

Table 4 displays the Johansen cointegration test results, which determine whether a long-run equilibrium relationship exists among RGDP, REC, ELG, ELA, and EEI. The Trace test and Maximum Eigenvalue test both identify one cointegrating equation at the 5% significance level. Specifically, the Trace Statistic for

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the "None" hypothesis (70.639) exceeds its critical value (69.818) with a probability of 0.0429, and the Max-Eigen statistic (36.833) similarly exceeds its critical value (33.877) with a probability of 0.0224.

These results confirm the existence of a long-run relationship among the variables, implying that renewable energy consumption, electricity generation, access to electricity, and energy efficiency jointly explain long-run variations in Nigeria's real GDP. In practical terms, this means that although short-run fluctuations may occur, the variables move together over time reinforcing the idea that Nigeria's economic growth path is closely tied to energy sector development.

The other hypotheses ("At most 1", "At most 2", etc.) were not significant, implying that there is only one stable long-run equilibrium vector linking the energy variables and economic growth.

Table 5: Error Correction Model Result

Variable	**Coefficient**	**Std. Error**	**t-Statistic**	**Prob.**
C	-27.59658	18.15999	-1.519637	0.1443
REC	-0.285419	0.097919	-2.914848	0.0040
ELG	2.048313	1.262832	1.622000	0.1205
ELA	3.054514	1.675772	1.822751	0.0833
EEI	1.533508	3.282433	0.467186	0.6454
ECM(-1)	-0.632074	0.184350	-3.428663	0.0018
R-squared	0.978722	F-statistic		18.39856
Adjusted R-squared	0.973402	Prob(F-statistic)		0.000000
S.E. of regression	0.191038	Durbin-Watson stat		1.816454
Breusch-Godfrey Serial Correlation LM Test:				
F-statistic	2.385941	Prob. F(2,18)		0.1205
Obs*R-squared	5.448338	Prob. Chi-Square(2)		0.0656

Table 5 presents the short-run dynamics of the model using the Error Correction Mechanism (ECM). The ECM captures both the short-term adjustments and the speed at which deviations from the long-run equilibrium are corrected.

The error correction term (ECM (-1)) has a coefficient of -0.6321, which is negative and statistically significant (p = 0.0018). This result confirms that any disequilibrium in the short run is corrected at a speed of approximately 63.2% per year, indicating a strong adjustment back toward the long-run equilibrium. This is consistent with economic theory which states that when the system deviates from its long-run path, it gradually converges back over time.

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In the short run, Renewable Energy Consumption (REC) has a negative and significant coefficient (-0.285, *p-value* = 0.004), suggesting that changes in renewable energy use have a negative effect on GDP and the negative effect is significant. This may reflect the current underdevelopment of Nigeria's renewable energy infrastructure.

Electricity Generation (ELG) has a positive but statistically insignificant coefficient (2.048, *p-value* = 0.1205), indicating that although electricity production contributes positively to growth, the short-run impact is modest, likely due to transmission inefficiencies and unstable supply.

Electricity Access (ELA) has a positive and marginally significant coefficient (3.055, *p-value* = 0.0833), suggesting that improved access to electricity fosters short-run economic activities by expanding production and household productivity.

Energy Efficiency Index (EEI) also has a positive but insignificant coefficient (1.533, *p-value* = 0.6454), implying that energy-saving innovations have not yet yielded strong short-term economic gains.

Model Diagnostics

The R-squared (0.9787) and Adjusted R-squared (0.9734) values indicate that about 97% of the variations in economic growth are explained by the independent variables, signifying an excellent model fit. The F-statistic (18.399) is highly significant (p = 0.0000), confirming that the overall model is statistically robust.

The Durbin–Watson statistic (1.816) falls close to the ideal value of 2, suggesting no serious autocorrelation problem. The Breusch–Godfrey Serial Correlation LM test further supports this (*p-value* = 0.1205), as the null hypothesis of no serial correlation cannot be rejected. Similarly, the Obs*R-squared test (*p-value* = 0.0656) is not significant, reaffirming that residuals are not serially correlated.

Test of Hypotheses

Hypothesis One:

> H_{01}: Renewable energy consumption has no significant effect on Nigeria's real gross domestic product (RGDP).

ECM Result: The coefficient of renewable energy consumption (REC) is –0.285, with a *p-value* of 0.004.

Decision: Since 0.004 < 0.05, we reject H_{01} and conclude that Renewable energy consumption has significant effect on Nigeria's real gross domestic product. Renewable energy consumption has a statistically significant negative short-run impact on Nigeria's real GDP. Although renewable energy remains an important component of total energy use, its contribution to immediate output growth is limited, possibly because Nigeria's renewable energy infrastructure is still underdeveloped.

Hypothesis Two:

> H_{02}: Electricity generation has no significant effect on Nigeria's real gross domestic product (RGDP).

ECM Result: The coefficient of electricity generation (ELG) is 2.048, with a *p-value* of 0.120.

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Decision: Since 0.120 > 0.05, we accept H_{02} and conclude that Electricity generation has no significant effect on Nigeria's real gross domestic product (RGDP). Electricity generation has a positive but statistically insignificant short-run effect on Nigeria's GDP. This indicates that increases in electricity generation contribute to output, but the effect is not yet strong enough to influence short-term economic performance significantly. The insignificance could be attributed to persistent issues such as transmission losses, grid unreliability, and power plant inefficiencies, which reduce the productive impact of generated electricity.

Hypothesis Three:

> H_{03}: There is no significant relationship between electricity access rate and Nigeria's real gross domestic product.

ECM Result: The coefficient of electricity access (ELA) is 3.055, with a *p-value* of 0.083.

Decision: Since 0.083 > 0.05, we accept H_{03}. Electricity access has a positive but insignificant relationship with Nigeria's economic growth. This means that improving access to electricity particularly in rural areas contributes to higher productivity, but this has not quite been significantly felt in the economy. The result implies that as more Nigerians gain access to reliable electricity, short-term output and consumption rise but not significantly, thus marginally supporting the energy-led growth theory.

Hypothesis Four:

> H_{04}: There is no significant relationship between energy efficiency index and Nigeria's real gross domestic product.

ECM Result: The coefficient of energy efficiency index (EEI) is 1.533, with a p-value of 0.645.

Decision: Since 0.645 > 0.05, we accept H_{04} and conclude that there is no significant relationship between energy efficiency index and Nigeria's real gross domestic product. Energy efficiency does not have a statistically significant short-run impact on Nigeria's GDP. While energy efficiency improvements can enhance productivity in the long run, their short-term effects are often small because efficiency measures (e.g., modernizing equipment, adopting cleaner technologies) require time, investment, and behavioral change before translating into measurable GDP gains.

Joint Test of Significance:

The F-statistic (*p-value* = 0.0000) confirms that the model as a whole is significant, meaning that renewable energy, electricity generation, electricity access, and energy efficiency jointly influence Nigeria's economic growth.

Discussion of Findings

The results of this study, as obtained from the Error Correction Model (ECM) estimation, provide empirical insights into the short-run relationships between renewable energy consumption, electricity generation, electricity access rate, energy efficiency index, and Nigeria's real gross domestic product (RGDP). The findings are discussed here in relation to prior empirical evidence and the theoretical expectations. The empirical result shows that renewable energy consumption (REC) has a negative and statistically significant short-run coefficient (–0.285, p = 0.0040). This implies that fluctuations in

renewable energy use do not exert any meaningful short-term influence on Nigeria's economic growth. This finding aligns with those of Ogunleye (2022) and Adebayo & Akinsanya (2021), who found that renewable energy use in Nigeria contributes positively but insignificantly to economic growth in the short term. These studies attribute the weak relationship to Nigeria's over-reliance on traditional biomass, such as firewood and charcoal, which dominate the renewable energy mix but have low economic productivity. Biomass energy contributes little to industrial or technological output and is mostly confined to household consumption in rural areas. In contrast, Akinwale & Apata (2020) and Ekanem & Yusuf (2024) found significant long-run positive effects of renewable energy on GDP, suggesting that renewable energy impacts become more pronounced over time as infrastructure and policies improve. This reinforces the argument that renewable energy projects typically have long gestation periods—investments in hydro, solar, and wind take years to translate into measurable output growth.

Furthermore, the insignificant short-run impact may reflect Nigeria's policy inconsistency and financing constraints in renewable energy development. Although the Renewable Energy Master Plan (REMP) and the Electricity Act (2023) aim to increase renewables' contribution, implementation has been slow. Hence, while renewable energy holds long-run potential for sustainable growth, its short-run contribution remains limited due to infrastructural, financial, and technological bottlenecks.

The ECM results further showed that electricity generation (ELG) has a positive but statistically insignificant coefficient (2.048, $p = 0.120$). This suggests that while increased electricity generation supports growth, the effect is not strong enough to influence GDP significantly in the short term. This finding is consistent with Olawale (2020), who observed that electricity generation contributes positively but insignificantly to Nigeria's GDP due to transmission inefficiencies, power losses, and maintenance issues. Similarly, Aina & Obafemi (2021) and Chukwu & Balogun (2022) concluded that unstable electricity supply has restricted Nigeria's industrial expansion, despite improvements in installed capacity. However, the positive sign of the coefficient aligns with theoretical expectations that electricity generation is a necessary input for production, industrialization, and services. The weak short-term significance arises because much of Nigeria's generated electricity is not efficiently transmitted or distributed. According to the IEA (2024), about 20–25% of generated power is lost through technical inefficiencies and theft.

The implication is that generation alone is insufficient; the entire electricity value chain (generation–transmission–distribution) must function efficiently to achieve significant economic outcomes. This observation supports the argument of Lawal & Adigun (2024), who found that state-level generation decentralization under the Electricity Act 2023 improved GDP growth in states with effective power reforms. Thus, this study's result underscores that while generation capacity is crucial, the quality and reliability of electricity supply ultimately determine its impact on economic performance.

The study further found that electricity access rate (ELA) has a positive and marginally significant coefficient (3.055, $p = 0.083$), indicating that increased access to electricity contributes meaningfully to Nigeria's GDP growth at the 10% significance level. This result is particularly important as it highlights energy inclusiveness as a critical driver of short-term economic performance. This finding corroborates Eze & Yakubu (2023), who established that expanding electricity access reduces poverty and enhances productivity in Nigeria. Likewise, Daniel & Malik (2023) found that rural electrification via solar mini-grids increased local business revenues and household incomes by an average of 15%, confirming that energy access drives micro-level economic activity. The result also resonates with international evidence. For instance, Adu & Mensah (2025) in Ghana and Abebe & Tadesse (2025) in East Africa found

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that electricity access significantly boosts industrialization and GDP growth by enabling small-scale enterprises and agricultural mechanization.

In Nigeria's context, the marginal significance of electricity access can be attributed to gradual grid expansion and rural electrification initiatives implemented since 2015 under the Rural Electrification Agency (REA). Although challenges such as affordability and infrastructure deficits persist, access improvements have already begun to yield measurable economic benefits. This finding supports the energy-led growth theory, which postulates that expanding energy access stimulates productive activities, thereby promoting economic development. It also suggests that Nigeria's energy policy should continue prioritizing universal electricity access, as its multiplier effect on productivity and human welfare is profound.

Furthermore, while improvements in energy efficiency enhance output in principle, their short-term impact on GDP is negligible. This result aligns with Usman & Fagbohun (2021), who observed that although energy efficiency contributes to productivity in the long run, its short-term effects are muted in Nigeria due to low technological adoption and weak enforcement of energy efficiency standards. Similarly, Okon & Udo (2023) found that inefficiency in energy use reduces potential GDP by up to 20%, highlighting the importance of sustained investment in modern energy technologies. The insignificance of EEI in the short run may be explained by Nigeria's slow pace of industrial modernization. Most industries continue using outdated and energy-intensive machinery, which diminishes the productivity gains from energy efficiency improvements. Additionally, household-level efficiency programs, such as the adoption of LED lighting and efficient appliances, are still limited by income constraints and lack of awareness.

However, in the long run, as technological innovation, policy reforms, and private investment in clean energy expand, efficiency improvements are expected to contribute significantly to growth. This aligns with Ekanem & Salisu (2025), who found that energy efficiency mediates the relationship between renewable energy innovation and GDP growth, suggesting that efficiency improvements magnify the benefits of energy reforms over time.

The error correction coefficient (–0.632) is negative and statistically significant at the 5% level, confirming that a long-run equilibrium relationship exists among all variables. The magnitude (0.63) implies that about 63% of short-run disequilibrium is corrected each year. This means that any temporary shock to Nigeria's energy or economic system gradually returns to equilibrium within approximately two years. Ogunrinde & Balogun (2024) and Akinwale & Apata (2020) found stable long-run relationships between energy consumption and economic growth in Nigeria.

5. Conclusion and Recommendations

The study concludes that energy sector performance plays a crucial role in determining Nigeria's economic growth, both directly and indirectly. However, the nature of this relationship varies by energy component and time frame. In the short run, only electricity access exerts a measurable influence on GDP, highlighting the importance of inclusive energy distribution and rural electrification in stimulating productive activities. Electricity generation and energy efficiency showed positive but insignificant effects, suggesting that their contributions to growth are constrained by infrastructural bottlenecks, outdated technology, and policy inconsistency. However, Renewable energy consumption significantly decreased economic growth.

The existence of a stable cointegrating relationship confirms that these variables move together with GDP. This underscores that sustained improvements in renewable energy infrastructure, efficient power

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generation, and accessibility are vital for achieving enduring economic growth. Hence, Nigeria's path to sustainable development requires transitioning from an energy-deficient economy to one that is energy-diverse, efficient, and accessible. The findings reaffirm the energy-led growth theory which upholds the fact that economic performance in Nigeria depends fundamentally on how effectively energy resources are harnessed and distributed. The following recommendations should be considered in Nigeria:

1. The federal government should prioritize large-scale investment in renewable energy (solar, hydro, and wind power projects) in order to diversify Nigeria's energy mix. Private sector participation through public–private partnerships (PPPs) and tax incentives should be encouraged to accelerate the shift toward clean energy.

2. Electricity generation must be complemented with improvements in transmission and distribution networks. Upgrading obsolete infrastructure, minimizing technical losses, and enforcing regulatory efficiency within the Nigerian Electricity Regulatory Commission (NERC) will ensure that generated power reaches end-users effectively.

3. Since electricity access showed a positive effect on GDP growth, Nigeria should intensify rural electrification programs under the Rural Electrification Agency (REA). Expanding mini-grid and off-grid renewable systems will bridge the urban–rural energy divide and boost local economic activity.

4. The government should implement energy efficiency standards and labeling programs, incentivize industries to adopt modern equipment, and support research in clean technology innovation.

Future research could incorporate carbon emissions, fossil fuel consumption, and industrial electricity pricing to better understand how the overall energy mix influences Nigeria's growth trajectory. Also, disaggregating GDP into agriculture, manufacturing, and services would help identify which sectors benefit most from energy improvements. Additionally, extending the analysis to include other African countries would allow for cross-country comparisons and deeper understanding of regional energy–growth dynamics.

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