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ENERGY CONSUMPTION, ENVIRONMENTAL SUSTAINABILITY, AND SUSTAINABLE DEVELOPMENT: EMPIRICAL EVIDENCE FROM NIGERIA

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Abstract *This study examines the relationship between energy consumption, environmental sustainability, and sustainable development in Nigeria using annual data from 1990 to 2023. The study specifically investigates the effects of energy use, access to electricity, renewable energy consumption, energy imports, and carbon emissions on sustainable development measured by the Human Development Index (HDI). Given the mixed order of integration among the variables, the Autoregressive Distributed Lag (ARDL) technique was employed to estimate both short-run and long-run relationships. The empirical findings reveal that energy imports and carbon emissions exert a statistically significant negative effect on HDI in both the short run and long run, suggesting that dependence on imported energy and environmental degradation undermine sustainable development in Nigeria. Conversely, access to electricity has a positive and significant influence on human development across both periods, highlighting the importance of improved electricity access in enhancing welfare and living standards. Energy use was found to be significant only in the short run, while renewable energy consumption showed no statistically significant effect on HDI during the study period. The study recommends policies aimed at reducing dependence on imported energy, expanding electricity access through grid and off-grid solutions, improving energy efficiency, promoting renewable energy development, and enforcing stricter environmental regulations to reduce carbon emissions. These measures are essential for achieving sustainable human development and long-term energy sustainability in Nigeria.*

Keywords Energy Consumption; Environmental Sustainability; Human Development Index (HDI); Sustainable Development; ARDL Model

JEL Classification Codes:

Q40, Q43, Q56, O15, C2

INTRODUCTION

Energy is fundamental to economic growth, social welfare, and environmental stewardship. As a primary driver of development, energy consumption powers industrialization, strengthens infrastructure, and catalyzes technological advancements that enhance the overall quality of life (Ogunjimi et al., 2022). In Nigeria, the dynamics of energy use have a profound impact on both national development and environmental sustainability. Like many emerging economies, Nigeria faces the dual challenge of meeting the increasing energy demands of a growing population while ensuring that such consumption does not undermine critical environmental goals. This growth is largely fueled by electricity, oil, and gas; however, a continued over-reliance on fossil fuels has come at the cost of accelerated environmental degradation and climate change. Consequently, the national discourse has shifted beyond the volume of energy consumed to focus on the sustainability of its sources.

The nexus between energy consumption and sustainable development in Nigeria is defined by economic, social, and environmental factors. Industrialization-driven economic growth often necessitates higher energy use, which can exacerbate environmental decline if not managed responsibly (Akinbami & Oloke, 2021). This demand is further intensified by rapid urbanization, population growth, and an expanding middle class, all of which require increased energy for domestic, transport, and industrial applications (Michaels & Adesoji, 2023).

Despite its importance, Nigeria's energy sector faces systemic hurdles. By 2023, Nigeria recorded the world's largest electricity access deficit, with only 61.2% of the total population—and a mere 27% of rural dwellers—having access to power (Statista, 2025). Furthermore, infrastructure investment remains stalled at 30% of GDP, significantly lower than the 70% threshold required for sustainable development (Power Africa, 2024). Social and environmental indicators are equally concerning: forest cover has declined to 23.4%, renewable energy penetration remains low at 3.5%, and nearly 38.9% of the population lives in poverty (Aninwagu & Nyeche, 2025).

While there is growing interest in renewable sources like solar energy, Nigeria remains heavily dependent on non-renewables; oil and natural gas account for approximately 80% of total production (International Energy Agency, 2023). This dependency leaves the economy vulnerable to global price volatility and worsens the domestic effects of climate change. Since the 1960s, temperatures in Nigeria have risen by 1.5°C, with northern regions seeing extremes above 40°C. The 2022 floods underscored this vulnerability, being associated over 600 mortalities and affecting 3.2 million people across 34 of the 36 states of the federation and the Federal Capital Territory (NBS, NEMA & UNDP, 2023). These climate shocks have directly impacted

food security, leaving millions of Nigerians facing chronic hunger and malnutrition (Otekunrin et al., 2023).

The transition to clean energy remains sluggish. Renewables supply less than 25% of total consumption (IRENA, 2023), hampered by policy incoherence and a massive funding gap. Although initiatives like "Solar Power Naija" and the Climate Change Act have been introduced, the $1.9 billion in renewable investment attracted between 2015 and 2022 falls far short of the $10 billion required annually (REAN, 2025; Andersen Global, 2024). These efforts are frequently undermined by poor implementation, limited funding, and political instability.

Furthermore, energy distribution remains deeply inequitable. A stark rural-urban divide persists, with 87% electricity access in cities compared to just 34% in rural areas (Gbaguidi & Adetou, 2024). This disparity limits rural access to healthcare and education, as evidenced by higher maternal mortality rates and lower school enrollment in energy-poor regions (Ajegbile, 2023; UNDP, 2024). Such inequality creates a significant barrier to achieving the United Nations Sustainable Development Goals (SDGs).

In light of these challenges, it is imperative to evaluate the relationship between energy use and national progress. This study seeks to address two critical questions: What is the impact of total energy use on sustainable economic development in Nigeria? How does renewable energy consumption specifically influence sustainable development outcomes?

The objective of this research is to investigate and compare the impacts of total versus renewable energy consumption on Nigeria's sustainable development. By analyzing current challenges and identifying opportunities for transition, this study aims to provide evidence-based policy strategies to improve energy access, promote clean energy adoption, and mitigate environmental degradation

2. LITERATURE REVIEW

2.1 Theoretical Review

2.1.1 The Energy-Growth Nexus Theory

The Energy-Growth Nexus explores the causal relationship between energy consumption and economic performance, serving as a cornerstone of energy economics. This theoretical framework originated with the seminal work of Kraft and Kraft (1978) who identified a definitive causal link between energy use and gross national product in the United States. Contemporary scholars have since categorized this relationship into four primary hypotheses:

The Growth Hypothesis: Posits that energy consumption is a direct driver of economic expansion. In this context, energy is a critical factor of production, and policies restricting energy use may inadvertently stifle economic growth.

The Conservation Hypothesis: Argues that economic growth determines energy demand. Under this view, energy-saving policies and efficiency gains can be implemented with minimal negative impact on total output.

The Feedback Hypothesis: Suggests a bidirectional, interdependent relationship where energy use and economic growth reinforce one another.

The Neutrality Hypothesis: Asserts that no significant causal relationship exists between the two variables, implying that energy policy has little to no macroeconomic effect.

In the context of sustainable development, this theory is increasingly relevant as nations transition from fossil fuels to renewable energy. While the "Energy Ladder" model provides initial insights into how households shift toward cleaner fuels as income rises, a modern approach must account for technological advancements and socio-economic disparities to fully understand the long-term economic benefits of green energy.

2.1.2 The Environmental Kuznets Curve (EKC) Theory

The Environmental Kuznets Curve (EKC), popularized by Grossman and Krueger (1991) hypothesizes an inverted U-shaped relationship between economic growth and environmental degradation. The theory suggests that in the early stages of industrialization, pollution and resource depletion increase alongside per capita income. However, once an economy reaches a certain "turning point" in wealth, structural shifts toward service industries and the adoption of cleaner technologies begin to reduce environmental pressure.

Despite its influence, the EKC has faced scrutiny. Critics argue that the inverted-U pattern is not universal and that environmental degradation often continues to rise in developing regions despite increasing income levels. Furthermore, improvements in environmental quality are not an automatic byproduct of growth; they typically require strong political will, institutional quality, and stringent regulatory frameworks. In this study, the EKC serves as a framework to analyze whether Nigeria's energy-intensive growth can eventually decouple from environmental harm through sustainable practices.

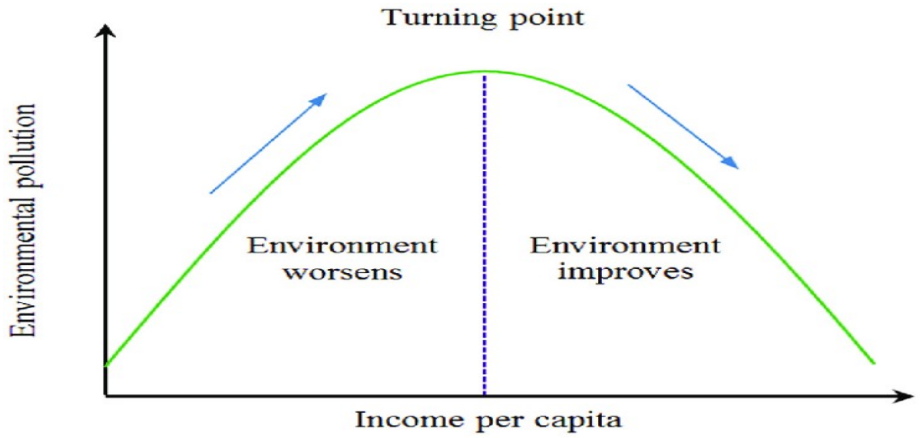

Figure 1 Environmental Kuznets Curve (EKC)
Source: Grossman and Krueger (1991)

2.1.3 Reiner Kümmel's LINEX Production Function

Traditional neoclassical models, such as the Cobb-Douglas function, often treat energy as an intermediate input rather than a primary driver of production. To address this limitation, Kümmel (2011) developed the LINEX (Linear-Exponential) production function. This model emphasizes that economic output is disproportionately influenced by energy inputs, aligning with the laws of thermodynamics.

The LINEX production function is mathematically represented as:

$$Y = AL^{\alpha}K^{\beta}e^{\gamma E}$$

where:

- Y is the total economic output,
- A is a scaling factor representing technological progress,
- L denotes labor input,
- K represents capital input,
- E is the energy input, and
- α,β, and γ are elasticity parameters reflecting the relative contributions of labor, capital, and energy, respectively.

The key distinguishing feature of the LINEX function is the exponential term $e^{\gamma E}$, which implies that small increases in energy input can lead to disproportionately large gains in economic output (Kümmel, 2011). Smil (2017) and Hall et al. (2018) emphasize that historical economic transformations have been largely driven by energy efficiency improvements rather than capital accumulation alone.

This perspective is vital for sustainable development research, as it highlights that the transition to renewable energy is not just an environmental necessity but a fundamental requirement for long-term economic stability and growth

2.2 Empirical Review

Global literature on the energy-development nexus reveals a complex interplay between energy types, economic growth, and environmental quality. Zakari et al. (2022) utilized Data Envelopment Analysis (DEA) and Panel Correction Standard Error (PCSE) estimators to study 20 Asia-Pacific countries from 2000–2018. Their findings established a positive correlation between sustainable economic development and energy efficiency, emphasizing that financial sustainability and green innovation are critical drivers of energy optimization. Similarly, Noor et al. (2024) applied the panel ARDL method to South Asian data (1995–2019), concluding that both renewable and non-renewable energy sources significantly bolster sustainable development in the long run, necessitating a balanced energy policy.

The environmental implications of energy consumption are a central theme in recent research. Ullah et al. (2021) employed a Panel Smooth Transition Model on the world's top 15 renewable energy economies (1996–2018). Their results indicated that while renewable energy consumption reduces the ecological footprint, a heavy reliance on natural resource rents exacerbates environmental degradation. In the United States, Pata et al. (2024) used Fourier causality tests and wavelet decomposition to find bidirectional

causality between renewable energy types (wood and biomass) and the Load Capacity Factor (LCF), supporting the renewable energy-based growth hypothesis.

However, the transition to cleaner energy is not without economic challenges. Khan et al. (2021) examined 38 IEA countries (1995–2015), finding that while energy transitions support long-term growth, they may initially hinder economic expansion due to high transition costs. This "cost of transition" is also reflected in the findings of Rusiadi et al. (2024) regarding ABRIC countries. Using Seemingly Unrelated Regression (SUR), they identified a paradox where green building initiatives were occasionally linked to higher (CO2) emissions due to the continued use of low-tech solutions, despite the positive growth impacts of green credit.

Regional studies in Africa and other developing economies provide further nuance. Gershon et al. (2024) analyzed 17 African countries in the context of SDGs 7, 8, and 13, finding that increased energy consumption drives economic growth while simultaneously increasing carbon emissions. Shahbaz et al. (2024) expanded on this by looking at 15 energy-importing countries, noting that while domestic energy consumption and trade openness drive growth, a heavy reliance on energy imports negatively impacts economic performance. In Ghana, Gyimah et al. (2022) identified a feedback effect between renewable energy and growth via Granger causality tests, though mediation analysis suggested the direct impact on growth remained limited.

Specific country-level analyses, such as those for Pakistan and Nigeria, highlight the demographic pressures on sustainability. Rehman et al. (2022) utilized the STIRPAT model and ARDL method in Pakistan, discovering that population growth and livestock production significantly drive (CO2) emissions. In Nigeria, Emonena and Osifo (2024) investigated the nexus between carbon emissions and growth from 1981–2021 using ARDL Bounds testing. Their research revealed a complex bidirectional relationship where economic expansion drives environmental degradation, which in turn creates a long-term feedback loop affecting economic stability. Finally, Salari et al. (2021) confirmed a consistent long-run relationship between disaggregated energy consumption and (CO2) emissions across U.S. states, reinforcing the global challenge of decoupling growth from emissions.

Expanding on the regional analysis, Muazu et al. (2023) employed a panel threshold regression model to examine 54 African countries from 1990 to 2018. Their findings revealed that renewable energy consumption significantly and negatively impacted economic growth, though this effect was contingent upon specific thresholds of non-renewable energy use, urbanization, and income levels. This asymmetric relationship suggests that while renewable energy is vital for long-term sustainability, its immediate economic benefits in Africa are often constrained by technological limitations and inadequate infrastructure.

Focusing specifically on Nigeria, Okoye et al. (2021) utilized the Autoregressive Distributed Lag (ARDL) method for the period 1981–2017. By incorporating financial development and capital formation into their model, they confirmed the energy-

led growth hypothesis, demonstrating that energy consumption is a primary driver of Nigerian economic expansion. Similarly, Musibau et al. (2021) applied a Non-linear ARDL (NARDL) approach (1981–2014) to test the Environmental Kuznets Curve (EKC) hypothesis in Nigeria. Their results supported the EKC framework, showing that while growth initially harms environmental quality—with (CO2) emissions rising by 0.002% for every unit increase in energy use—it eventually contributes to environmental improvement. More recently, Aninwagu and Nyeche (2025) used an Error Correction Model (ECM) for the 1990–2023 period, finding that while renewable energy consumption effectively reduces (CO_2) emissions, traditional economic growth and forest depletion continue to drive carbon output in Nigeria.

Global perspectives further highlight the critical role of electricity infrastructure. Wani et al. (2024) combined ARDL and ARIMA models to analyze Afghanistan's energy landscape (2002–2019), finding a bidirectional long-run relationship that supports the feedback hypothesis. In a study of the BRICS nations (1992–2021), Wahyudi (2024) utilized Fully Modified Ordinary Least Squares (FMOLS) to show that electricity consumption, alongside labor force participation and fixed capital formation, remains a significant determinant of GDP growth across these emerging economies.

2.3 Summary and Gaps in Empirical Literature

The existing body of literature provides substantial evidence regarding the nexus between energy consumption, economic growth, and environmental sustainability. Research consistently shows that both renewable and non-renewable energy sources are vital contributors to GDP growth (Khan et al., 2021; Wahyudi, 2024). Furthermore, studies on the EKC hypothesis suggest that technological adoption can eventually mitigate the environmental degradation caused by early-stage industrialization (Salari et al., 2021; Musibau et al., 2021).

Despite these insights, several critical gaps remain:

There was the over-reliance on GDP as a Metric. While the link between energy and economic growth (GDP) is well-documented, there is a dearth of research explicitly examining energy's impact on broader sustainable development indicators, such as the Human Development Index (HDI). GDP fails to capture the social dimensions of development, including education and healthcare, which are deeply influenced by energy access.

Previous studies came out with inconsistency in Renewable Energy Outcomes. Findings regarding renewable energy in developing regions remain contradictory. Some studies suggest it fosters stability (Gyimah et al., 2022), while others—such as Muazu et al. (2023)—indicate a negative short-term impact due to high transition costs and infrastructure deficits.

There was also the lack of Comprehensive Country-Specific Data for Nigeria. Most studies on Nigeria focus on isolated variables like (CO_2) emissions or total energy use. There is a lack of

integrated research that simultaneously analyzes energy imports, electricity access, and carbon emissions in relation to human welfare outcomes.

This study addresses these gaps by investigating the multidimensional impact of energy consumption—comprising energy imports, electricity access, total energy use, renewable energy, and carbon emissions—on sustainable development in Nigeria. By utilizing the HDI as the dependent variable for the period 1990–2023, this research moves beyond traditional macroeconomic metrics to provide a holistic understanding of how energy policy influences the actual well-being of Nigeria citizens.

3. METHODOLOGY

3.1 Theoretical Framework

This study rests on the Reiner Kümmel's LINEX (Linear-Exponential) production function theory in analysing the impact of energy consumption on sustainable development in Nigeria. The theory incorporates energy as a critical factor in economic production, emphasizing that energy plays a disproportionately large role in driving economic output. The LINEX theory is relevant for Nigeria, a country facing significant energy challenges, including low electricity access, high dependence on fossil fuels, and increasing energy import dependency. By explicitly modelling the nonlinear contribution of energy to economic performance, the LINEX framework offers valuable insights into how different aspects of energy consumption—such as energy imports, electricity access, energy use, renewable energy consumption, and carbon emissions—affect sustainable development, as measured by the Human Development Index (HDI).

The LINEX production function is expressed as:

$$Y = AL^{\alpha}K^{\beta}e^{\gamma E}$$

…… (1)

where:

- Y is the total economic output,
- A is a scaling factor representing technological progress,
- L denotes labor input,
- K represents capital input,
- E is the energy input, and
- α,β, and γ are elasticity parameters reflecting the relative contributions of labor, capital, and energy, respectively.

The distinguishing feature of the LINEX function is the exponential term $e^{\gamma E}$, which signifies that small increases in energy consumption can lead to disproportionately large gains in output. Kümmel et al., 2015). The LINEX model suggests that improving energy efficiency and expanding access to sustainable energy sources can significantly enhance human development outcomes.

The model suggests that reducing energy import dependence, increasing access to electricity, and promoting renewable energy will positively contribute to sustainable development, while excessive carbon emissions may have negative externalities that hinder long-term human development. This aligns with existing literature highlighting the importance of clean energy

transitions for economic sustainability (Stern, 2018; Smil, 2017).

3.2 Model specification

The study adapted the model by Rusiadi et al. (2024). Their model is stated thus:

$LogGE=a_0+a_1log(EmissionCo2)+a_2log(GF)+a_3log(GI)+a_4log(CE)+a_5log(GBS)$------ (2)

where: GE (Green Economy), EmissionCo2, GF (Green Finance), (Green Investment), CE (Energy Consumption), and GBS (Green Business).

This study made several modifications by adopting human development index as a measure of sustainable development, while introducing energy import, access to electricity, energy use, and renewable energy consumption as additional independent variables to capture energy consumption.

Following the theoretical framework based on Reiner Kümmel's LINEX Production Function, the model for this study is specified in the functional form as follows:

$$HDI_t = f(EM_t, AE_t, EU_t, REC_t, CO2_t) \text{ ---------- (3)}$$

The econometric form of the model is specified as:

$$HDI_t = \beta_0 + \beta_1 EM_t + \beta_2 AE_t + \beta_3 EU_t + \beta_4 REC_t + \beta_5 CO2_t + U_t \text{ ---------- (4)}$$

Where:

- **HDI_t** = Human Development Index at time t, representing sustainable development.
- **EM_t** = Energy import at time t, capturing Nigeria's reliance on imported energy. It is expected to have a negative effect on HDI ($\beta_1<0$). Excessive reliance on imported energy can strain the economy, increase production costs, and create external vulnerabilities, reducing resources available for human development initiatives (Shahbaz et al., 2024). However, in the short run, energy imports may support economic activities if domestic energy production is insufficient.
- **AE_t** = Access to electricity at time t, representing the proportion of the population with access to electricity. This is expected to have a positive effect on HDI ($\beta_2>0$). Increased electricity access enhances economic productivity, improves healthcare and education outcomes, and raises overall living standards (Wani et al., 2024).
- **EU_t** = Energy use at time t, reflecting total energy consumption per capita. This is also anticipated to have a positive impact on HDI ($\beta_3>0$), provided that energy is used efficiently. Greater energy

consumption supports industrialization, economic growth, and better living standards. However, inefficient energy use, particularly from non-renewable sources, may contribute to environmental degradation, potentially offsetting its positive impact (Kümmel et al., 2015).

- **REC_t** = Renewable energy consumption at time t, measuring the proportion of total energy derived from renewable sources. This is expected to positively influence HDI ($\beta_4>0$). A shift towards renewable energy reduces environmental degradation and ensures long-term energy sustainability (Gyimah et al., 2022). However, the impact of renewable energy may be limited if infrastructure and investment in the sector are insufficient (Muazu et al., 2023).

- **$CO2_t$** = Carbon emissions at time t, serving as an environmental indicator of sustainability. is expected to have a negative effect on HDI ($\beta_5<0$). High CO_2 emissions contribute to climate change and environmental degradation, which can adversely affect agricultural productivity, health, and overall well-being (Gershon et al., 2024).
- **β_0** = Intercept term, representing the baseline level of sustainable development when all independent variables are zero.
- **$\beta_1,\beta_2,\beta_3,\beta_4,\beta_5$** = Coefficients of the independent variables, measuring their respective effects on sustainable development.
- **U_t** = Error term, capturing unobserved factors that may influence sustainable development.

3.2.1 Description of Variables and Measurements

The description of variables and measurements which shows how the variables of the study is presented in table 3.1

Table 3.1: Operationalization and Measurement of Variables

S/No	Variable Name	Measurement Formula/Annual Aggregate	Source
1	Energy Import (EM)	Annual aggregate energy import (measured in metric tons or TWh)	World Bank, World Development Indicators (WDI))
2	Access to Electricity (AE)	Percentage of the population with access to electricity	World Bank (World Development Indicators (WDI))
3	Energy Use (EU)	Total energy consumption per capita (kg of oil equivalent)	World Bank (World Development Indicators (WDI))
4	Renewable Energy Consumption (REC)	Share of renewable energy in total final energy consumption	World Bank (World Development Indicators (WDI))
5	Carbon Emissions (CO_2)	CO_2 emissions per capita (metric tons)	World Bank (World Development Indicators (WDI))

6	Human Development Index (HDI)	Composite index of life expectancy, education, and income	United Nations Development Programme (UNDP)

(Source: Author's compilation, 2025)

3.3 Estimation Techniques

The variables of the study were tested for the presence of unit root using the Augmented Dickey-Fuller (ADF) test. The outcome of the unit root test (mixed integration orders, I(0) and I(1)) allowed us to carryout the cointegration test using the Bound testing method according to Pesaran, Shin and Smith, (2001). With the presence of long run relationship confirmed by the cointgration test, we carried out an error correction model. To ensure model reliability, diagnostic tests—including Breusch-Godfrey serial correlation test, Breusch-Pagan heteroskedasticity test, and Jarque-Bera normality test—were carried out too. The model was estimated using the Auto Regressive Distributed Lag (ARDL) model, developed by Pesaran et al. (2001) for analyzing both short-run and long-run relationships among time-series variables. By distinguishing between short-run adjustments and long-run equilibrium relationships, the ARDL model provides a more comprehensive understanding of how energy consumption affects sustainable development over different time horizons.

The ARDL model for examining the impact of energy consumption on sustainable development in Nigeria is specified as follows:

$$\Delta HDI_t = \alpha_0 + \sum_{i=1}^{p} \alpha_1 \Delta HDI_{t-i} + \sum_{j=0}^{q} \alpha_2 \Delta EM_{t-j} + \sum_{k=0}^{r} \alpha_3 \Delta AE_{t-k} + \sum_{l=0}^{s} \alpha_4 \Delta EU_{t-l} + \sum_{m=0}^{v} \alpha_5 \Delta REC_{t-m} + \sum_{n=0}^{w} \alpha_6 \Delta CO2_{t-n}$$

$$+\lambda_1 HDI_{t-1} + \lambda_2 EM_{t-1} + \lambda_3 AE_{t-1} + \lambda_4 EU_{t-1} + \lambda_5 REC_{t-1} + \lambda_6 CO2_{t-1} + \varepsilon_t \quad \text{----- (5)}$$

Where all the variables are as defined above.
Δ = First difference operator.

- α_0 = Constant term.
- $\alpha_1,\alpha_2,\alpha_3,\alpha_4,\alpha_5,\alpha_6$ = Short-run coefficients of the lagged differenced variables.
- $\lambda_1,\lambda_2,\lambda_3,\lambda_4,\lambda_5,\lambda_6$ = Long-run coefficients of the lagged level variables.
- **p,q,r,s,v,w** = Lag lengths for each variable.
- ε_t = Error term, capturing unobserved factors affecting HDI, assumed to be independently and identically distributed (i.i.d).

3.4 Sources of Data

The secondary data for this study were sourced from the World Bank's World Development Indicators (WDI), and United Nations Development Programme (UNDP).

4. PRESENTATION AND DISCUSSION OF RESULT

4.1 Descriptive statistics

Table 4.1 Descriptive statistics

	HDI	EM	AE	EU	REC	CO2
Mean	0.510941	-234.5769	48.07080	303.9508	84.10882	43.97789
Maximum	0.595000	-66.28810	61.20000	376.0699	88.60000	76.39594
Minimum	0.438000	-333.3996	27.30000	256.9182	77.30000	2.188869
Std. Dev.	0.049911	81.99537	8.410516	30.82018	3.009416	24.81028
Skewness	0.135222	0.659683	-0.390372	0.424636	-0.416260	-0.411489
Kurtosis	1.588485	2.166814	2.424172	2.270300	2.144301	1.864417
Jarque-Bera	2.926145	3.449479	1.333280	1.776112	2.019190	2.786359
Probability	0.231524	0.178219	0.513431	0.411455	0.364367	0.248285

Source: Author's computation from data (2025)

The descriptive statistics for the variables under study are summarized in Table 4.1. The Human Development Index (HDI) exhibits a mean value of 0.511, signifying moderate developmental progress over the sampled period. A low standard deviation (0.0499) suggests consistent, incremental growth rather than volatile shifts. Furthermore, the distribution is relatively symmetric (skewness = 0.135) and mesokurtic (kurtosis = 1.588); the Jarque-Bera statistic (p = 0.2315) confirms that HDI does not significantly depart from a normal distribution.

Energy Imports (EM), measured as a percentage of total energy use, yield a negative mean of -234.58%, corroborating Nigeria's position as a persistent net energy exporter. This variable displays the highest volatility in the dataset (SD = 81.99), with values fluctuating between -333.40% and -66.29%. The positive skewness (0.66) and modest kurtosis (2.17) indicate a right-tailed, platykurtic distribution, reflecting periodic contractions in net export volumes.

Access to Electricity (AE) shows a mean coverage of 48.07%, highlighting a substantial deficit in universal electrification. The standard deviation (8.41) reflects moderate inter-annual variation. A negative skewness (-0.39) suggests a concentration of data points toward the lower end of the scale, particularly in earlier periods, while a kurtosis of 2.42 and a Jarque-Bera p-value of 0.5134 indicate a normal distribution.

Energy Use per capita (EU) averaged 303.95 kg of oil equivalent with relatively stable dispersion (SD = 30.82). The positive skewness (0.42) points to intermittent spikes in consumption—likely aligned with periods of economic expansion—while the kurtosis (2.27) suggests a near-normal distribution.

Renewable Energy Consumption (REC) maintains a high mean of 84.11%, illustrating the continued structural reliance on traditional biomass. The low standard deviation (3.01) indicates negligible structural change over time. The distribution is modestly left-skewed (-0.42) and platykurtic (2.14), consistent with the

entrenched nature of renewable energy in the domestic mix.

Carbon Dioxide (CO_2) Emissions per capita average 43.98 metric tons, though with significant variance (SD = 24.81) that reflects an inconsistent energy transition path. The negative skewness (-0.41) suggests a recent trend toward lower per capita emissions, particularly after 2010. Finally, Figure 4.1 visually illustrates the aggregate normality of these variables.

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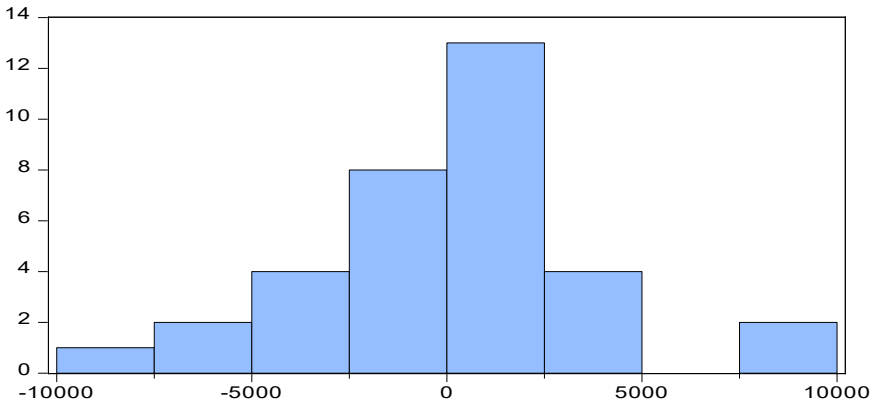


Series: Residuals	
Sample 1990 2023	
Observations 34	
Mean	1.03e-11
Median	574.1466
Maximum	8118.864
Minimum	-9066.749
Std. Dev.	3534.660
Skewness	-0.099240
Kurtosis	3.695801
Jarque-Bera	0.741672
Probability	0.690157

Figure 2 Aggregate Normality Graph
Source: Author's computation from data (2025)

From Figure 2, the p.value of 0.6902 is greater than 0.05, thus it is inferred that on aggregate the variables of the study are normally distributed.

4.2 Trend Analysis

Figures 3 to 8 present charts depicting the yearly trend of the variables of the study

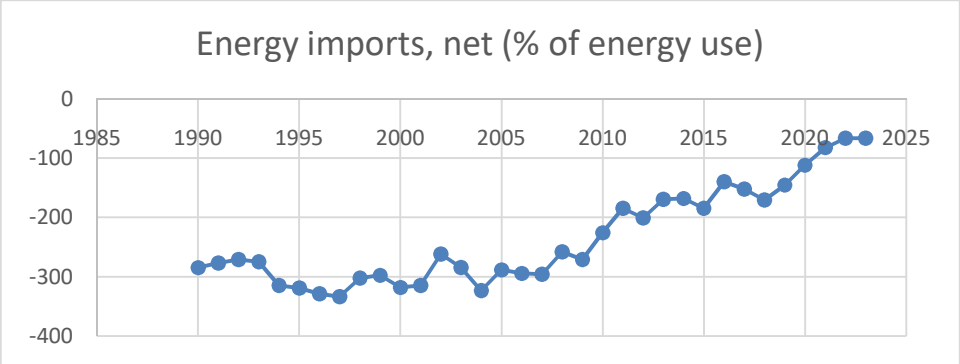


Figure 3 Trend Analysis of Energy Import
Source: Author's computation from data (2025)

Figure 3 reveals that Nigeria consistently maintained a negative net energy import percentage from 1990 to 2023, indicating that it was a net exporter of energy throughout this period. However, a gradual but persistent decline is observed from 2010 onward, with net energy exports dropping to -225.74% in 2010 and further declining to -66.29% by 2023. This trend suggests a decline in import.

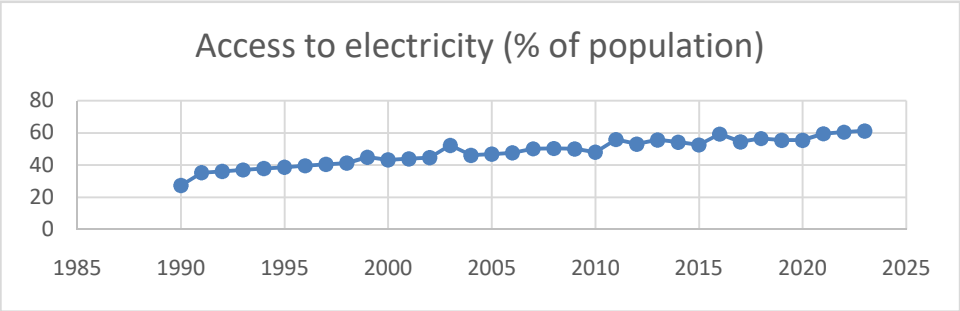


Figure 4 Trend Analysis of Access to Electricity
Source: Author's computation from data (2025)

Figure 4 reveals a gradual but uneven improvement in access to electricity in Nigeria from 1990 to 2023. The early 2000s saw fluctuating progress, with a notable peak of 52.2% in 2003 followed by a dip to 46.1% in 2004, suggesting infrastructural or policy challenges. However, from 2006 onwards, access generally improved, with significant increases observed in 2011 (55.9%) and 2016 (59.3%). By 2023, the percentage of the population with access to electricity had reached 61.2%. This overall upward trend reflects ongoing efforts to improve energy access.

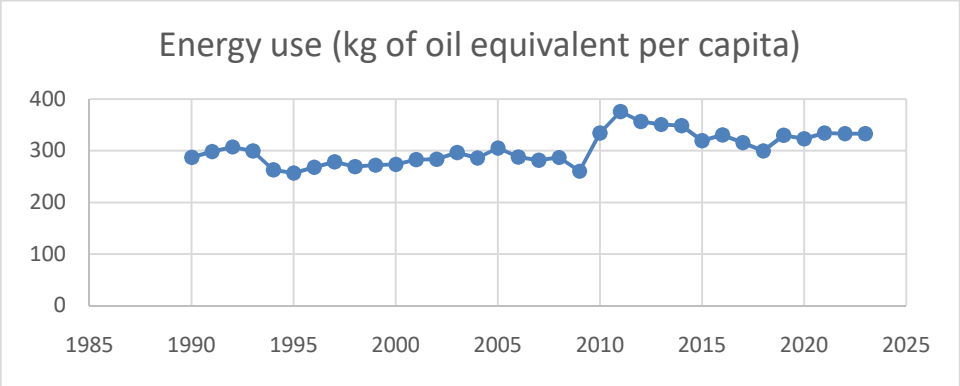
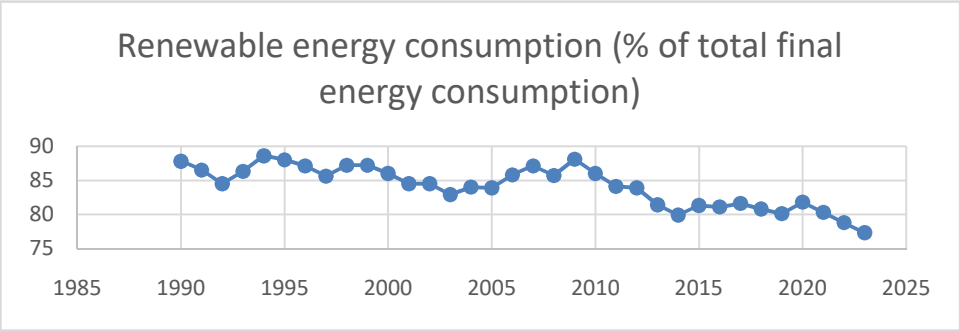


Figure 5 Trend Analysis of Energy Use
Source: Author's computation from data (2025)

Figure 5 reveals that energy use per capita in Nigeria, measured in kilograms of oil equivalent, has experienced fluctuating trends between 1990 and 2023. Starting at 287.48 kg in 1990, energy use rose moderately in the early 1990s, peaking at 307.49 kg in 1992. Although slight declines were observed after 2012, the general trend from 2010 onward indicates higher energy consumption levels compared to earlier decades. By 2023, energy use stabilized at 333.06 kg per capita, suggesting a more sustained, though modest, level of energy demand, shaped by demographic growth, urbanization, and gradual industrial expansion.

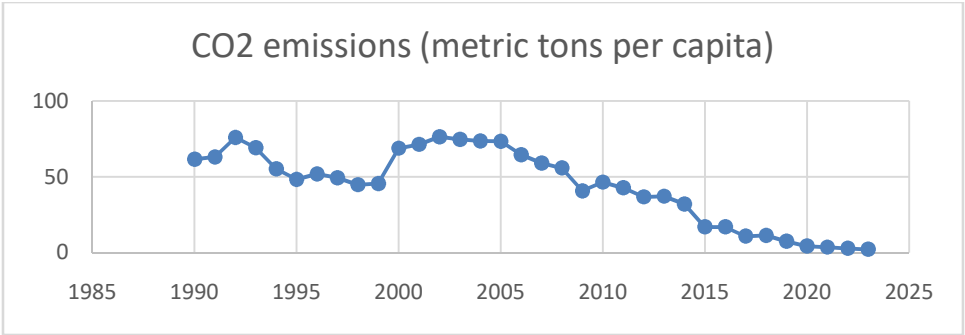
Figure 4.5 Trend Analysis of Renewable Energy Consumption



Source: Author's computation from data (2025)

Figure 4.5 reveals that renewable energy consumption as a percentage of total final energy consumption in Nigeria has remained relatively high but shows a gradual declining trend from 1990 to 2023. However, beginning in the early 2010s, a more noticeable decline set in, with renewable energy use falling to 79.9% in 2014 and further to 77.3% by 2023. This downward trend suggests a slow transition from traditional biomass to modern energy sources.

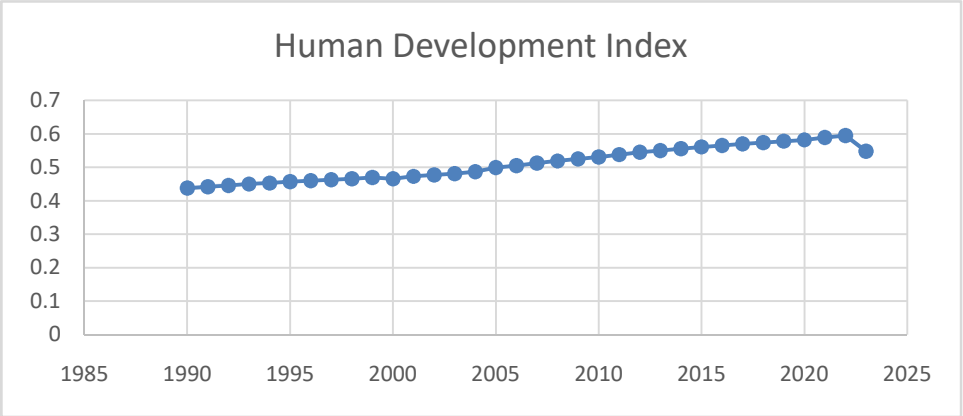
Figure 4.6 Trend Analysis of Energy Carbon Emissions



Source: Author's computation from data (2025)

Figure 4.6 reveals a significant decline in Nigeria's per capita CO_2 emissions from 1990 to 2023, reflecting both structural and economic transformations. In 1990, CO_2 emissions stood at 61.60 metric tons per capita and peaked in 2002 at 76.40 metric tons, coinciding with periods of industrial activity and fossil fuel reliance. However, from the mid-2000s onward, emissions began a sharp downward trajectory, declining to just 2.19 metric tons per capita by 2023. This reduction may be attributed to a combination of factors including

Figure 4.7 Trend Analysis of Sustainable Development (HDI)



Source: Author's computation from data (2025)

Figure 4.7 reveals a generally upward trend in Nigeria's Human Development Index (HDI) from 1990 to 2022, indicating gradual improvements in key dimensions of human development such as life expectancy, education, and income. Starting at 0.438 in 1990, the HDI steadily increased over the decades, reaching 0.595 in 2022, reflecting policy efforts in expanding access to education, healthcare, and economic opportunities. However, the index experienced a significant drop to 0.548 in 2023, potentially pointing to recent socio-economic disruptions such as inflationary pressures, insecurity, declining living standards, or setbacks in education and healthcare delivery.

4.3 Unit Root Test

Table 4.2 Unit Root Tests

	LEVEL			FIRST DIFFERENCE			Order of Integration
Variable	**ADF (Level)**	**95% Critical Value**	**Remark**	**ADF (1st Diff.)**	**95% Critical Value**	**Remark**	
HDI	-0.8469	-3.552973	Not Stationary	-4.1375	-3.557759	Stationary	I(1)
EM	-2.0653	-3.552973	Not Stationary	-6.5597	-3.562882	Stationary	I(1)
AE	-6.7523	-3.552973	Stationary			Stationary	I(0)
EU	-2.7875	-3.552973	Not Stationary	-5.7685	-3.557759	Stationary	I(1)
REC	-2.2952	-3.552973	Not Stationary	-5.6908	-3.557759	Stationary	I(1)
CO2	-1.6284	-3.552973	Not Stationary	-4.9838	-3.557759	Stationary	I(1)

Source: Author's computation from data (2025)

The results of the unit root tests presented in Table 4.2 reveal a mixed order of integration among the variables under consideration. At level, only Access to Electricity (AE) is stationary. In contrast, the remaining variables—Human Development Index (HDI), Energy Imports (EM), Energy Use per Capita (EU), Renewable Energy Consumption (REC), and Carbon Dioxide Emissions (CO_2)—are non-stationary at level, but were stationary at first differenced,

integrated of order one, I(1). This combination of I(0) and I(1) variables, satisfies the preconditions for employing the Bound testing method of cointegration.

4.4 Correlation Test

Table 4.3 Correlation Matrix and Test for Multicollinearity (Variance Inflation Factor {VIF})

	HDI	**EM**	**AE**	**EU**	**REC**	**CO2**	**VIF**
HDI	1.000000						
EM	0.780082*	1.000000					1.236436
AE	0.823756*	0.805643*	1.000000				1.308326
EU	0.691139*	0.770850*	0.648562*	1.000000			3.224822
REC	-0.789427*	-0.764736*	-0.801619*	-0.713373*	1.000000		1.163440
CO2	-0.741917*	-0.766682*	-0.723148*	-0.513865*	0.694725*	1.000000	2.409367

* Sig @ 1%; * * Sig @ 5%

Source: Author's computation from data (2025)

The correlation matrix in Table 4.3 indicates several statistically significant relationships among the study variables, all significant at the 1% level. Notably, Human Development Index (HDI) is strongly and positively correlated with all the variables with the exception of Renewable Energy Consumption and Carbon Dioxide Emissions having a strong negative correlation with them. In assessing multicollinearity using the Variance Inflation Factor (VIF), none of the variables exceed the conventional threshold of 10, indicating that multicollinearity is not a serious concern in this model.

Table 4.4 Diagnostics Test: Serial, Heteroskedasticity, and Specification Tests

Breusch-Godfrey Serial Correlation LM Test:			
F-statistic	1.329914	Prob. F(2,26)	0.2819
Obs*R-squared	3.155432	Prob. Chi-Square(2)	0.2064
Heteroskedasticity Test: Breusch-Pagan-Godfrey			
F-statistic	0.968960	Prob. F(5,28)	0.4536
Obs*R-squared	5.015198	Prob. Chi-Square(5)	0.4140
Ramsey RESET Test: Specification: HDI EM AE EU REC CO2 C			
t-statistic	1.958689	27	0.0606
F-statistic	3.836463	(1, 27)	0.0606
Likelihood ratio	4.517274	1	0.0336

Source: Author's computation from data (2025)

The diagnostic tests presented in Table 4.4 showed that the Breusch-Godfrey Serial Correlation LM test results indicate the absence of serial correlation in the residuals. With a Prob. F(2,26) value of 0.2819 and a Prob. Chi-Square(2) of 0.2064, at the 5% significance level. Similarly, the Breusch-Pagan-Godfrey heteroskedasticity test confirms homoscedasticity in the model given the F-statistic (0.9689) with p-value of (0.4536) and the Chi-Square probability (0.4140) that are both statistically insignificant, indicating constant variance of the error terms across observations.

The Ramsey RESET test for functional form misspecification produces a mixed result. Although the F-statistic (3.836) and t-statistic (1.959) yield p-values slightly above the conventional 5% threshold (0.0606), the likelihood ratio test is significant at the 5% level (p = 0.0336), suggesting a mild indication of misspecification. However, given that two out of the three test statistics are statistically insignificant, the model can be considered reasonably well-specified.

4.5 The Autoregressive Distributed Lag (ARDL) and Bounds testing approach

The Autoregressive Distributed Lag (ARDL) Bounds testing approach was adopted for the cointegration test while the Autoregressive Distributed Lag (ARDL) model was adopted for the analysis.

Table 4.5: ARDL Bounds Test Result

F-Bounds Test		Null Hypothesis: No levels relationship		
Test Statistic	Value	Signif.	I(0)	I(1)
F-statistic	6.462504	10%	1.92	2.89
K	7	5%	2.17	3.21
		2.5%	2.43	3.51
		1%	2.73	3.9

Source: Author's computation from data (2025)

From Table 4.5 the ARDL Bounds results showed the presence of long run relationship given the calculated F-statistic of 6.4625 which is significantly higher than both the upper and lower critical bounds at all levels of significance

Table 4.6: ARDL Long Run Form

Dependent Variable: D(HDI)
Selected Model: ARDL(2, 0, 2, 2, 2, 2, 2, 2)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	52291.01	11497.47	4.548045	0.0011
HDI(-1)*	-0.959790	0.233167	-4.116323	0.0021
EM(-1)	-12015.54	5254.902	-2.286539	0.0453
AE(-1)	11492.54	3244.371	3.542301	0.0053
EU(-1)	0.008431	0.020249	0.416378	0.6859
REC(-1)	-66.19408	72.31135	-0.915404	0.3815
CO2(-1)	-1909.112	582.7716	-3.275918	0.0083
D(HDI(-1))	0.401812	0.237825	1.689532	0.1220
D(EM)	-11700.10	3467.574	-3.374145	0.0071
D(EM(-1))	10105.90	2807.239	3.599944	0.0048
D(AE)	10369.72	3530.105	2.937510	0.0148
D(AE(-1))	-9173.228	2841.623	-3.228165	0.0090
D(EU)	0.012970	0.009249	1.402250	0.1911
D(EU(-1))	-0.012672	0.009494	-1.334631	0.2116
D(REC)	-46.87730	98.59041	-0.475475	0.6447

D(REC(-1))	222.6789	105.1774	2.117175	0.0603
D(CO2)	-607.7367	348.4068	-1.744331	0.1117
D(CO2(-1))	833.7242	277.2504	3.007116	0.0132
Long Run Estimation Results				
Variable	Coefficient	Std. Error	t-Statistic	Prob.
EM	-12518.93	6877.089	-1.820382	0.0987
AE	11974.01	3820.862	3.133852	0.0106
EU	0.008784	0.021109	0.416149	0.6861
REC	-68.96725	78.82063	-0.874990	0.4021
CO2	-1989.093	393.7147	-5.052118	0.0005
C	54481.72	10179.72	5.351986	0.0003
EC = HDI - (-3893.0126* EM + 11974.0132*AE + 0.0088 *EU -68.9673*REC -1989.0933*CO2 + 54481.7243)				

NB: *Significant at 10%, **Significant at 5%, and ***Significant at 1%.
Source: Author's computation from data (2025)

The ARDL long-run estimation in Table 4.6 reveals that among the long-run coefficients, access to electricity (AE) has a positive and statistically significant effect on HDI at the 5% level (coefficient = 11,974.01; p = 0.0106), indicating that improvements in electricity access are strongly associated with better human development outcomes. Similarly, carbon dioxide emissions (CO_2) show a significant negative long-run impact on HDI (coefficient = -1,989.09; p = 0.0005), suggesting that increased emissions are detrimental to sustainable development. Energy imports (EM) also have a negative effect on HDI, although significant at the 10% level (coefficient = -12,518.93; p = 0.0987), implying that reductions in net energy exports may hinder long-term development. In contrast, energy use per capita (EU) and renewable energy consumption (REC) are statistically insignificant in the long-run, suggesting their limited direct impact on HDI over time.

The short-run dynamics reinforce the significance of some energy indicators. Short-run changes in access to electricity (D(AE)) and its lagged value both showed statistically significant effects on HDI, though in opposite directions, reflecting potential transitional fluctuations in electrification's impact. Changes in energy imports (D(EM) and D(EM(-1))) also significantly influence HDI in the short term, highlighting the sensitivity of development outcomes to fluctuations in energy trade. Furthermore, the short-run effect of lagged carbon emissions (D(CO2(-1))) is positive and significant, though this might capture temporary growth-related emissions rather than sustained environmental degradation. The lag of HDI (HDI(-1)), is negative and statistically significant (coefficient = -0.9598; p =

0.0021), indicating that previous levels of development significantly impact on current level.

Table 4.7: ARDL Error Correction Regression- Short Run Estimates

Dependent Variable: D(HDI)
Selected Model: ARDL(2, 0, 2, 2, 2, 2, 2, 2)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
D(HDI(-1))	0.401812	0.097747	4.110747	0.0021
D(EM)	-11700.10	1514.281	-7.726504	0.0000
D(EM(-1))	10105.90	1621.206	6.233572	0.0001
D(AE)	10369.72	1873.483	5.534994	0.0002
D(AE(-1))	-9173.228	1636.710	-5.604676	0.0002
D(EU)	0.012970	0.003398	3.816998	0.0034
D(EU(-1))	-0.012672	0.003935	-3.220325	0.0092
D(REC)	-46.87730	44.46678	-1.054209	0.3166
D(REC(-1))	222.6789	39.14179	5.689032	0.0002
D(CO2)	-607.7367	129.1953	-4.704017	0.0008
D(CO2(-1))	833.7242	150.3492	5.545251	0.0002
CointEq(-1)*	-0.959790	0.093803	-10.23194	0.0000
R-squared: 0.852911				
Adjusted R-squared: 0.818902				
Durbin-Watson stat: 1.696623				
* p-value incompatible with t-Bounds distribution.				

Source: Author's computation from data (2025)

The short-run dynamics presented in Table 4.7 from the ARDL error correction regression indicate strong and statistically significant relationships between changes in energy-related variables and human development (HDI) in Nigeria. Most first-differenced variables, including energy imports (D(EM), D(EM(-1))), access to electricity (D(AE), D(AE(-1))), energy use (D(EU), D(EU(-1))), and carbon emissions (D(CO2), D(CO2(-1))) are all significant at the 1% level, demonstrating their immediate impact on HDI. Notably, energy imports and access to electricity have alternating positive and negative effects across lags, highlighting short-term volatility in their influence. Renewable energy consumption shows mixed effects but is largely insignificant in the current period ($p = 0.3166$), although its lagged value is positive and significant, indicating a delayed benefit. The error correction term (CointEq(-1)) is highly significant and negative (-0.9598; $p < 0.01$), confirming a strong adjustment toward long-run equilibrium at a correction speed of approximately 96% per year. The R-squared (0.85) and further confirm the model's strong explanatory power and absence of autocorrelation, reinforcing the robustness of the short-run estimates.

Discussion of Findings

The analysis revealed that energy imports (EM) have a significant negative impact on Nigeria's HDI in both the short and long run, with p-values of 0.0000 (short run) and

0.0987 (long run), indicating that increased dependence on energy imports undermines sustainable human development. This aligns with the findings of Shahbaz et al. (2024), who observed that energy imports negatively influence economic performance in 15 energy-importing countries due to their strain on fiscal resources, current account deficits, and heightened exposure to global energy market volatility. Thus, underscoring the importance of enhancing domestic refining capacity and energy self-sufficiency to foster long-term human development.

The outcome of energy use (EU) showed a statistically insignificant impact in the long run ($p = 0.6861$), but short-run dynamics were highly significant (p-values < 0.01), indicating that changes in energy use have immediate, though transient, effects on HDI. This finding resonates with the work of Okoye et al. (2021), who found that energy consumption plays a vital role in driving economic development in Nigeria, but with a delayed and structurally constrained response. The positive short-run impact likely reflects Nigeria's reliance on inefficient and outdated energy systems, as highlighted by Onuh et al. (2024), who noted substantial transmission losses and infrastructure deficiencies that limit long-term benefits. However, to translate this into sustainable development gains, Nigeria must address its structural energy inefficiencies through modernization and policy reform.

It was also revealed from the result that renewable energy consumption (REC) does not have a statistically significant impact on HDI in either the short run ($p = 0.3166$) or the long run ($p = 0.4021$). This finding is in diverges from the broader consensus in the literature, including Ullah et al. (2021) who found that renewable energy consumption contributes positively to sustainable development and economic growth in various global and African contexts. However, this contrast can be explained by Nigeria's limited integration of renewable energy into its national energy mix, as noted by IRENA (2020). Structural barriers such as weak policy support, high initial costs, and underdeveloped infrastructure hinder large-scale adoption, rendering the impact of renewables on development negligible in the short to medium term. Moreover, as Muazu et al. (2023) argue, renewable energy's developmental benefits in Africa are often constrained by technical and economic limitations. Thus, while renewables hold long-term potential, their current underutilization in Nigeria explains the lack of statistically significant influence on HDI in this study.

The analysis found that carbon emissions (CO_2) have a significant and negative long-run impact on HDI ($p = 0.0005$), reaffirming the detrimental effects of environmental degradation on human development. The short-run results also show significant effects ($p < 0.01$), further aligning with Rehman et al. (2022), who identified a strong association between rising emissions and economic-environmental trade-offs in developing countries. These findings echo the conclusions of Musibau et al. (2021) and Salari et al. (2021) that energy-induced emissions undermine environmental sustainability and quality of life. This also supports the Environmental Kuznets Curve hypothesis. Therefore, the results emphasize the urgency for Nigeria to implement comprehensive carbon mitigation strategies, including energy diversification,

environmental regulation, and public awareness campaigns, to reconcile development with ecological preservation.

4.6 Short-Run Dynamics and Error Correction Model

The short-run estimates derived from the ARDL Error Correction Model (Table 4.7) reveal statistically significant relationships between energy-related fluctuations and the Human Development Index (HDI) in Nigeria. Most first-differenced variables—specifically energy imports (\(D(EM)\)), access to electricity (\(D(AE)\)), energy use (\(D(EU)\)), and carbon emissions ($D(CO_2)$—are significant at the 1% level, suggesting that these factors exert an immediate impact on human development. Notably, energy imports and electricity access exhibit alternating coefficients across lags, indicating short-term volatility in their influence on HDI. While the current-period effect of renewable energy consumption (REC) is statistically insignificant ($p = 0.3166$), its lagged value is positive and significant, suggesting a gestation period before the developmental benefits of renewables are realized.

The Error Correction Term (CointEq(-1) is highly significant and carries the expected negative sign (-0.9598); ($p < 0.01$). This confirms the existence of a long-run relationship among the variables and indicates a rapid speed of adjustment; approximately 96% of the disequilibrium from the previous year is corrected within the current year. The (R^2) value (0.85) further demonstrates the model's robust explanatory power and its reliability for policy inference.

Discussion of Findings

The empirical results indicate that energy imports (EM) have a significant negative impact on Nigeria's HDI in both the short and long run ($p < 0.01$) and ($p < 0.10$), respectively). This suggests that a heavy reliance on imported energy undermines sustainable development. This finding is consistent with Shahbaz et al. (2024), who argue that energy import dependence drains fiscal reserves, exacerbates current account deficits, and increases vulnerability to global price shocks. Consequently, enhancing domestic refining capacity is critical for stabilizing the macroeconomic environment necessary for human development.

Regarding energy use (EU), the long-run impact was found to be statistically insignificant ($p = 0.6861$), whereas short-run dynamics were highly significant (\($p < 0.01$\)). This implies that while energy consumption triggers immediate developmental gains, these effects are transient and fail to translate into long-term structural improvements. This aligns with Okoye et al. (2021), who noted that Nigeria's energy-development nexus is often constrained by structural inefficiencies. As Onuh et al. (2024) observed, substantial transmission losses and aging infrastructure likely prevent current energy consumption patterns from yielding sustainable long-term benefits.

A notable departure from existing literature is the statistically insignificant impact of renewable energy consumption (REC) on HDI ($p > 0.10$) for both terms). While scholars such as Ullah et al. (2021) advocate for the positive role of renewables in African development, the Nigerian case

appears constrained by low penetration levels. This lack of significance is likely attributable to structural barriers identified by IRENA (2020), including weak policy frameworks and high capital costs. As Muazu et al. (2023) suggest, until renewable energy reaches a critical threshold in the national energy mix, its contribution to aggregate development metrics remains negligible.

Finally, carbon emissions (CO_2) exert a significant and negative long-run influence on HDI ($p = 0.0005$). This reaffirms the Environmental Kuznets Curve (EKC) hypothesis and aligns with the findings of Rehman et al. (2022) and Musibau et al. (2021), who argue that environmental degradation directly erodes quality of life. The result underscores an urgent need to decouple economic and human development from high-carbon energy sources.

4.7 Policy Implication

The critical importance of formulating an integrated energy policy that prioritizes both human development and environmental sustainability has been underscored from this study. Given the significant positive impact of access to electricity on the Human Development Index (HDI), Nigerian policymakers must accelerate efforts to expand electricity access, particularly in underserved rural and peri-urban areas. This requires substantial investment in national grid extension, off-grid renewable solutions such as mini-grids and solar home systems, and the modernization of aging transmission infrastructure. Moreover, the short-run benefits observed from increased energy use suggest that enhancing energy efficiency through technological upgrades, demand-side management, and incentives for industrial modernization can yield immediate gains in education, health, and economic productivity. Reducing technical and commercial losses within the energy sector will also be essential to improving the reliability and affordability of electricity services, which are central to achieving inclusive human development outcomes.

Additionally, the negative long-run impact of carbon emissions and energy imports on HDI calls for urgent policy action to transition Nigeria toward a cleaner and more self-sufficient energy system. Policymakers should implement stringent environmental regulations, phase out inefficient fossil fuel subsidies, and promote investments in domestic refining capacity to reduce dependence on imported petroleum products. Simultaneously, the government must scale up the deployment of renewable energy technologies by creating enabling environments—through fiscal incentives, clear regulatory frameworks, and public-private partnerships—to attract investment and lower the entry barriers for green energy adoption. To align national energy strategies with sustainable development goals, an integrated policy approach is needed—one that coordinates energy, environmental, and development planning to achieve long-term resilience, energy security, and improved quality of life for the Nigerian population.

5. SUMMARY, CONCLUSION, AND RECOMMENDATIONS

5.1 Summary

This study empirically investigated the impact of energy dynamics—specifically energy imports (EM), access to electricity

(AE), energy use per capita (EU), renewable energy consumption (REC), and carbon dioxide emissions (CO_2)—on sustainable development in Nigeria between 1990 and 2023. Utilizing the Human Development Index (HDI) as a proxy for development, the research employed the Autoregressive Distributed Lag (ARDL) framework to account for the mixed integration order of the variables and to delineate both short- and long-run relationships.

The empirical results indicate that energy imports exert a significant negative pressure on HDI, particularly in the short run, highlighting the economic vulnerability inherent in Nigeria's reliance on foreign petroleum products. Conversely, access to electricity emerged as a consistent and potent driver of human development across both time horizons. While energy use per capita yielded significant short-run benefits, its long-run impact was negligible, suggesting that current consumption patterns support immediate economic activities rather than structural developmental shifts. Furthermore, renewable energy consumption remains statistically insignificant, reflecting its marginal role in the current national energy mix. Finally, the study found a robust negative correlation between (CO_2) emissions and HDI, underscoring the high developmental costs of environmental degradation.

Conclusion

The study concludes that Nigeria's path to sustainable human development is inextricably linked to its energy architecture. The findings demonstrate that while electricity access acts as a catalyst for human welfare, the nation's reliance on energy imports and high-carbon emission pathways serves as a significant structural drag on the HDI. The disconnect between renewable energy consumption and development outcomes further underscores a critical policy gap in the transition to a green economy. Ultimately, the results suggest that for Nigeria to achieve meaningful improvements in human development, it must transition from a volatile, import-dependent energy model toward a domestic, low-carbon, and electricity-centric framework

5.3 Recommendations

Based on the empirical findings, the following recommendations are proposed:

i. Enhance Domestic Refining Capacity: To mitigate the adverse effects of energy imports, the Federal Government should prioritize the rehabilitation of local refineries and incentivize private-sector participation in modular refining. Reducing the fiscal drain of petroleum imports will redirect essential capital toward social sectors such as health and education.

ii. Accelerate Universal Electrification: Given the positive impact of electricity access on HDI, policymakers should adopt a dual approach: expanding the national grid for industrial hubs while aggressively deploying decentralized renewable mini-grids and solar home systems for rural and underserved peri-urban populations.

iii. Institutionalize Energy Efficiency: To translate short-run energy use into long-run developmental gains, the government should implement an Energy Efficiency Policy. This includes setting standards for industrial

equipment, providing tax rebates for energy-efficient technologies, and conducting national awareness campaigns on sustainable consumption.

iv. Scale Up Renewable Energy Integration: To move beyond the current insignificant impact of renewables, Nigeria must create a more attractive investment climate. This involves streamlining licensing for IPPs (Independent Power Producers), providing concessional financing for green projects, and setting mandatory renewable energy targets for the national grid.

v. Enforce Environmental Regulations: To curb the negative impact of carbon emissions, the Ministry of Environment should enforce stricter emission limits and consider a carbon pricing framework. Transitioning toward cleaner energy sources is essential to protect public health and ensure that economic growth does not come at the expense of human welfare.

5.4 Contribution to Knowledge

This study contributes to the literature by providing a multi-dimensional analysis of the energy-development nexus in Nigeria, moving beyond traditional GDP-centric models to focus on the Human Development Index (HDI). It offers a nuanced temporal distinction between the short-run and long-run effects of energy imports and carbon intensity, which are often conflated in broader African studies. Furthermore, by identifying the statistical insignificance of renewables at current levels, the study provides a critical empirical baseline for future research into the "threshold effects" required for green energy to catalyze human development in resource-dependent economies.

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