ENERGY CONSUMPTION AND SUSTAINABLE GROWTH IN NIGERIA: A Time Series Analysis

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ABSTRACT

Energy resources are vital for Nigeria's economic growth. However, energy usage also has implications for sustainable development via resource sustainability and environmental safety. Thus, it is imperative to assess the sustainability of any energy-induced growth in an economy. This study, therefore, uses a simple but robust estimation technique to examine the impact of energy usage on sustainable development in Nigeria using time series data spanning 1990 to 2023. The study estimates two models, including an aggregated model and a model that disaggregates energy consumption into renewable and non-renewable energy to determine which energy type has the most profound impact on sustainable development in the country. The findings show that aggregated energy consumption cannot significantly drive sustainable development because of the disproportionate dominance of non-renewable energy in the total energy profile of the country. The results further show that non-renewable energy sources are detrimental to sustainable development, while renewable energy sources can propel the country toward sustainable development. This study, therefore, advocates that Nigeria should rejig its energy mix through policies to increase the proportion of renewable energy in its total energy mix.

Keywords: non-renewable energy, renewable energy, sustainable development, ARDL, Nigeria

JEL classification: Q01, Q43, Q56, C32, O13, O55

1. Introduction

Attaining sustainable economic growth has emerged as a central global development challenge, particularly in the context of rising energy demand, environmental degradation, and climate change. While energy consumption remains a critical driver of economic growth, its long-term sustainability depends on how energy resources are produced, consumed, and managed. The global energy mix is dominated disproportionately by fossil fuels, with significant contributions to greenhouse gas emissions, resource depletion, and ecological stress, thereby raising concerns about the compatibility of energy-led growth with sustainable development objectives. Consequently, policymakers and researchers increasingly emphasize the need to evaluate the drivers of growth, especially energy, within a sustainability framework that balances economic performance with environmental protection.

In developing economies, these concerns are more pronounced due to rapid population growth, increasing urbanization, and rising energy needs. Many countries in Africa, despite being richly endowed with energy resources, continue to depend largely on non-renewable energy sources to fuel growth, thereby exposing their economies to environmental risks, energy insecurity, and macroeconomic volatility. The challenge for these economies is not merely to grow, but to achieve growth that is resilient, inclusive, and environmentally sustainable.

Nigeria presents a compelling case in this regard. With a gross domestic product (GDP) of 550.65 billion (at constant US$) in 2023, Nigeria is the largest economy on the African continent (World Bank, 2024). Central to this economy is its energy sector, including a vibrant crude oil subsector. The country is Africa's major gas user and producer, accounting for two-thirds of Africa's energy endowment. For instance, Nigeria had a proven oil reserve of 36.9 billion barrels as of the end of 2020, making it Africa's second-largest oil-rich nation, second only to Libya (British Petroleum, 2024). With a proven reserve of 5.5 trillion cubic meters at the end of 2022, Nigeria is also the 10th largest natural gas-endowed country in the world (British Petroleum, 2024). The country outperforms other African nations in terms of conventional energy reserves. Nigeria is presently undergoing significant power sector changes, including proposals for electrification. The country is among the member nations of the Organization of Petroleum Exporting Countries (OPEC), and is well-positioned to become a behemoth in the emerging energy transition regime, given its over 200 million people and enormous energy resources. Apart from creating employment, the energy sector is also the biggest earner of foreign exchange in the country, making it the backbone of Nigeria's economy.

However, despite the importance of energy in Nigeria's economic growth process, there are question marks on the sustainability of such growth. This is because Nigeria's economic dependence on the energy sector also makes it susceptible to volatility, as fluctuations in global energy markets are dynamically linked to instability in domestic financial markets, including foreign exchange and stock returns, all of which add to the macroeconomic risk of the country's growth process (Umoru et al., 2025). Furthermore, fossil fuels disproportionately dominate Nigeria's energy profile. Between 1980 and 2022, Nigeria produced a total of 199.57 quad (BTU) of energy, and 198.74 quad (BTU) or 99.58% was from fossil fuels, including natural gas, oil, and coal, while renewable energy accounted for only 0.83 quad (BTU), representing a meagre 0.42% (Energy Information Administration, 2024). This has serious implications for the country's drive towards the attainment of sustainable development, both in terms of energy security and with respect to environmental safety. Energy security is threatened by the non-renewable nature of fossil fuels, which makes them susceptible to exhaustion. For instance, by the end of 2020, Nigeria's total estimated proven reserves of oil stood at 36.9 billion barrels, with a reserves-to-production (R/P) ratio of 56.1 (British Petroleum, 2024). This implies that the total proven reserves would be exhausted after 56.1 years, provided the production continues at the same rate. Similarly, the proven reserve of natural gas, which stood at 5.5 trillion cubic meters at the end of 2020, was projected to be exhausted in a century if the current reserve-to-production rate is maintained (British Petroleum, 2024).

The safety of the environment is also of great concern, as over one-third of human-instigated greenhouse gas emissions are a result of the burning of hydrocarbons (World Nuclear Association, 2024). This has manifested in several forms in the country. For instance, Nigeria was the 4^{th} largest emitter of CO_2 emissions from fuel combustion in Africa, behind only South Africa, Egypt, and Algeria in 2021 (International Energy Agency, 2024). Nigeria's ecological deficit also increased from 331,982.32 gha in 1975 to 77.58 million (gha) in 2022, an equivalent of a 23,268% increase over 48 years (Global Footprint Network, 2022). This is, together with other detrimental effects on the nation's ecological resources, particularly in the Niger Delta region, where substantial deposits of these resources are located, caused by energy-related activities like oil spills, mud drilling, gas flaring, canalization of oilfields, and seismic explosives detonation (Newsom, 2012). The imperative for a managed energy transition is clear, as evidence confirms that coordinated policies targeting urban energy transition and green energy access are effective in reducing pollution and promoting environmental sustainability (Mesagan et al., 2024).

Nigeria was among the member states of the United Nations (UN) that embraced the 2030 Agenda for SD, which comprises a set of 17 Sustainable Development Goals (SDGs) that include providing clean and affordable energy (Goal 7) and addressing climate change (Goal 13), which symbolizes a significant landmark in placing the world on a development path that is not only inclusive but also sustainable. Thus, it is imperative to assess any growth driver, including energy resources, within the confines of sustainable development (United Nations Development Programme (UNDP), 2015). This study, therefore, examines the effect of energy resources on sustainable development in Nigeria, and its importance is underscored in several distinct ways.

First, as a departure from extant studies, the present study adopts an alternative measure of growth that captures sustainability dynamics. The majority of extant studies in this area of research employ GDP as the target variable. Studies such as Stern (2004), Akinlo (2008), Odhiambo (2009), Soytas and Sari (2009), Apergis and Payne (2010), and Omri (2013) have used GDP to proxy growth in energy-growth nexus research. While GDP remains a widely used measure of economic activity, it is increasingly criticized as an inadequate proxy for sustainable development. The GDP records the market value of goods and services produced but does not distinguish between activities that improve welfare and those that harm it, thereby failing to reflect sustainability (Talberth et al., 2007). The GDP is also insufficient to explain economic development and welfare improvements since it ignores the impacts of natural activities on the environment. Furthermore, according to Menegaki and Tugcu (2018), GDP only considers formal economic activity and excludes activities of shadow economies, the influence of human economic and non-economic pursuits on society and the environment, and the impact of leisure on the livelihood of the people.

To adequately capture the sustainability implications of energy consumption, this study adopts adjusted net savings (ANS) as the indicator of sustainable development. Adjusted net savings is a forward-looking measure rooted in the theory of intergenerational welfare, which posits that an economy is on a sustainable development path if it maintains or increases its total wealth over time (Hamilton & Clemens, 1999). Unlike GDP, ANS adjusts gross national savings by accounting for depreciation of produced capital, investment in human capital (education expenditure), depletion of natural resources such as energy and minerals, and damages associated with pollution emissions; as such, it directly links current economic activity to future welfare prospects.

Empirical evidence demonstrates that ANS provides a more reliable signal of sustainability than conventional income-based measures. Hamilton and Clemens (1999) show that persistently negative ANS predicts future declines in consumption and welfare, even in countries experiencing positive GDP growth. Similarly, Ferreira and Vincent (2005) provide cross-country evidence that ANS is a consistent indicator of sustainability under fairly general conditions. Arrow et al. (2012) further establish that comprehensive wealth measures, including ANS, offer a theoretically sound basis for assessing whether development paths are sustainable over time. The World Bank has also institutionalized ANS as a core sustainability indicator in its World Development Indicators and Changing Wealth of Nations reports, using it to assess long-term development performance across countries (Hamilton, 2006; Lange et al., 2018).

Given that energy-driven growth often involves trade-offs between short-term income gains and long-term environmental costs, ANS is particularly suitable for this study. By internalizing natural resource depletion and environmental damages associated with energy use, ANS enables a more comprehensive assessment of whether Nigeria's energy consumption pattern supports or undermines sustainable development. The adoption of ANS therefore provides stronger policy-relevant insights than GDP-based approaches, especially in resource-dependent economies.

Secondly, apart from investigating the impact of aggregate energy use on sustainable development in Nigeria, this study also examines the disaggregated impact of energy into renewable and non-renewable energy on sustainable development in Nigeria. The importance of this disaggregation is underscored by enabling the identification of the energy type with the most profound impact on sustainable development. Disaggregating energy consumption into renewable and non-renewable sources is crucial because the two types have fundamentally different implications for sustainability. Non-renewable energy consumption is associated with resource depletion and pollution, whereas renewable energy aligns with long-term environmental and economic resilience (Güney, 2019). Analysing them separately prevents aggregation bias, allows for targeted policy insights, and helps identify which energy type supports sustainable development, and this approach is supported by recent studies such as Ahmed et al. (2019) and Khan et al. (2023). Thus, the disaggregation increases the possibility of more comprehensive and reliable policy insights because failing to separate the impact of each energy type on sustainable development may mask unique impacts and result in inaccurate policy prescriptions (Bello et al., 2018). Thus, while broadening the understanding of the trade-offs and synergies between energy utilization and attaining sustainable development objectives, the study provides robust insights for energy planners, policymakers, and other relevant stakeholders on ways to navigate a more sustainable and resilient energy future for Nigeria.

Furthermore, this study provides critical empirical evidence from the specific context of a major fossil fuel-dependent developing economy. While much of the existing literature examines this nexus in developed or mixed panels, Nigeria's dual status as Africa's largest oil producer and a nation facing severe energy poverty presents a unique and critical case. This analysis, therefore, offers nuanced insights into the political economy and practical challenges of energy transition in a resource-rich yet sustainable-development-poor setting, filling a crucial gap in context-specific knowledge.

The subsequent sections of this paper are arranged as follows. Section 2 presents a summary of the extant work related to the current research. Section 3 focuses on the research methodology, which outlines the methods employed for investigation and sources of data. Section 4 presents the data analysis and research findings. Lastly, Section 5 concludes the paper with an overview of study implications and policy recommendations.

2. Review of Literature

The mainstream economic growth theories, including the neoclassical exogenous growth theories of Solow (1956) and Swan (1956) and the endogenous growth theories such as Rebelo (1991), Mankiw et al. (1992), and Romer (1994), did not place much relevance on the significance of energy to propel economic growth. Rather, the theories emphasized capital, labour, and technological progress as the main drivers of economic growth. However, as submitted by Stern (2004), nothing is innate in economics that limits the potential of energy resources to drive nations to the path of growth and sustainable development. Energy economists have made significant efforts in exploring the dynamic relationships between energy and economic growth. The exploration of the theoretical connection between energy consumption and economic growth is primarily grounded in the augmented production function framework, where energy is treated as a key input alongside capital and labour. Within this framework, four major hypotheses have emerged in the literature: the growth hypothesis, the conservation hypothesis, the feedback hypothesis, and the neutrality hypothesis (Ozturk, 2010).

The growth hypothesis posits that energy consumption drives economic growth, implying that energy is a critical factor of production and that restrictions on energy use may adversely affect output. Conversely, the conservation hypothesis suggests that economic growth drives energy consumption, meaning that energy-saving policies may not significantly harm growth. The feedback hypothesis proposes bidirectional causality between energy consumption and economic growth, while the neutrality hypothesis argues that no significant causal relationship exists between the two variables.

In terms of empirical studies on the dynamic linkage between economic growth and energy use, the seminal paper belongs to Kraft and Kraft (1978). Since then, a considerable body of studies has been dedicated to this realm of literature. Within the context of this study, two strands of literature can be identified. The first is the strand examining the dynamic relationship between aggregate energy use and economic growth, while the other strand involves studies that disaggregate energy use into non-renewable and renewable. One study on the connection between energy consumption and economic growth is that of Le et al. (2021), which investigated the relationship between energy consumption and growth by taking into account the various forms of energy in a global sample of 107 countries and discovered that overall energy use favourably and significantly increased income. In Germany and Brazil, Lu et al. (2021) discovered a two-way causative relationship between energy consumption and economic growth, but in Japan and the U.S., they discovered a unidirectional causal relationship between renewable energy and economic development.

Similarly, Saidi et al. (2020) examined the role of institutions in the relationship between growth and the use of renewable energy and discovered evidence to support the growth hypothesis, which holds that the use of renewable energy is associated with notable advancements in economic growth. However, Roubaud and Shahbaz (2017) found that financial development stimulated electricity consumption and economic growth, with a loop hypothesis. Zafar et al. (2019) found that in Asia-Pacific Economic Cooperation countries, higher energy use, R&D spending, trade openness, and investment in capital stock positively influenced economic growth. The study provided evidence for two-way causal dynamics and the feedback hypothesis, highlighting the importance of energy, capital, and trade openness in boosting economic growth.

Studies have also been carried out on how energy usage, both renewable and non-renewable, affects economic growth. According to Ahmed et al. (2019), non-renewable energy had detrimental effects because of poor technology, but renewable energy boosted Myanmar's economic growth. Rahman and Velayutham (2020) investigated how fixed capital formation and the use of renewable and non-renewable energy affected economic growth in South Asian nations. In a related study, Bello and Ch'ng (2022) found that energy consumption positively impacted GDP in France, but the long-run impact on sustainable development was insignificant. Kumar et al. (2015) found a significant correlation between electricity consumption and GDP per capita in Gibraltar, suggesting efficient use of electricity in key sectors for economic growth. However, Aslan (2016) found evidence of the growth hypothesis with a unidirectional causality flowing from biomass energy consumption to economic growth in the U.S.

Finally, among the studies on the relationship between renewable energy consumption and economic growth is the work of Çetin (2016), who found a long-term positive relationship between economic growth and renewable energy consumption in E-7 countries from 1992 to 2012. Menegaki and Ozturk (2016) examined the causal relationship between non-renewable energy and economic growth in MENA countries from 1997 to 2009, finding that non-renewable energy had a negative long-term impact on GDP growth. Focusing on sub-Saharan Africa, Fodol et al. (2025) found that renewable energy consumption can sometimes correlate with higher emissions in transitional energy systems, suggesting that clean energy may initially complement rather than fully substitute for fossil fuels. Moreover, Destek (2016) investigated the nexus between economic growth and renewable energy consumption in newly industrialized economies and found evidence supporting two-way causal dynamics between the two. Similarly, Rasoulinezhad and Saboori (2018) found a bidirectional long-run relation between carbon emissions, renewable and non-renewable energy consumption, trade openness, and economic growth in the Commonwealth of Independent States region. However, a one-way causal effect running from economic growth, financial transparency, and trade openness to CO_2 emissions and fossil fuel energy consumption was established.

The preceding review of the extant literature shows that despite the remarkable research efforts dedicated to investigating the energy-growth nexus, the findings remain largely inconclusive, with outcomes hovering between the four testable hypotheses of growth, feedback, neutrality, and conservative hypotheses. Furthermore, the sustainability dynamics have not been accorded adequate attention, especially within the context of Nigeria. Thus, there remains a gap in understanding the nuanced effect of energy consumption on sustainable development, especially within the context of a developing country like Nigeria that desires a growth path that is consistent with the Sustainable Development Agenda.

3. Methodology: Model, Data, and Estimation Technique

3.1 The model

The study adopts the simple but expandable Cobb-Douglas production function that expresses output as a function of traditional capital and labour inputs, augmented by including energy consumption as an extra regressor, specified as follows:

$$Y_t = f\left(K_t, L_t, EC_t\right) = K_t^{\beta_1} L_t^{\beta_2} EC_t^{\beta_3} \quad (1)$$

where: *Y* is economic growth, *K* is physical capital, *L* is labor, and *EC* is energy.
The β_s are the estimable parameters which respectively capture the shares of final output in terms of physical capital, labour, and energy consumption, and the subscript *t* denotes time, which is yearly in this case.

By taking the natural logs, the model can be linearized as follows:

$$\ln Y_t = \beta_0 + \beta_1 \ln K_t + \beta_2 \ln L_t + \beta_3 \ln EC_t + \mu_t \quad (2)$$

where: μ_t is the stochastic error term satisfying the attributes of a normal distribution, mean of zero, and constant variance.

In line with the study objective, the dependent variable *Y* is transformed into SD to reflect sustainable development. Thus, equation (2) is rendered as follows:

$$\ln SD_t = \beta_0 + \beta_1 \ln K_t + \beta_2 \ln L_t + \beta_3 \ln EC_t + \mu_t \quad (3)$$

Equation (3) is the baseline model capturing the impact of the explanatory variables on sustainable development. To help us determine the specific impact of each energy type on sustainable development, an additional model is specified, which disaggregates the total impact of energy consumption into non-renewable energy (*NRE)* and renewable energy (*RE)* as follows:

$$\ln SD_t = \alpha_0 + \alpha_1 \ln K_t + \alpha_2 \ln L_t + \alpha_3 \ln RE_t + \alpha_4 \ln NRE_t + \varepsilon_t \quad (4)$$

The *a priori* expectations of these parameters are summarized in Table 1. If properly deployed, physical capital and labour are expected to promote sustainable development, so it is expected that $\beta_1; \beta_2 > 0$ in equation (3) and $\alpha_1; \alpha_2 > 0$ in equation (4). The effect of energy consumption on sustainable development may be favourable or unfavourable depending on the energy consumption profile of the country, so β_3 in equation (3) can be > 0 or < 0. Renewable energy consumption is expected to promote sustainable development, while non-renewable energy consumption is expected to have an adverse effect on sustainable development, so it is expected that, in equation (4), $\alpha_3 > 0$ while $\alpha_4 < 0$.

Table 1: A-priori Expectation of Signs of the Parameters

Dependent Variable	Independent Variables	Expected Relationships	Expected Coefficients
Sustainable Development	Physical Capital	+	$\beta_1; \alpha_1 > 0$
	Labour	+	$\beta_2; \alpha_2 > 0$
	Energy Consumption	±	$\beta_3 > 0$ or $\beta_3 < 0$
	Renewable Energy Consumption	+	$\alpha_3 > 0$
	Non-renewable Energy Consumption	-	$\alpha_4 < 0$

3.3 Data

The dataset used in the study consists of annual time series data on sustainable development, physical capital, human capital, energy consumption, renewable energy consumption, non-renewable energy consumption, research and development, and human capital in Nigeria from 1990 to 2023. The sustainability index is proxied by the adjusted net savings (ANS), which incorporates the economic, environmental, and social dimensions of sustainable development. Consistent with Hamilton and Clemens (1999), the ANS is computed in equation (5) as follows:

$$ANS = GDS + XED - DCO_2 - FK_C - ER_D - MR_{Dt} \pm F_D \tag{5}$$

where: GDS is the gross domestic savings, XED represents education expenditure, DCO_2 captures damages arising from carbon dioxide emissions, while FK_C is the consumption of fixed capital. ER_D denotes energy resources that are being depleted, while the depletion of mineral resources is denoted by MR_D, and F_D captures forest depletion.

The physical capital stock is proxied by the gross fixed capital formation at constant 2017 USD to factor in inflationary factors, labour is captured by the number of gainfully employed people in the economy, while the energy series are expressed in quadrillion British Thermal Units (BTU) of energy consumption.

Data on the ANS, physical capital, and labour series are provided by the World Development Indicators of the World Bank (2024), while the International Energy Statistics section of the United States Energy Information Administration (2024) provided the data on the energy series.

3.4 Estimation technique

The estimates of the parameters in the baseline model in equation (3) and the disaggregated model in equation (4) are obtained using the autoregressive distributed lag (ARDL) modelling technique developed by Pesaran et al. (2001). The technique is straightforward and can generate robust and reliable parameters irrespective of the order of cointegration of the series in the model. This means that the estimates are consistent with mixed integrating orders of zeros and ones, provided that no variable is integrated of an order above 1. Through the mechanism of the error correction model (ECM), the technique can provide robust and unbiased parameters, even with the challenges of endogeneity, by simultaneously estimating the short-run and long-run parameters (Harris & Sollis, 2003).

Following Pesaran et al. (2001), the basic ARDL specification for the baseline equation (3) and the disaggregated model in equation (4) are respectively specified as equations (6) and (7):

$$\begin{aligned}\Delta \ln SD_t &= \beta_0 + \beta_1 \ln SD_{t-1} + \beta_2 \ln K_{t-1} + \beta_3 \ln L_{t-1} + \beta_4 \ln EC_{t-1} + \sum_{k=1}^{a} \beta_5 \Delta \ln SD_{t-k} \\ &\quad + \sum_{k=1}^{b} \beta_6 \Delta \ln K_{t-k} + \sum_{k=1}^{c} \beta_7 \Delta \ln L_{t-k} + \sum_{k=1}^{d} \beta_8 \Delta \ln EC_{t-k} + \mu_t \end{aligned} \tag{6}$$

$$\begin{aligned}\Delta \ln SD_t &= \alpha_0 + \alpha_1 \ln SD_{t-1} + \alpha_2 \ln K_{t-1} + \alpha_3 \ln L_{t-1} + \alpha_4 \ln RE_{t-1} + \alpha_5 \ln NRE_{t-1} \\ &\quad + \sum_{k=1}^{a} \alpha_6 \Delta \ln SD_{t-k} + \sum_{k=1}^{b} \alpha_7 \Delta \ln K_{t-k} + \sum_{k=1}^{c} \alpha_8 \Delta \ln L_{t-k} + \sum_{k=1}^{d} \alpha_9 \Delta \ln RE_{t-k} \\ &\quad + \sum_{k=1}^{e} \alpha_{10} \Delta \ln NRE_{t-k} + \varepsilon_t \end{aligned} \tag{7}$$

where: *Δ* is the difference operator and the letters *a, b, c, d,* and *e* are the optimal lag lengths, endogenously determined using the Schwarz Information Criteria (SIC). The remaining variables remain as earlier defined.

To establish cointegration, the computed F-statistic of the joint lagged level of the parameter estimates should exceed the upper-bound critical values. After establishing cointegration, several diagnostic examinations are carried out to scrutinize the stability and robustness of the model. Normality is verified using the Jarque-Bera test, while the White and ARCH tests are performed to check for heteroscedasticity. Serial correlation is tested using the Breusch and Godfrey Lagrange Multiplier (LM) test, while the plots of the recursive coefficients are used to determine model stability.

4. Empirical Analysis and Discussion of Results

4.1 Correlation analysis

The analysis of the empirical results begins with the summary statistics of the variables in the models. As presented in Table 2, the value of the ANS ranges between 3.15 billion US$ and 87.15 billion US$, with an average of 26.16 billion US$ and a median value of 16.5 billion US$. Physical capital ranges from 12.3 billion US$ to 146 billion US$, averaging 53.8 billion US$ and a median value of 55.7 billion US$. Labour has a range of values from 32.85 million to 75.72 million, with mean and median values of 50.86 million and 49.48 million, respectively.

As regards the energy series, the range of values of total energy consumption is between 0.67 quad (BTU) and 1.97 quad (BTU) with an average value of 1.13 quad (BTU) and a median value of 0.92 quad (BTU) while renewable energy consumption has a range of 0.01 quad (BTU) and 0.03 quad (BTU) averaging 0.02 quad (BTU) and a median value of 0.02 quad (BTU). Non-renewable energy consumption ranges from 0.65 quad (BTU) to 1.84 quad (BTU), with an average figure of 1.11 quad (BTU) and a median value of 0.90 quad (BTU). All variables have positive kurtosis and are positively skewed. Normality is established for all variables as depicted by the Jarque-Bera statistics and their probability values for the ANS series, which exhibits non-normality. The variables are thus logged to attain linearity, enhance normality, and promote homoscedasticity.

Table 2: Summary Statistics

	ANS (Billion $)	K (Billion $)	L (in millions)	EC (Btu)	RE (Btu)	NRE (Btu)
Mean	26.7	53.8	50.863	1.13	0.02	1.11
Median	16.5	55.7	49.476	0.92	0.02	0.90
Maximum	83.7	146	75.721	1.97	0.03	1.84
Minimum	3.15	12.3	32.845	0.67	0.01	0.65
Std. Dev.	23.4	34.6	12.733	0.43	0.00	0.42
Skewness	1.26	0.78	0.29	0.63	0.27	0.60
Kurtosis	3.23	2.87	1.93	1.75	1.74	1.66
Jarque-Bera	9.09	3.49	2.12	4.44	2.66	4.56
	(0.01)	(0.18)	(0.35)	(0.11)	(0.27)	(0.10)

4.1.2 *The Correlation Analysis*

The result of the correlation matrix presented in Table 3 shows that ANS has a positive correlation with all the explanatory variables used in the study. However, the degrees of correlation vary. For instance, physical capital has a strong positive relationship, while energy consumption and non-renewable energy consumption have a moderate positive relationship with ANS. Renewable energy consumption was found to be weakly correlated with ANS. As for the interaction among the independent variables, none of the correlation values exceeds 0.8, suggesting the absence of any possible multicollinearity problem.

Table 3: Correlation Matrix

	ANS	*K*	*LAB*	*EC*	*REC*	*NREC*
ANS	1					
K	0.7770	1				
L	0.6649	0.7248	1			
EC	0.5749	0.6657	0.7277	1		
RE	0.3086	0.5115	0.6320	0.6293	1	
NRE	0.5630	0.7654	0.7248	0.6988	0.6219	1

Source: Author's computation.

4.2 The unit root test

Following the correlation analysis, we proceed with the investigation of the stationarity attributes of the variables in the model through the tests of unit roots. This is important because the validity of time series analysis is conditioned upon the stationarity of the variables in the model. In particular, the estimation technique adopted in the series – ARDL – requires that the explained variable have a strict integrating order of 1. This implies that the dependent variable should not attain stationarity at the level. Furthermore, none of the explanatory variables in the model should have an integrating order exceeding 1. However, the model is invariant with a mixed integrating among the variables in the model, provided that the variable with the highest integrating order is integrated of order 1 or less – a property that underscores the flexibility of the ARDL modelling technique in contrast to other techniques, such as the Johansen cointegration technique.

The results of the Phillips-Perron (PP) test (Phillips & Perron, 1988) and the Augmented Dickey-Fuller (ADF) test (Dickey & Fuller, 1979) are presented in Table 4. Based on the results, there appears to be a mixed integrating order among the variables as the labour and the R&D series attained stationarity at the level in both the ADF and the PP tests. The condition of having a maximum integrating order of 1 is also satisfied as all variables attained stationarity after first differencing.

Table 4: Results of the ADF and PP Unit Root Tests

	ADF		PP	
Variable	Level	First Difference	Level	First Difference
ln*ANS*	-0.772	-9.511***	-2.258	-9.511***
ln*K*	0.993	-5.162***	-0.137	-7.606***
ln*L*	5.623***	-4.912***	6.267***	-4.589***
ln*EC*	-0.064	-6.460***	-0.072	-6.438***
ln*RE*	-2.320	-6.805***	-2.399	-6.885***
ln*NRE*	-0.373	-6.516***	-0.288	-6.493***

Notes: *** represents significance at 1%, based on Vogelsang's (1993) asymptotic one-sided p-values. The maximum lag is set at 9, and the optimal lag length is selected based on the Akaike Information Criterion.

4.2 Bounds test results and analysis

To ascertain the existence of a long-run cointegrating relationship among the variables in the models, we examine the result of the bounds test, which is presented in Table 5. For cointegration to exist, the estimated F-statistic for the overall significance of all lagged-level series in the models should be greater than the upper critical bound known as the I(1). As shown in Table 5, for the baseline model, the computed F-statistic of 6.851 exceeded the upper critical bound of 4.66 at the 1% significant level, thereby establishing the presence of a long-run cointegrating relationship among the series in the model. The R^2 and the adjusted R^2 of 0.819 and 0.723, respectively, suggest that more than 70% of the variations in sustainable development are due to the independent variables, which indicate that the model fits well. Similarly, in the disaggregated model, the computed F-statistic of 4.104 exceeded the upper critical bound of 3.4 at the 5% significant level, thereby establishing the presence of a long-run cointegrating relationship among the variables in the model. The R^2 and the adjusted R^2 of 0.885 and 0.792, respectively, suggest that more than 70% of the variations in sustainable development are explained by the explanatory variables, which indicate that the model is a good fit.

Table 5: Summary of Bounds Test Cointegration Results

	Baseline Model	Disaggregated Model
	F_{ANS} *(ANS/K, L, EC): K=3*	F_{ANS} *(ANS/K, L, RE, NRE): K=4*
Optimal lags	(1, 4, 2, 4)	(4, 3, 0, 4, 3)
F-Statistics	6.851***	4.104**
Lower bound *I(0)*	3.65	2.56
Upper bound *I(1)*	4.66	3.49
Level of significant	1%	5%
R^2	0.819	0.885
Adjusted-R^2	0.723	0.792
Diagnostic Tests		
Breusch-Godfrey LM	0.3577 (0.706)	0.9198 (0.360)
Breusch-Pagan-Godfrey	0.5358 (0.875)	0.4179 (0.952)
Harvey	0.3173 (0.981)	1.0508 (0.482)
Glejser	0.5354 (0.875)	0.6959 (0.761)
ARCH	0.0177 (0.895)	1.5357 (0.235)

Notes: The optimal lag length is based on the Akaike Information Criterion. The specified model is an unrestricted constant and unrestricted trend. *** represents a 1% level of significance.

4.3 Estimation results and discussion

Since the ARDL bounds test revealed that a long-run relationship exists among the variables in both the baseline and alternate models, the long-run marginal effects of the explanatory variables on sustainable development are estimated, and the results of the estimated parameters are presented in Table 6. Starting with the baseline model, it is seen that the long-run marginal effect of physical capital is positive (1.915) and significant at 1%, while that of labour is negative (-3.488) but insignificant. This implies that, all other things remaining constant, a 1% change in physical capital will boost sustainable development by 1.915% while a 1% change in labour will adversely affect sustainable development by 3.488%. Turning to energy consumption, which is the main explanatory variable of interest, it is seen that its marginal impact on sustainable development is 0.3997. This means that all things being equal, a 1% change in energy consumption will lead to a 0.399% positive change in sustainable development. This impact is, however, largely insignificant as evidenced by the t-statistics.

The finding that total energy consumption could not significantly spur sustainable development in Nigeria is consistent with the findings of Bello and Ch'ng (2022) for France. However, the result contradicts Aderemi et al. (2021), who found a significant positive causal relationship between energy consumption and sustainable development in Nigeria. This is because, unlike Aderemi et al. (2021), the current study employs a composite index to proxy sustainable development instead of the traditional GDP. Thus, our finding is consistent with Nigeria being at the developmental stage, with increased energy consumption promoting economic growth at the expense of sustainable development, mainly due to reliance on non-renewable energy sources.

We now turn to the disaggregated model, where energy consumption is divided into its disaggregated constituents of renewable and non-renewable energy consumption. While the impact of physical capital remained positive and significant, the marginal effect of labour became positive but remained insignificant, as it was in the baseline model. In the disaggregated model, it is observed that the long-run marginal of both renewable and non-renewable energy consumption on sustainable development is statistically significant. Interestingly, while the impact of renewable energy consumption is positive, that of non-renewable energy consumption is negative, suggesting that while renewable energy consumption can potentially promote sustainable development, non-renewable energy consumption is harmful to sustainable development in Nigeria.

Non-renewable energy consumption in Nigeria was found to significantly negatively impact sustainable development, aligning with economic expectations. This negative relationship indicates that the environmental and social harms arising from the increase in non-renewable energy consumption outweigh the economic benefits of non-renewable energy. Consumption of non-renewable sources like crude oil and coal has led to severe environmental, economic, and social repercussions, as the increase in non-renewable energy consumption has contributed to higher carbon emissions, damaging the ozone layer and countering SDG 14. Additionally, in efforts to boost Nigeria's foreign exchange earnings, crude oil exploration has caused oil spills, adversely affecting water and land animals, violating SDGs 14 and 15. These findings align with Khan et al. (2023), who found that fossil fuel consumption degrades the environment in sub-Saharan Africa. However, Güney (2019) and Noor et al. (2024) found a positive influence of non-renewable energy on sustainable development in developing countries and South Asia, respectively.

Contrarily, renewable energy consumption was found to have a positive but insignificant impact on sustainable development in Nigeria. This indicates the necessity of using renewable energy sources to achieve sustainable development, as emphasized by Sustainable Development Goal 7, which prioritizes green energy. This is why Liu et al. (2023) stated that renewable energy is key to reducing air pollution and boosting ecological sustainability. Osakede et al. (2024) also found that a positive link between renewables and sustainable development is reinforced by broader African studies, though the specific benefits may depend on the type of renewable access; for instance, access to clean cooking technologies has been shown to have a more direct positive effect on human development than aggregate renewable electricity consumption.

However, its impact remains insignificant due to the limited accessibility and affordability of renewable energy technologies compared to non-renewable sources. This finding aligns with economic expectations and mirrors the results of Khan et al. (2023), who found a positive impact of renewable energy consumption on sustainable development, using environmental quality as a proxy. Similar findings were also reported by Güney (2019) and Xing et al. (2023). This finding aligns with Kolawole et al. (2025), who identify high upfront costs and unreliable grid supply as critical barriers to green energy adoption even among businesses, highlighting a significant market failure that policy must address.

Furthermore, capital was found to have a significant positive impact on sustainable development in the long run for both baseline and aggregate models. This aligns with economic expectations, indicating that capital, measured by gross fixed capital formation, is essential for driving sustainable development in Nigeria. Investment in infrastructure is a critical component of this capital formation. As seen in neighbouring Ghana, improving fundamental infrastructure like electricity access directly and significantly increases energy consumption, which is a prerequisite for economic and social development (Osei-Gyebi, 2022). This finding is consistent with Bello and Ch'ng (2022). Labour, another variable in this study, has an insignificant positive impact on sustainable development in the long run for both models. This suggests that while labour contributes to sustainable development, its impact is insufficient to significantly boost sustainable development in Nigeria. As the labour force increased, sustainable development remained stagnant, growing at an insignificant rate. This finding contradicts Bello and Ch'ng (2022), who found a negative impact of labour on sustainable development in France.

The finding that non-renewable energy negatively impacts sustainable development implies that every increase in fossil fuel use erodes Nigeria's long-term wealth through environmental damage and resource depletion. Practically, this means that oil and gas revenues, if not reinvested in renewable capital, do not contribute to genuine prosperity. Conversely, the positive impact of renewable energy suggests that investments in solar, hydro, or wind power can enhance sustainable wealth by reducing pollution and conserving resources. The insignificant effect of labour indicates that job creation alone, without improvements in green skills and technology, is insufficient for sustainability.

Table 6: Estimated coefficients

	Baseline Model F_{ANS} *(ANS/K, L, EC): K=3*		Disaggregated Model F_{ANS} *(ANS/K, L, RE, NRE): K=4*	
Independent variables	Coefficient	t-stat	Coefficient	t-stat
ln*K*	1.9149***	2.9182	1.0401**	2.4247
ln*L*	-3.4880	-1.1849	0.1223	0.0779
ln*EC*	0.3997	0.4038	-	-
ln*RE*	-	-	1.4908***	3.2297
ln*NRE*	-	-	-0.9312***	-2.8981
Constant	36.663	0.9692	1.7424	0.0929
Diagnostic Tests				
Breusch-Godfrey LM	0.3577 (0.706)		0.9198 (0.360)	
Breusch-Pagan-Godfrey	0.5358 (0.875)		0.4179 (0.952)	
Harvey	0.3173 (0.981)		1.0508 (0.482)	
Glejser	0.5354 (0.875)		0.6959 (0.761)	
ARCH	0.0177 (0.895)		1.5357 (0.235)	

Notes: ** denotes the significance at the 5% level. *** denotes the significance at 1% level.

To assess the validity and robustness of the bounds test results, several diagnostic procedures were conducted. First, is the LM serial correlation test of Breusch-Godfrey. Since the calculated p-value in the baseline model and the disaggregated model are respectively (0.706) and (0.360), the null hypothesis of no serial correlation cannot be rejected; it is concluded that both models are free from autocorrelation. Four tests of homoscedasticity, including the Breusch-Pagan-Godfrey, Harvey, Glejser, and ARCH, were conducted in both models, and the results of the tests supported the absence of heteroscedasticity. Lastly, the stability of the models was verified by the plots of the recursive coefficients in both models. As shown in Figures 1 and 2, the blue lines (middle lines) of the recursive coefficient for all estimates in both models lie within the upper and lower band (red lines) across boards, suggesting that the models are stable and that the estimates are reliably consistent.

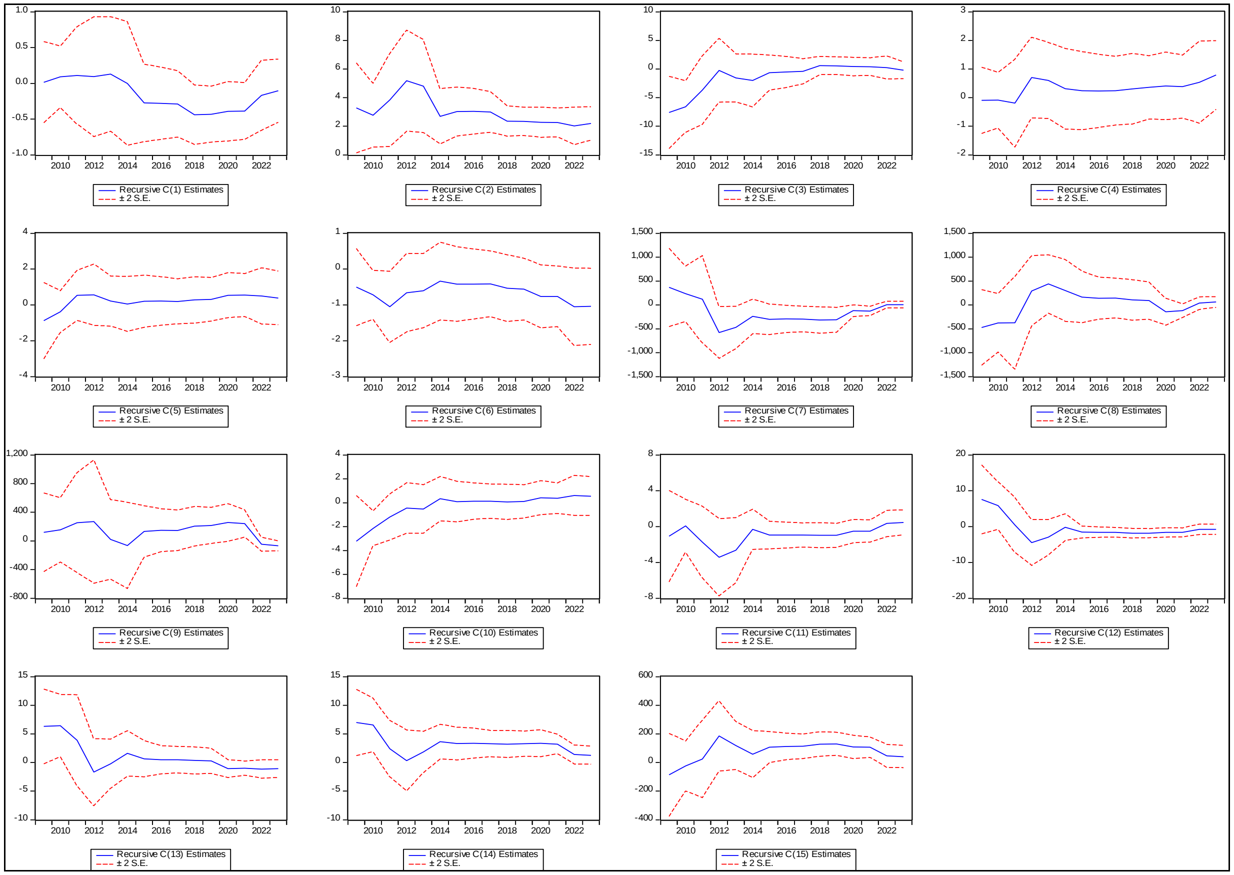

Figure 1: Recursive coefficients for the baseline model stability

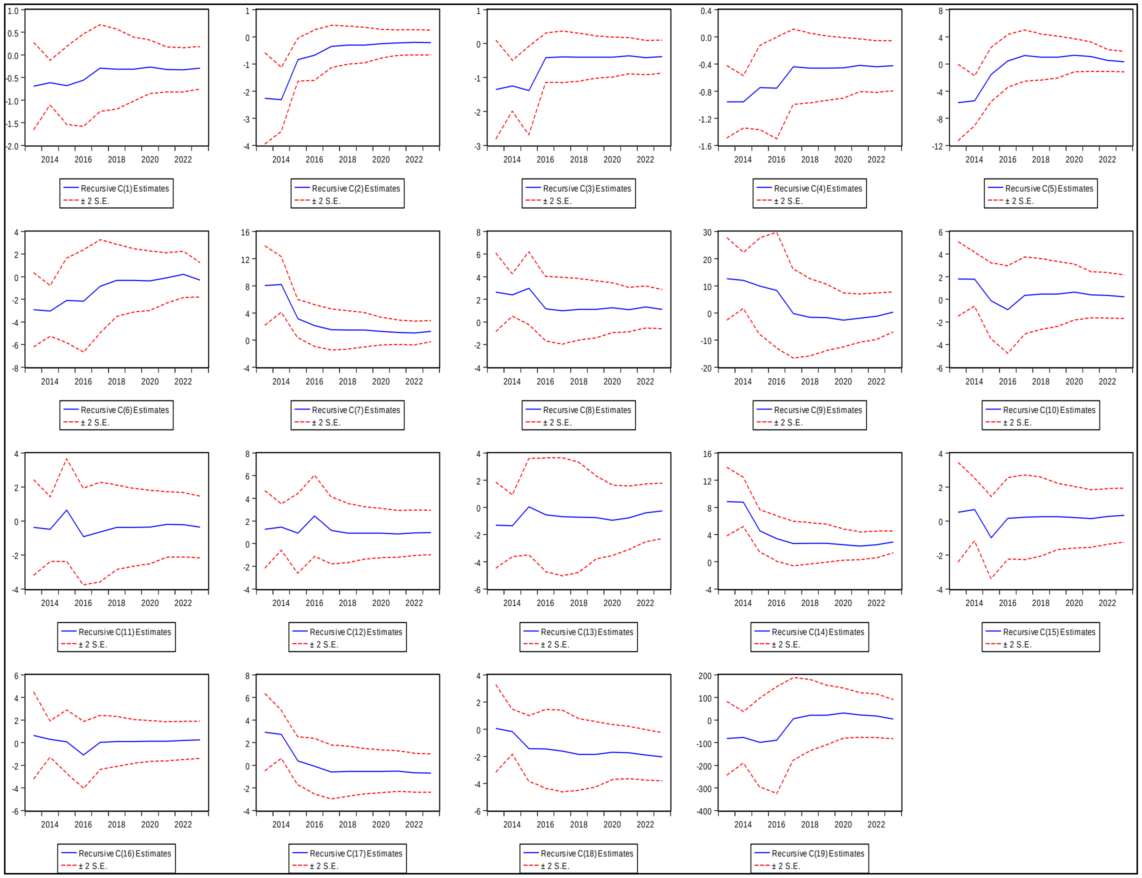

Figure 2: Recursive coefficients for the disaggregated model stability

5. Conclusion

The fact that energy is vital for Nigeria's economic progress cannot be gainsaid. However, Nigeria's total energy consumption mix is disproportionately dominated by fossil fuels, thereby heightening concerns for resource sustainability and environmental safety with huge implications for sustainable development. Thus, it is important to gauge the contribution of energy resources from the perspective of sustainable development. Hence, this study contributes to the empirical studies on the energy-growth nexus by examining the impact of energy consumption on sustainable development in Nigeria using a simple but robust economic modelling technique of the autoregressive distributed lag model, on time series data from 1990 to 2023. The study disaggregated energy consumption into renewable and non-renewable energy to provoke a more robust policy inference.

Overall, the summary of the findings shows that physical capital has a significant positive impact on sustainable development, as evidenced by both the baseline model and the disaggregated model, while labour hovers from being negative in the baseline model to positive in the disaggregated model, but remains largely insignificant across both models. Energy consumption was positive but insignificant in the baseline model. However, in the disaggregated model, renewable energy consumption significantly enhances sustainable development, while non-renewable energy consumption significantly harms sustainable development in Nigeria. These findings are laced with the following important policy implications.

First, despite the fact that energy resources are vital for Nigeria's economic growth, as evidenced by the study's findings, the resources are not significant enough to propel the country on the path to attaining the goals of the Sustainable Development Agenda, most notably SDG 7. This transition is, however, fraught with macroeconomic challenges. As noted in the Nigerian context, fiscal vulnerability can significantly hinder energy transition efforts, underscoring the need for strong fiscal institutions and stable policy frameworks to support renewable energy investments (Ekesiobi et al., 2024).

This evidence is further laid bare in the disaggregated model, where non-renewable energy, which is the dominant component of the country's energy mix, was found to significantly hinder sustainable development in Nigeria. The negative impact of non-renewable energy on sustainable development extends beyond direct environmental harm. In Nigeria, environmental degradation exacerbated by such activities has been shown to adversely affect long-term economic growth, creating a vicious cycle that undermines both ecological and economic health (Efayena & Olele, 2023). Interestingly, the renewable energy component of the energy mix can significantly drive sustainable development. The implication is that increasing the share of renewable energy in Nigeria's energy mix will have a favourable trickle-down impact on the attainment of the SDGs in Nigeria.

For Nigeria to achieve an accelerated path to a sustainable economy through its naturally endowed energy resources, it is recommended that the federal government, through relevant energy agencies, should increase the proportion of renewable energy consumption in the overall energy consumption of the country. This can be done by increasing investment in renewable energy resources and technologies to increase their availability, accessibility, and affordability among citizens, especially in rural and underserved areas. This can be achieved through implementing sustainable off-grid solar renewable energy systems in rural areas. As a complementary policy to this, there is a need to divest from non-renewable energy sources in order to reduce their current disproportionate dominance in the country's energy mix. Moreover, non-renewable energy exploration firms should take necessary preventive measures while extracting non-renewable energy sources, especially crude oil, to avoid degrading the environment and distorting life in water as well as human access to clean water, air, and land.

It is important to highlight some of the limitations of the current study. First, the use of annual data may obscure short-term dynamics and seasonal effects in energy consumption and sustainability indicators. Second, while ANS is a comprehensive measure, it may not capture all social dimensions of sustainability, such as inequality or health outcomes. Third, the analysis focuses on Nigeria; thus, generalizing findings to other countries requires caution due to contextual differences in energy infrastructure and policy environments.

Future studies could extend this research by employing higher-frequency data, incorporating additional sustainability indicators like the Inclusive Wealth

Index, or using spatial econometric models to account for regional disparities within Nigeria. Comparative studies across other oil-dependent economies in Africa could also provide broader insights into the renewable energy transition.

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