Impact of Energy Consumption on Agricultural Sector Productions in Nigeria: 1986-2025

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DOI: https://doi.org/10.47772/IJRISS.2026.1015EC0092

Received: 02 August 2026; Accepted: 07 August 2026; Published: 24 August 2026

ABSTRACT

Agriculture remained central to food supply, employment generation, and rural income in Nigeria; however, its productive capacity had been constrained by unreliable and costly energy sources required for irrigation, processing, storage, preservation, and transportation in spite of various economic reforms. Nigeria's agricultural potential remains largely underutilized, with only about 40% of the country's 84 million hectares of arable land currently under cultivation, suggesting substantial room for expansion. This paper thus examined the impact of energy consumption on agricultural sector production in Nigeria from 1986 to 2025. The paper adopted an ex-post facto research design and relied on Dynamic Ordinary Least Squares estimation technique. The findings revealed that natural gas consumption had a positive and statistically significant impact on agricultural sector production, indicating that gas-based electricity had supported agricultural activities through power supply for irrigation, processing and storage. Petroleum consumption had a negative and statistically significant effect, suggesting that dependence on Premium Motor Spirit had imposed cost pressures on farm operations, transportation and agro-processing. Solar energy consumption also had a positive and statistically significant impact, showing that renewable energy expansion had strengthened rural productive energy access. The paper recommended that the Federal Ministry of Petroleum Resources, Federal Ministry of Power, Rural Electrification Agency and Nigerian Electricity Regulatory Commission should expand gas-to-power and solar mini-grid projects for agro-processing clusters and farming communities. It also recommended that the Federal Ministry of Agriculture and Food Security, Bank of Agriculture and Development Bank of Nigeria should support farmers with credit facilities for solar pumps, cold rooms, dryers and energy-efficient machinery to reduce dependence on costly petrol-powered systems.

Keywords: Energy consumption, Agricultural sector production, Natural gas consumption, Premium Motor Spirit consumption, Solar energy consumption

JEL Codes: Q43, Q10, Q42, O13, C32

INTRODUCTION

Over the years, agriculture has been recognised as a cornerstone of global economic development, serving as a primary source of food security, employment, and livelihood for billions of people worldwide. Globally, the agricultural sector contributes significantly to economic growth, particularly in developing nations where it accounts for substantial portions of national gross domestic product (GDP) and employs a considerable proportion of the labour force. According to the Food and Agriculture Organization, agriculture employs approximately 26.7% of the global workforce and contributes about 4% to global GDP, though these figures vary considerably across regions and development levels (Jouakeu & Fouopi, 2026). The sector has experienced transformative changes over recent decades, driven by technological advancements, mechanization, and increased integration of modern inputs including energy resources. Global agricultural production has intensified to meet the demands of a growing population projected to reach 9.7 billion by 2050, necessitating a 70% increase in food production from 2010 levels (World Bank, 2025). This expansion has brought increased attention to the energy-agriculture nexus, as modern agricultural practices have become increasingly energy-intensive, relying on various energy sources for irrigation, mechanization, processing, storage, and transportation of agricultural products.

In sub-Saharan Africa, agriculture occupies an even more central position in economic and social development, accounting for approximately 15% of the region's GDP and employing over 60% of the workforce (Abah et al., 2023). Nigeria, Africa's most populous nation with over 220 million people, presents a particularly compelling case for examining the agriculture-energy nexus. The agricultural sector has historically been the backbone of Nigeria's economy, contributing significantly to GDP, employment, and export earnings before the oil boom of the 1970s shifted economic focus toward petroleum extraction. According to the National Bureau of Statistics (2026), agriculture's contribution to Nigeria's GDP has shown remarkable growth trajectory over the past four decades, rising from ₦35.70 billion in 1986 to ₦62,825.57 billion in 2025, representing an exponential increase that reflects both nominal growth and the sector's expanding productive capacity. This growth pattern reveals several distinct phases: a period of steady increase from 1986 to 1995, when agricultural GDP rose from ₦35.70 billion to ₦790.14 billion; an acceleration phase between 1995 and 2002, characterized by sharp increases culminating in ₦4,251.52 billion; and a sustained growth trajectory from 2002 to 2025, during which agricultural GDP expanded from ₦4,585.93 billion in 2003 to ₦62,825.57 billion in 2025 (Central Bank of Nigeria, 2025). Despite this impressive nominal growth, Nigeria's agricultural sector faces persistent challenges including low productivity, post-harvest losses estimated at 40-50% for certain crops, limited mechanization with only 0.27 tractors per 100 square kilometers of arable land compared to global averages of 2.0, and inadequate value addition infrastructure (Federal Ministry of Agriculture and Rural Development, 2024). The sector employs approximately 36% of Nigeria's labour force yet contributes about 24% to GDP, indicating significant productivity gaps compared to other economic sectors (National Bureau of Statistics, 2026). Furthermore, Nigeria's agricultural potential remains largely underutilized, with only about 40% of the country's 84 million hectares of arable land currently under cultivation, suggesting substantial room for expansion contingent upon addressing critical constraints including energy access (African Development Bank, 2025).

Energy consumption patterns globally have undergone significant transformations over the past several decades, reflecting economic development trajectories, technological innovations, and evolving policy priorities regarding sustainability and climate change. Global primary energy consumption has increased by approximately 50% since 2000, reaching 604.04 exajoules in 2023, driven primarily by economic growth in emerging markets and developing economies (Energy Institute, 2024). Nigeria's energy consumption patterns reflect the country's unique position as Africa's largest oil producer yet one facing significant energy access challenges, creating what scholars have termed the "resource curse paradox" where hydrocarbon abundance coexists with energy poverty (Oyedepo et al., 2024).

Available statistics shows that natural gas consumption, measured as electricity production from natural gas sources as a percentage of total electricity production, has shown considerable volatility but an overall upward trend from 48.76% in 1986, reaching a peak of 86.98% in 2014 before declining to 63.68% in 2025 (World Bank, 2025). Petroleum consumption, specifically Premium Motor Spirit (PMS), has exhibited a different pattern, starting at 251 thousand barrels per day in 1986, experiencing fluctuations through the 1990s and 2000s, then demonstrating more pronounced growth from 2015 onward, rising from 428 thousand barrels per day in 2015 to reach 575 thousand barrels per day in 2023 (Energy Institute, 2024; Energy Commission of Nigeria, 2025). The trajectory shows continued increase to 590 thousand barrels per day in 2024, representing a modest 2.6% growth, before experiencing a notable decline to 401 thousand barrels per day in 2025, marking a 32% reduction from the previous year (Organization of the Petroleum Exporting Countries, 2025). This recent sharp decline from 2024 to 2025 reflect several interconnected factors including aggressive subsidy removal policies that significantly increased PMS prices and reduced consumption, potential shifts toward alternative fuels and energy sources particularly in transportation and agricultural applications, economic pressures that curtailed fuel purchasing power, enhanced fuel efficiency measures, and possibly increased adoption of compressed natural gas (CNG) and electric vehicles as part of Nigeria's energy transition initiatives (Iwegbu et al., 2026).

Solar energy consumption in Nigeria, though starting from a negligible base of 0.07 GWh in 1986, has experienced exponential growth, particularly from 2010 onward, reaching 380.42 GWh in 2025 (Solar Power Deployment Statistics 2000-2023, REA Publications; Nigerian Electricity Regulatory Commission, 2024). This remarkable expansion, accelerating from 26.42 GWh in 2010 to 380.42 GWh in 2025, reflects declining costs of solar photovoltaic technology, government initiatives such as the Nigerian Renewable Energy and Energy Efficiency Policy (NREEEP), increasing private sector participation, and growing adoption of off-grid solar solutions in response to persistent electricity grid inadequacies (Enerdata, 2025). The exponential growth pattern in solar energy, with consumption more than doubling in several successive years, positions solar as the fastest-growing energy source in Nigeria's energy mix, though it still represents a small fraction of total energy consumption compared to fossil fuels.

Energy thus serves as a fundamental input in modern agricultural production systems, powering irrigation infrastructure, enabling mechanization through tractors and other farm equipment, facilitating processing and value addition, supporting cold storage and preservation systems, and enabling transportation of inputs and outputs across value chains (Adom et al., 2024). Therefore, energy consumption remains a critical driver of productive activities, rural transformation, mechanisation, processing, storage, and transportation, and as such this paper becomes necessary to examine how selected energy consumption components have influenced agricultural sector production in Nigeria.

The paper is guided by the following research questions:

i. What is the impact of natural gas consumption on agricultural sector production in Nigeria?

ii. How has petroleum consumption influenced agricultural sector production in Nigeria?

iii. What is the impact of solar energy consumption on agricultural sector production in Nigeria?

LITERATURE REVIEW

Conceptual Clarifications

Energy Consumption

Energy consumption represented a fundamental economic concept defined as the total amount of energy utilized by various sectors, industries, or entire economies to facilitate productive activities and support development processes. Ahmed et al. (2023) conceptualized energy consumption as the aggregate utilization of different energy sources including fossil fuels, renewable resources, and nuclear power to generate electricity, heat, and mechanical power necessary for economic production and human welfare. Similarly, Khan and Rana (2024) defined energy consumption as the quantity of primary and secondary energy sources employed across residential, commercial, industrial, transportation, and agricultural sectors to power machinery, equipment, and infrastructure essential for economic activities. Ogbokor and Sancho (2025) articulated energy consumption as the total energy inputs utilized throughout agricultural value chains, encompassing direct energy use in farm operations such as mechanization and irrigation, as well as indirect energy embodied in inputs like fertilizers and pesticides.

Natural gas consumption was conceptualized by scholars as the utilization of gaseous hydrocarbon resources primarily composed of methane for various applications including electricity generation, heating, and industrial processes. Rehman et al. (2023) defined natural gas consumption as the volume of natural gas extracted and converted into useful energy forms, measured typically in cubic meters, British thermal units, or as percentage contributions to total energy supply. Petroleum consumption, particularly Premium Motor Spirit, was defined by Zou et al. (2023) as the quantity of refined petroleum products consumed primarily for transportation, agricultural mechanization, and industrial applications, measured in barrels or liters. Solar energy consumption was conceptualized by Gorjian et al. (2023) as the utilization of photovoltaic and thermal technologies to convert solar radiation into electricity or heat for productive applications across economic sectors.

For this paper, energy consumption was operationally defined as the combined utilization of natural gas, petroleum, and solar energy sources to power agricultural production activities in Nigeria, measured respectively through electricity production from natural gas sources, Premium Motor Spirit consumption, and solar energy generation capacity.

Agricultural Production

Agricultural sector production represented a multidimensional concept defined as the total output of crops, livestock, fisheries, and forestry activities generated within an economy over a specified period. Chen et al. (2024) conceptualized agricultural sector production as the aggregate value of all agricultural commodities produced, encompassing both food and non-food items, measured through physical output quantities or monetary values that reflected the sector's contribution to national economic output. Similarly, Adenle et al. (2023) defined agricultural production as the systematic transformation of natural resources including land, water, and biological materials through human labor and capital inputs into consumable products that satisfied food security needs and provided raw materials for industrial processing.

Takeshima and Liu (2023) articulated agricultural sector production as the measurable output resulting from combinations of traditional factors including land and labour with modern inputs such as fertilizers, improved seeds, mechanization, and irrigation technologies that collectively determined productivity levels and sectoral contributions to gross domestic product. Falaye and Itadare (2026) described agricultural production output as a growth-related sectoral variable that reflected agriculture's capacity to support livelihoods, poverty reduction and macroeconomic expansion in Nigeria.

Agricultural sector production in this paper was operationally defined as the monetary value of agricultural output in Nigeria measured through the sector's annual contribution to gross domestic product in billions of Naira, reflecting the aggregate productive performance of crop production, livestock, fisheries, and forestry subsectors.

Theoretical Underpinning

The theoretical underpinning for this paper is the Energy-Led Growth Hypothesis, which emerged from the energy-growth nexus literature and was popularised by Kraft and Kraft (1978). The Energy-Led Growth Hypothesis suggests that energy consumption is not merely a supportive input in the production process, but a fundamental driver of economic and sectoral growth. The theory holds that productive activities depend heavily on the availability, affordability and reliability of energy, since energy is required to power machinery, support transportation, enhance processing, improve storage and sustain value-added activities. In this regard, the theory assumes that increases in energy consumption can stimulate output expansion by improving the productive capacity of key sectors of the economy, including agriculture.

In relation to the present study, the Energy-Led Growth Hypothesis provides a useful basis for explaining how energy consumption may influence agricultural sector production in Nigeria. Natural gas consumption may support agricultural production through electricity generation for irrigation, cold storage, agro-processing and other productive activities. Petroleum consumption, measured by Premium Motor Spirit, may facilitate farm transportation, fuel small generators, operate pumping systems and support the movement of agricultural inputs and outputs. Solar energy consumption may also strengthen agricultural production by providing decentralised power for rural farms, especially in areas where access to grid electricity remains weak. The significance of this theory therefore lies in its ability to show how energy consumption can improve productive efficiency and contribute to agricultural sector output.

Empirical Review

Recent empirical literature had increasingly treated energy consumption as a major factor in agricultural performance, especially because agriculture had depended on fuel, electricity and renewable power for mechanisation, irrigation, storage, processing and transportation. The reviews below therefore focused on studies that had examined energy use, renewable energy, fossil energy or related energy indicators in relation to agricultural output, agricultural value added, agricultural productivity or crop production.

Jouakeu and Fouopi (2026) studied the integration of renewable energies into the agricultural sector in Sub-Saharan Africa. The paper covered 40 countries from 1995 to 2023 and used the generalized method of moments, panel quantile regression and the Dumitrescu-Hurlin causality test. The paper examined renewable energypowered agricultural technologies, renewable energy consumption, arable land, labour, foreign direct investment, fertilizer consumption, forestry income and nitrous oxide emissions in relation to agricultural productivity. The findings showed that renewable energy-based agricultural technologies had a positive and significant effect on agricultural productivity. The panel quantile results further showed that the relationship varied across productivity levels, while the causality test indicated bidirectional links between agricultural productivity and renewable energy consumption, arable land, labour, foreign direct investment, forestry income and nitrous oxide emissions. The paper was strong in scope and methodology, but it focused on Sub-Saharan Africa as a panel and did not specifically examine Nigeria's natural gas, Premium Motor Spirit and solar energy consumption patterns.

Iwegbu et al. 2026) examined renewable energy consumption, clean technology trade and agricultural productivity in Africa. The paper covered 53 African countries from 1995 to 2023 and applied the cross-sectional augmented distributed lag estimation technique. Agricultural productivity was measured using four indicators, namely Solow residuals, agricultural output per capita, output per worker and stochastic frontier efficiency. The findings showed that renewable energy consumption and clean technology trade were relevant to agricultural productivity across Africa, suggesting that cleaner energy systems and renewable energy-related technologies could support productivity improvement in the sector. The paper was particularly useful because it used multiple agricultural productivity measures, making the analysis broader than studies that relied on one output indicator. However, the paper treated renewable energy consumption as an aggregate indicator and did not isolate solar energy consumption. It also did not include petroleum consumption or natural gas consumption, which limited its direct application to the present study's disaggregated energy-consumption structure.

Nor et al. (2026) investigated the nexus between renewable energy and agricultural productivity in Somalia. The paper covered 1990 to 2022 and applied the Autoregressive Distributed Lag model to estimate the effects of renewable energy consumption, trade openness and foreign direct investment on agricultural productivity. The findings revealed that renewable energy consumption had a positive and significant long-run effect on agricultural productivity, suggesting that renewable energy supported agricultural improvement over time. Trade openness also showed a positive effect, while foreign direct investment produced an unfavourable result, indicating that external investment did not necessarily translate into agricultural productivity gains within the period examined. The paper was relevant to the present discussion because solar energy consumption formed part of renewable energy pathways in agricultural systems. However, it did not disaggregate renewable energy into solar, hydro, wind or biomass, and it did not consider petroleum-based energy or natural gas, thereby making it less suitable for explaining the combined role of Nigeria's energy mix in agriculture.

Ogbokor and Sancho (2025) examined the impact of energy use on the agriculture sector in Nigeria. The paper covered time-series data sourced from the World Bank, International Energy Agency and Organisation for Economic Cooperation and Development, and it used an Autoregressive Distributed Lag approach to capture both short-run and long-run effects. The authors measured agricultural sector performance with agriculture value added, while energy use was captured through fossil fuel energy use, renewable energy use, alternative energy use and total electricity consumption. The findings showed that fossil fuel energy use had a negative and significant effect on agriculture value added in both the short run and long run, while renewable and alternative energy use had more favourable implications for agricultural performance. Total electricity consumption did not provide the same strong explanatory effect. However, the paper used broad fossil fuel and renewable energy indicators and did not separate natural gas, Premium Motor Spirit and solar energy, which limited its direct alignment with disaggregated energy policy decisions in Nigeria.

Ngarava et al. (2025) conducted a comparative study on renewable energy, agricultural development and economic development in the Netherlands and South Africa. The paper covered 1991 to 2021 and employed an Autoregressive Distributed Lag error correction model to determine short-run and long-run relationships among renewable energy consumption, value of agricultural production, gross domestic product, economic diversification, urban population, agricultural water withdrawal and trade balance. The results showed that in South Africa, renewable energy consumption and gross domestic product increased the value of agricultural production in the long run, while agricultural production also stimulated gross domestic product. In the Netherlands, no clear short-run or long-run relationship was found among renewable energy consumption, agricultural development and economic development. The paper was useful because it introduced a comparative country perspective, but its energy measurement focused mainly on renewable energy consumption and did not include petroleum consumption or natural gas consumption, which were central to the present Nigerian study.

Situma (2025) examined renewable energy consumption, non-renewable energy consumption and agricultural sector performance in Kenya. The paper used annual time-series data and employed econometric techniques to determine how energy sources affected agricultural output. Renewable energy was found to have supported agricultural sector performance, particularly where energy access improved productive use in rural areas. Non-renewable energy also remained relevant because agricultural activities still depended on fuel-based transport, machinery and processing. The findings implied that both clean and conventional energy sources had contributed to agricultural performance, although renewable energy offered stronger sustainability advantages. The paper was useful because it reflected the energy transition problem faced by many African economies, where agriculture still relied on fossil fuels while renewable energy gradually expanded. However, the analysis was conducted in Kenya and did not directly address Nigeria's natural gas electricity structure, Premium Motor Spirit consumption pattern or solar energy deployment, making the present Nigerian study necessary for country-specific evidence.

Baloyi and Maiwashe-Tagwi (2024) assessed the impact of renewable energy consumption, foreign direct investment, carbon dioxide emissions and economic growth on soybean production in South Africa. The paper used annual data and adopted the Autoregressive Distributed Lag model, while Dynamic Ordinary Least Squares, Fully Modified Ordinary Least Squares and Canonical Cointegrating Regression were used for robustness. The findings showed that renewable energy consumption positively influenced soybean production in the long run, while foreign direct investment also had a favourable effect. Carbon dioxide emissions had a negative effect in the short run, which implied that environmental pressure could reduce crop performance. The paper was important because it linked renewable energy consumption directly to a specific agricultural output, soybean production. Nevertheless, its concentration on a single crop and one country restricted the generalisation of the findings to broader agricultural sector production. It also did not include fossil fuel components such as Premium Motor Spirit and natural gas consumption.

Soni and Manogna (2024) investigated the dynamic nexus between agricultural productivity and renewable energy consumption in Brazil, Russia, India, China and South Africa. The paper covered 2000 to 2020 and used data from the World Bank and International Monetary Fund. The Autoregressive Distributed Lag approach was employed to estimate the short-run and long-run effects of renewable energy consumption, carbon emissions, foreign direct investment and financial inclusion on agricultural productivity. The findings showed that renewable energy consumption had a positive effect on agricultural productivity, suggesting that cleaner energy use supported agricultural performance in the selected emerging economies. Carbon emissions and foreign direct investment also showed positive effects, while financial inclusion, measured in terms of access, was not significant. The paper added cross-country evidence, but its renewable energy variable was aggregated and did not separate solar energy from other renewable sources. It also excluded petroleum and natural gas consumption, which were central to the Nigerian energy mix.

Abah et al. (2023) examined the effect of energy consumption on agricultural productivity in Nigeria. The paper covered 1981 to 2020 and used annual time-series data obtained from the Food and Agriculture Organization. The authors applied descriptive statistics, the Augmented Dickey-Fuller unit root test, Johansen cointegration test and Vector Error Correction Model. Energy consumption was measured using fuel wood consumption, charcoal consumption and electricity consumption, while agricultural productivity served as the dependent variable. The findings showed that fuel wood had a negative and significant long-run effect on agricultural productivity, charcoal had a positive and significant long-run effect, while electricity consumption had a negative and significant effect at the 10 percent level. In the short run, fuel wood remained negative, while charcoal remained positive. The paper was useful, but it did not include natural gas, Premium Motor Spirit or solar energy, making its energy measurement different from the present study.

Lawal (2023) assessed the nexus among economic growth, energy consumption, agricultural output and carbon dioxide emissions in Africa. The paper covered 1980 to 2019 and used panel data for African countries. The method of analysis combined time-domain and frequency-domain panel Granger causality techniques in order to compare causal relationships across different time horizons. The findings indicated that energy consumption had important causal links with economic growth and emissions, while agricultural value addition and forest variables played moderating roles in the broader energy-growth-environment framework. The results supported the feedback hypothesis between energy and economic growth in Africa and showed that causality differed depending on the frequency horizon. Although the paper was relevant because it brought agricultural output into the energy-growth discussion, its main emphasis was causality among growth, energy and emissions rather than the direct effect of natural gas, petroleum or solar energy on agricultural production. Its Africa-wide scope also reduced country-specific policy interpretation for Nigeria.

METHODOLOGY

This paper adopted the ex-post facto research design because it relies on already existing annual time-series data. The design is appropriate since the variables under investigation cannot be manipulated by the researcher, but can only be observed as they have occurred over time. In line with the energy–growth nexus perspective and the empirical literature reviewed, ex-post facto design allows the paper to examine historical patterns, trends, and relationships among the variables.

The paper used annual secondary time-series data covering the period 1986 to 2025. The data are quantitative in nature and were drawn from credible national and international statistical sources. Agricultural sector contribution to GDP, was sourced from the National Bureau of Statistics (2026) and the Central Bank of Nigeria (2025). Data on natural gas consumption, represented by electricity production from natural gas sources as a percentage of total electricity production, were obtained from the World Bank (2025) and complemented with Enerdata (2025). Petroleum consumption, measured by Premium Motor Spirit consumption in thousand barrels per day, was sourced from the Energy Institute (2024), OPEC (2025), the Energy Commission of Nigeria (2025), and Enerdata (2025). Solar energy consumption data were obtained from REA publications, NERC (2024), and Enerdata (2025).

Anchored on the energy-led growth hypothesis, this paper adapted its model specification from Ogbokor and Sancho (2025), who investigated the effect of energy use on the agricultural sector in Nigeria. On this basis, the functional and econometric model for the paper is expressed as follows:

$$ASP_t = \alpha_0 + \alpha_1 NGC_t + \alpha_2 PC_t + \alpha_3 SEC_t + u_t \quad (1)$$

Where;

ASP is Agricultural sector productions

NGC is natural gas consumption

PC is petroleum consumption (Premium Motor Spirit)

SEC is solar energy consumption

α_0 intercept

$\alpha_1, \alpha_2, \alpha_3$ are the coefficients of natural gas consumption, petroleum consumption (Premium Motor Spirit), solar energy consumption

u_t residual

The empirical analysis commenced with the conduct of unit root tests to examine the stationarity characteristics of the time-series variables. This procedure was necessary because macroeconomic and energy-related series often contain trends that may cause non-stationarity over time. Following the approach developed by Dickey and Fuller (1979), the unit root test helped to determine whether the variables were stationary at level or required differencing before estimation. Establishing the order of integration was important because estimating non-stationary variables without proper transformation could produce spurious regression results and weaken the reliability of the paper's conclusions. The Augmented Dickey-Fuller test was therefore specified as follows:

$$\Delta Y_t = \alpha_0 + \beta t + \gamma Y_{t-1} + \sum_{i=1}^{p} \delta_i \Delta Y_{t-i} + \varepsilon_t \quad (2)$$

Where ΔY_t represented the first difference of the variable under consideration, α_0 was the constant term, tcaptured the time trend, Y_{t-1} denoted the lagged level of the variable, $\sum_{i=1}^{p} \delta_i \Delta Y_{t-i}$ represented the lagged differences included to correct for serial correlation, and $\varepsilon_t$was the error term.

After establishing the order of integration of the variables, the paper proceeded to examine whether a stable long-run relationship existed among the series using the Engle and Granger cointegration approach. This technique was appropriate because it is designed for time-series models in which the variables are integrated of order one, I(1). The purpose of the test was to determine whether the selected energy consumption indicators and agricultural sector production moved together in the long run despite possible short-run fluctuations. The Engle and Granger procedure first required estimating the long-run regression model and then testing the residuals obtained from the model for stationarity.

The residual-based unit root test is specified as:

$$\Delta \hat{\mu}_t = \rho \hat{\mu}_{t-1} + \sum_{i=1}^{p} \lambda_i \Delta \hat{\mu}_{t-i} + \varepsilon_t \quad (3)$$

where $\hat{\mu}_t$ represented the estimated residual from the long-run regression. If the residual series was stationary at level, I(0), the variables were considered cointegrated, implying the existence of a long-run equilibrium relationship among the variables.

After confirming the presence of a long-run relationship among the variables, the paper estimated the long-run model using the Dynamic Ordinary Least Squares technique. This method was appropriate because the variables were integrated of order one and cointegrated, making it necessary to apply an estimator capable of producing reliable long-run coefficients.

The general specification of the DOLS model is given as:

$$y_t = \alpha + \sum_{i=1}^{k} \beta_i x_{it} + \sum_{j=-p}^{q} \delta_j \Delta x_{t-j} + \grave{o}_t \quad (4)$$

Where:

y_t is the dependent variable.

x_{it} represents explanatory variables affecting y_t

$\sum_{j=-p}^{q} \delta_j \Delta x_{t-j}$ captures the leads and lags of the first differences of the independent variables to account for endogeneity.

α is the intercept.

β_i represents long-run coefficients of explanatory variables.

$\grave{o}_t$ is the error term.

For this paper, it can be expressed as:

$$ASP_t = \alpha_0 + \alpha_1 NGC_t + \alpha_2 PC_t + \alpha_3 SEC_t + \sum_{j=-p}^{q} \alpha_j \Delta NGC_{t-j} + \sum_{j=-p}^{r} \alpha_j \Delta PC_{t-j} + \sum_{j=-p}^{s} \alpha_j \Delta SEC_{t-j} + u_t \quad (5)$$

Dynamic Ordinary Least Squares was preferred because it corrects for possible endogeneity among the regressors by including leads and lags of the first-differenced explanatory variables. It also helps to reduce serial correlation in the error term, thereby improving the consistency and efficiency of the estimated results.

RESULTS AND DISCUSSION

Descriptive Statistics Results

Descriptive statistics provided a preliminary summary of the behaviour, spread and distributional properties of the variables used in the paper. It helped to show the average performance of agricultural sector production and the selected energy consumption indicators, the degree of variation around their means, and whether the series followed a normal distribution. In line with the paper, the results offered useful insights into the historical patterns of agricultural sector production, natural gas consumption, petroleum consumption and solar energy consumption in Nigeria.

Table 1: Summary Statistics

	ASP	NGC	PC	SEC
Mean	14234.46	66.45484	335.4575	58.43250
Maximum	62825.57	86.97578	668.3000	380.4200
Minimum	35.70264	44.68114	232.0000	0.070000
Std. Dev.	17644.69	13.23244	114.5233	94.99666
Skewness	1.346597	-0.23738	1.466362	1.964836
Kurtosis	3.771021	1.764856	4.013194	6.039813
Jarque-Bera	13.07961	2.918297	16.04571	41.13797
Probability	0.001445	0.232434	0.000328	0.000000
Observations	40	40	40	40

Source: Researcher's Computation Using EViews-12 (2026)

Agricultural sector production (ASP) recorded a mean value of 14,234.46, indicating the average level of agricultural sector contribution to Gross Domestic Product over the period under review. The maximum value of 62,825.57 and minimum value of 35.70 showed a very wide range, suggesting that agricultural production increased substantially over time. The standard deviation of 17,644.69 was higher than the mean, indicating strong dispersion and considerable fluctuations in agricultural sector production. The skewness value of 1.3466 showed that ASP was positively skewed, meaning that the distribution had a longer right tail, reflecting the sharp rise in agricultural output in later years. The kurtosis value of 3.7710 exceeded the normal benchmark of 3, implying that the series was leptokurtic and had relatively peaked distribution with heavier tails. The Jarque-Bera statistic of 13.0796 with a probability value of 0.0014 showed that agricultural sector production was not normally distributed at the 5 percent level.

Natural gas consumption (NGC) had a mean value of 66.4548, suggesting that, on average, natural gas accounted for a sizeable share of energy consumption within the period. Its maximum value of 86.9758 and minimum value of 44.6811 indicated noticeable variation, although the range was not as wide as that of agricultural sector production. The standard deviation of 13.2324 showed moderate dispersion from the mean, implying that natural gas consumption fluctuated, but not excessively. The skewness value of -0.2374 indicated a mild negative skewness, meaning that the distribution was slightly tilted to the left. The kurtosis value of 1.7649 was below 3, showing that NGC was platykurtic, with a flatter distribution than the normal curve. The Jarque-Bera statistic of 2.9183 and probability value of 0.2324 indicated that natural gas consumption was normally distributed, since the probability value was greater than 0.05.

Petroleum consumption (PC), measured by Premium Motor Spirit, had a mean value of 335.4575, showing the average level of petroleum consumption over the paper period. The maximum value of 668.3000 and minimum value of 232.0000 reflected a relatively wide difference between the highest and lowest consumption levels, indicating changes in fuel demand over time. The standard deviation of 114.5233 showed that petroleum consumption varied considerably around its mean. The skewness value of 1.4664 indicated positive skewness, meaning that the distribution had a longer right tail, reflecting higher petroleum consumption in some periods. The kurtosis value of 4.0132 was above 3, showing a leptokurtic distribution with heavier tails than the normal distribution. The Jarque-Bera statistic of 16.0457 and probability value of 0.0003 suggested that petroleum consumption was not normally distributed at the 5 percent level.

Solar energy consumption (SEC) recorded a mean value of 58.4325, indicating that the average level of solar energy consumption remained relatively low compared with its later-period values. The maximum value of 380.4200 and minimum value of 0.0700 showed a very wide range, reflecting the gradual but strong expansion of solar energy use over time. The standard deviation of 94.9967 was greater than the mean, suggesting high variability in solar energy consumption. The skewness value of 1.9648 showed strong positive skewness, implying that the series was concentrated around lower values in earlier years but increased sharply in later years. The kurtosis value of 6.0398 was far above 3, indicating a highly leptokurtic distribution with heavy tails and extreme values. The Jarque-Bera statistic of 41.1380 and probability value of 0.0000 confirmed that solar energy consumption was not normally distributed at the 5 percent level.

Unit Root Test

The unit root test was conducted to determine the stationarity properties of the variables used in the paper. This was necessary because time-series variables often exhibit trends over time, and estimating non-stationary series at level may produce misleading regression results.

Table 2: Unit Root Test Results

Variable	Levels: ADF Test Statistics (Critical Values)	1st Difference: ADF Test Statistics (Critical Values)	Order of Integration
ASP	-1.974049 (-3.529758)	-3.288187 (-3.202445)***	I(1)
NGC	-0.680628 (-3.529758)	-5.546966 (-4.226815)*	I(1)
PC	-1.173779 (-4.211868)	-7.137579 (-4.219126)*	I(1)
SEC	-1.364203 (-3.557759)	-3.709049 (-3.562882)**	I(1)

Note: The tests include intercept with trend; * , **and *** significant at 1, 5 and 10 percent.

Source: Researcher’s Computation Using EViews-12 (2026)

Agricultural sector production (ASP) became stationary at first difference. At level, the ADF statistic of -1.974049 was not more negative than the critical value of -3.529758, indicating non-stationarity. However, after first differencing, the ADF statistic became -3.288187, which was more negative than the critical value of -3.202445 at the 10 percent level. This showed that ASP achieved stationarity after first differencing and was therefore integrated of order one, I(1).

Natural gas consumption (NGC) was also found to be stationary after first differencing. The level ADF statistic of -0.680628 was not sufficient to reject the null hypothesis of unit root when compared with the critical value of -3.529758. However, at first difference, the ADF statistic of -5.546966 was more negative than the critical value of -4.226815 at the 1 percent level. This indicated strong evidence of stationarity after differencing. Therefore, natural gas consumption was integrated of order one, I(1), suggesting that its original series was non-stationary but became stable after taking the first difference.

Petroleum consumption (PC), measured by Premium Motor Spirit, became stationary at first difference. At level, the ADF statistic of -1.173779 was less negative than the critical value of -4.211868, indicating that the series contained a unit root. After first differencing, the ADF statistic increased in absolute terms to -7.137579, which was more negative than the critical value of -4.219126 at the 1 percent level. This confirmed that PC was stationary after first differencing and was integrated of order one, I(1).

Solar energy consumption (SEC) was equally stationary after first differencing. The ADF statistic at level was -1.364203, which was not more negative than the critical value of -3.557759, meaning that the null hypothesis of unit root could not be rejected. However, at first difference, the ADF statistic became -3.709049, which was more negative than the critical value of -3.562882 at the 5 percent level. This showed that SEC became stationary after first differencing and was integrated of order one, I(1).

Co-integration Test

The Engle-Granger cointegration test was conducted to determine whether a stable long-run equilibrium relationship existed among agricultural sector production, natural gas consumption, petroleum consumption and solar energy consumption in Nigeria.

Table 3: Cointegration Test - Engle-Granger

Test Statistic	Value	Prob.*
Engle-Granger tau-statistic	-3.187352	0.0022
Engle-Granger z-statistic	-12.83876	0.0000

*MacKinnon (1996) p-values.

Source: Researcher’s Computation Using EViews-12 (2026)

Focusing on the Engle-Granger tau-statistic at the 5 percent level of significance, the result showed a tau-statistic value of -3.187352 with a probability value of 0.0022. Since the probability value was less than 0.05, the null hypothesis of no cointegration was rejected. This implied that there was a statistically significant long-run relationship among the variables in the model. In other words, agricultural sector production and the selected energy consumption indicators did not drift apart permanently over time, but rather maintained a stable long-run association.

DOLS Regression Estimates

Having confirmed the existence of a long-run cointegrating relationship between energy consumption indicators and agricultural sector production in Nigeria, the paper proceeded to estimate the long-run equation using the Dynamic Ordinary Least Squares technique. The DOLS approach was appropriate because it provides reliable long-run estimates by accounting for possible endogeneity among the explanatory variables and correcting for serial correlation through the inclusion of leads and lags of the differenced regressors. The outcome of the DOLS estimation is presented in Table 4.

INTERNATIONAL JOURNAL OF RESEARCH AND INNOVATION IN SOCIAL SCIENCE (IJRISS)
ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue XV August 2026 | Special Issue on Economics

Table 4: DOLS Result

Dependent Variable: ASP

Variable	Coefficient	Std. Error	t-Statistic	Prob.
NGC	0.0789	0.0242	3.2648	0.0033
PC	-0.0176	0.0059	-2.9680	0.0067
SEC	1.2940	0.5397	2.3979	0.0246
C	-3.5617	1.9865	-1.7929	0.0856
Reliability estimates				
R-squared	0.7647			
Adjusted R-squared	0.6470			
Long-run variance	0.3728			

Source: Researcher's Computation Using EViews-12 (2026)

Natural gas consumption had a coefficient of 0.0789, a t-statistic of 3.2648 and a probability value of 0.0033. Since the probability value was below the 5 percent level of significance, natural gas consumption had a positive and statistically significant effect on agricultural sector production in the long run. The coefficient implied that a one percentage point increase in natural gas consumption sources, as a share of total electricity production, was associated with an approximate 7.89 percent increase in agricultural sector production, holding solar energy consumption and petroleum consumption constant.

Petroleum consumption, measured as Premium Motor Spirit consumption in thousand barrels per day, had a coefficient of -0.0176, a t-statistic of -2.9680 and a probability value of 0.0067. The result was statistically significant at the 5 percent level, indicating that petroleum consumption had a negative long-run effect on agricultural sector production. The coefficient implied that a one thousand barrels per day increase in PMS consumption was associated with an approximate 1.76 percent decline in agricultural sector production, holding solar energy consumption and natural gas consumption constant.

Solar energy consumption, measured in gigawatt-hours, had a coefficient of 1.2940, a t-statistic of 2.3979 and a probability value of 0.0246. Since the probability value was below 0.05, solar energy consumption had a positive and statistically significant effect on agricultural sector production in the long run. The coefficient indicated that a one gigawatt-hour increase in solar energy consumption was associated with an approximate 129.4 percent increase in agricultural sector production, holding natural gas and petroleum consumption constant.

The reliability estimates provided additional information on the explanatory strength and overall usefulness of the Dynamic Ordinary Least Squares model. The R-squared value of 0.7647 indicated that approximately 76.47 percent of the variations in agricultural sector production were explained by the selected energy consumption indicators, namely natural gas consumption, petroleum consumption measured by Premium Motor Spirit, and solar energy consumption.

The adjusted R-squared value of 0.6470 further showed that, after adjusting for the number of explanatory variables in the model, about 64.70 percent of the variation in agricultural sector production was still explained by the energy consumption indicators. Since the adjusted R-squared penalises the model for the inclusion of additional variables, its value confirmed that the model remained reasonably reliable and that the selected proxies of energy consumption had meaningful relevance in explaining agricultural sector production in Nigeria.

ISSN No. 2454-6186 | DOI: 10.47772/IJRISS | Volume X Issue XV August 2026 | Special Issue on Economics

The long-run variance value of 0.3728 indicated the estimated variance of the error term in the long-run relationship. A relatively low long-run variance suggested that the deviations from the estimated long-run equilibrium path were not excessively large.

DISCUSSION OF FINDINGS

Findings from the paper showed that natural gas consumption had a positive and significant impact on agricultural sector production in Nigeria. The implication of this positive impact is that the use of natural gas as a source of electricity generation had supported agricultural sector contribution to Gross Domestic Product through improved access to productive energy. Since natural gas consumption was measured as electricity production from natural gas sources as a percentage of total electricity production, the result suggests that an increase in the share of gas-based electricity could improve energy availability for irrigation, milling, storage, agro-processing, preservation and other farm-related productive activities. This finding agrees with Lawal (2023), who found that energy consumption had important links with economic growth and agricultural output in Africa. It also supports the position of Iwegbu et al. (2026), who showed that modern energy and clean technology trade improved agricultural productivity across African countries. The outcome, however, differs from Ogbokor and Sancho (2025), whose findings showed that fossil fuel energy use had a negative and significant effect on agriculture value added in Nigeria. The difference may be traced to the nature of measurement, as this paper used natural gas specifically, while Ogbokor and Sancho used a broader fossil fuel energy indicator.

More so, findings from the paper also revealed that petroleum consumption, measured by Premium Motor Spirit in thousand barrels per day, had a negative and significant impact on agricultural sector production in Nigeria. The negative result implies that increases in petrol consumption reduced agricultural sector contribution to Gross Domestic Product over the paper period. This outcome suggests that heavy dependence on Premium Motor Spirit may have raised production and distribution costs for farmers and agro-processors, especially through generator use, farm machinery, irrigation pumps, transportation of inputs and movement of agricultural produce to markets. Where petrol prices and supply conditions were unstable, increased petroleum consumption may not have translated into higher productive efficiency, but rather into higher operating costs. This agrees with Ogbokor and Sancho (2025), who found that fossil fuel energy use had a negative and significant effect on agriculture value added in Nigeria. It also relates to Abah et al. (2023), whose study showed that some energy consumption indicators had negative effects on agricultural productivity in Nigeria. Similarly, Lawal (2023) linked energy consumption and agricultural activities with carbon emission concerns, suggesting that fossil energy dependence may create environmental and productivity burdens.

The result also showed that solar energy consumption had a positive and significant impact on agricultural sector production in Nigeria. The result implies that increased solar energy use contributed positively to agricultural sector contribution to Gross Domestic Product. The implication is that solar energy had become increasingly useful in addressing energy access gaps within rural agricultural communities, especially where grid electricity remained inadequate or unreliable. Solar energy could support irrigation systems, cold storage, drying, lighting, water pumping, small-scale processing and other farm-level operations. This finding agrees with Soni and Manogna (2024), who found that renewable energy consumption improved agricultural productivity in BRICS economies. It also supports Ngarava et al. (2025), who found that renewable energy consumption increased the value of agricultural production in South Africa in the long run. In the same direction, Nor et al. (2026) found that renewable energy consumption had a positive effect on agricultural productivity in Somalia, while Baloyi and Maiwashe-Tagwi (2024) showed that renewable energy consumption positively influenced soybean production in South Africa. This implies that solar energy expansion may strengthen Nigeria’s agricultural sector if it is deliberately linked to productive rural energy needs.

CONCLUSION AND RECOMMENDATIONS

Based on the findings, the paper concluded that energy consumption played a significant role in explaining agricultural sector production in Nigeria. The results established that natural gas consumption improved agricultural sector production, suggesting that gas-based electricity remained important for irrigation, processing, storage and other agro-allied activities. Solar energy consumption also exerted a positive and significant effect, indicating that renewable energy expansion could strengthen rural farm operations, especially where grid electricity remained unreliable. Conversely, petroleum consumption measured by Premium Motor Spirit had a negative and significant impact, implying that heavy reliance on petrol increased production and distribution costs and weakened agricultural performance. Therefore, the paper concluded that Nigeria's agricultural sector benefited more from cleaner and electricity-supporting energy sources than from petrol-dependent energy use. Sustainable agricultural growth would require expanding gas-to-power infrastructure and solar energy access while reducing costly PMS dependence among rural farmers.

Based on the findings, the paper made the following recommendations:

Given that natural gas consumption had a positive and significant impact on agricultural sector production, the Federal Ministry of Petroleum Resources, Nigerian Midstream and Downstream Petroleum Regulatory Authority, Nigerian Upstream Petroleum Regulatory Commission, Nigerian Gas Infrastructure Company, and Federal Ministry of Agriculture and Food Security should expand gas-to-power projects that directly serve agro-processing clusters, irrigation schemes, grain milling centres and cold storage facilities. This should be done by prioritising gas supply to agricultural processing zones and rural industrial parks, especially in major food-producing states. The Rural Electrification Agency and Nigerian Electricity Regulatory Commission should also support embedded gas-powered mini-grids for large farming communities and agro-allied enterprises where national grid supply remains unreliable.

Since petroleum consumption, measured by Premium Motor Spirit, had a negative and significant impact on agricultural sector production, the Federal Ministry of Agriculture and Food Security, Federal Ministry of Transportation, Nigerian Midstream and Downstream Petroleum Regulatory Authority, and state ministries of agriculture should reduce farmers' dependence on petrol-powered production and distribution systems. This can be achieved by promoting energy-efficient farm machinery, supporting shared tractor and harvester hiring centres, and improving rural transport infrastructure to lower the cost of moving inputs and produce. The Bank of Agriculture, Development Bank of Nigeria and commercial banks should provide targeted credit facilities for farmers and agro-processors to replace petrol generators and pumps with cleaner and cheaper energy alternatives.

More so, since solar energy consumption had a positive and significant impact on agricultural sector production, the Rural Electrification Agency, Energy Commission of Nigeria, Nigerian Electricity Regulatory Commission, Federal Ministry of Power, and Federal Ministry of Agriculture and Food Security should scale up solar-powered irrigation, cold storage, drying systems and agro-processing equipment in rural farming communities. Solar energy projects should be tied to productive agricultural use, not only household lighting. The Rural Electrification Agency should expand solar mini-grid programmes to food-producing clusters, while the Bank of Industry and Bank of Agriculture should provide low-interest financing for solar pumps, solar dryers, solar cold rooms and solar-powered processing machines.

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Table A: Data Presentation

year	**Solar Energy Consumption (GWh)**	**Natural gas consumption sources (% of total)**	**Petroleum Consumption (PMS Thousand Barrels/Day)**	**Agricultural productions (Annual (₦' Billion))**
1986	0.07	48.76	251	35.70
1987	0.1	48.84	253	50.29
1988	0.14	48.91	254	73.76
1989	0.19	48.99	255	88.26
1990	0.25	53.65	251	106.63
1991	0.35	46.43	259	123.24
1992	0.48	44.68	265	184.12
1993	0.65	48.12	271	295.32
1994	0.85	53.18	252	445.27
1995	1.12	46.23	284	790.14
1996	1.45	45.74	286	1,070.51
1997	1.85	65.30	277	1,211.46
1998	2.35	61.78	260	1,341.04
1999	2.95	61.79	252	1,426.97
2000	3.68	62.72	281	1,508.41
2001	4.56	62.64	306	2,015.42
2002	5.62	62.32	304	4,251.52

2003	6.89	63.71	288	4,585.93
2004	8.41	67.06	277	4,935.26
2005	10.25	67.55	312	6,032.33
2006	12.45	73.46	284	7,513.30
2007	15.08	73.69	232	8,551.98
2008	18.21	74.67	263	10,100.33
2009	21.95	78.69	253	11,625.44
2010	26.42	76.90	290	13,048.89
2011	31.75	79.57	287	14,037.83
2012	38.11	81.78	279	15,816.00
2013	45.68	84.35	283	16,816.55
2014	54.71	86.98	277	18,018.61
2015	65.45	85.70	428	19,636.97
2016	78.23	84.39	425	21,523.51
2017	93.42	77.80	438	23,952.55
2018	111.46	78.92	452	27,371.30
2019	132.89	76.71	446	31,904.14
2020	158.35	79.55	430	37,241.61
2021	188.64	79.45	495	41,126.06
2022	224.75	75.46	560	47,944.06
2023	267.89	70.42	575	53,273.14
2024	319.23	67.62	668.3	56,478.98
2025	380.42	63.68	615	62,825.57

Sources: Central Bank of Nigeria. (2025). 2024 statistical bulletin: Domestic production, consumption and prices. Central Bank of Nigeria.

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