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Impact of Energy Equity on The Growth of Agro-Processing Sector in Nigeria: 1986-2024

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ABSTRACT
This study examined the impact of energy equity on the growth of the agro-processing sector in Nigeria from 1986 to 2024. The motivation for the study stemmed from the persistent underperformance of the agro-processing sector despite Nigeria's vast agricultural base and repeated government interventions aimed at stimulating rural industrialization and economic diversification.The study employed an ex-post facto research design, while the Fully Modified Ordinary Least Squares (FMOLS) technique was used for estimation, as it effectively addressed issues of endogeneity and serial correlation in the model.The findings revealed that fossil fuel subsidies had a negative and statistically significant impact on the agro-processing sector, indicating that such subsidies, instead of promoting productivity, have hindered sectoral growth due to poor targeting and inefficiencies. Access to electricity also showed a negative and significant effect, suggesting that unreliable and costly grid power has imposed additional burdens on agro-processors. In contrast, renewable energy consumption had a positive and significant influence, confirming its role as a viable and sustainable energy source for rural-based processing enterprises.Based on these outcomes, the study recommended that the Federal Government, through institutions such as the Ministry of Finance and the Petroleum Products Pricing Regulatory Agency (PPPRA), should redirect fuel subsidy spending toward rural energy infrastructure. The Nigerian Electricity Regulatory Commission (NERC) and the Rural Electrification Agency (REA) were advised to improve electricity reliability and expand off-grid solutions. Additionally, the Ministry of Power and the Bank of Industry (BoI) were encouraged to increase investment in renewable energy technologies tailored for agro-processing. Strengthening these targeted interventions would enhance the sector's productivity, reduce energy-related constraints, and support Nigeria's broader goals of economic growth and rural development.

Keywords: *Energy equity, Agro-processing, Fossil fuel subsidies, Electricity access, Renewable energy*
JEL Codes: *Q42, Q48, O13, L66, O55*

I. Introduction

Energy equity represents the fair distribution of energy resources and services across populations, ensuring that all segments of society have reliable, affordable, and sustainable access to energy. Globally, energy equity remains a significant challenge, with disparities existing between developed and developing nations, urban and rural areas, and across different income levels. According to the International Energy Agency (IEA) (2024), approximately 733 million people worldwide still lacked access to electricity in 2022, with 80% of this population concentrated in Sub-Saharan Africa. The disparity is further highlighted by the fact that while developed nations consume an average of 10,000 kWh per capita annually, developing nations average below 1,000 kWh, illustrating a profound energy divide that impacts economic development, particularly in sectors like agro-processing (Dlamini& Mpofu, 2024).

Energy equity can be measured through various proxies, including fossil fuel subsidies, access to electricity, and renewable energy consumption. Fossil fuel subsidies represent government interventions that artificially lower the cost of fossil fuels, often benefiting wealthier segments of society disproportionately while constraining resources that could be directed toward more equitable and sustainable energy solutions. The International Monetary Fund (IMF) estimated that global fossil fuel subsidies amounted to $5.9 trillion in 2022, equivalent to 6.8% of global GDP, with significant variations across regions (IMF, 2023). Access to electricity, another critical measure of energy equity, refers to the percentage of the population with reliable connections to electricity grids or off-grid solutions, which directly impacts productivity and quality of life. The World Bank (2024) reports that global access to electricity reached 91% in 2022, representing significant progress but still leaving hundreds of millions without this essential service. Renewable energy consumption, measured as a percentage of total final energy consumption, indicates a country's transition toward cleaner, more sustainable energy sources that can enhance energy security and reduce environmental impacts. The IEA (2024) notes that renewable energy constituted 19% of global final energy consumption in 2022, showing an upward trend but with notable regional disparities.

Energy equity policy in Nigeria has evolved from broad fossil fuel subsidies in the 1980s and 1990s to more targeted interventions aimed at expanding electricity access and promoting renewable energy. The removal of fuel subsidies began in the early 2010s, intensifying after 2015 to reduce fiscal burdens and redirect funds toward infrastructure. Key initiatives such as the Rural Electrification Strategy and Implementation Plan (RESIP) and Nigeria's Energy Transition Plan (2022) aimed to improve energy access and support clean energy adoption. Available data from World bank (2023) and IEA (2024) shows that access to electricity in Nigeria has shown steady improvement from 28.3% in 1986 to 62.3% in 2024. This improvement represents significant progress but masks substantial urban-rural disparities. The Nigerian Rural Electrification Agency (2023) reported that while urban electricity access exceeded 80% in 2022, rural access remained below 40%, affecting agricultural communities disproportionately. Fossil fuel subsidies in Nigeria have fluctuated considerably over the years, ranging from 0.2% of GDP in 1986 to a peak of 4.1% in 2012, before declining to 0.5% in 2024. These subsidies have been controversial, with the International Institute for Sustainable Development (IISD) (2023) estimating that only 10% of subsidy benefits reach the poorest 50% of Nigerians, raising questions about their equity implications. Renewable energy consumption in Nigeria has declined from 91.4% in 1986 to 79.5% in 2024, which, similar to the broader Sub-Saharan African context, primarily reflects traditional biomass use rather than modern renewables. Ibrahim and Okoro (2023) reported that modern renewable energy sources constituted less than 2% of Nigeria's energy mix in 2023, indicating limited progress in transitioning to cleaner energy technologies. Thus, Nigeria's energy equity profile is characterized by growing electricity access, volatile subsidies, and a transition in renewable energy composition, highlighting both progress and the need for coordinated energy reform.

The agro-processing sector globally has experienced significant growth, contributing approximately 4.5% to global GDP in 2022 and employing over 450 million people worldwide (Food and Agriculture Organization [FAO], 2023). This sector transforms raw agricultural commodities into processed products, adding value and extending shelf life while creating employment opportunities across the value chain. In developed economies, agro-processing contributes between 3-5% to GDP, with high levels of mechanization and energy efficiency. In contrast, developing economies often see contributions of 5-10% to GDP, reflecting the greater relative importance of agriculture in these economies but also lower productivity levels due in part to energy constraints (FAO, 2023). The Uzochukwu et al. (2024) identified reliable and affordable energy access as one of the top three constraints to agro-processing growth in developing countries, alongside market access and financing.

Nigeria's agro-processing sector has however experienced a prolonged period of stagnation and underperformance. Despite its potential, the sector's contribution to GDP has declined from 7.05% in 1999 to just 2.36% in 2024, indicating a persistent downturn over the past two decades (FAO, 2023; FMARD, 2024). This reversion is alarming given that Nigeria has a vast agricultural base and a growing domestic market. The underperformance reflects systemic challenges such as limited infrastructure, weak value chain integration, and, crucially, inadequate access to reliable and equitable energy sources required for processing, storage, and distribution. The decline in sectoral growth also implies reduced competitiveness, poor value addition, and minimal export readiness. In response to these challenges, policymakers have implemented several initiatives aimed at revitalizing the sector. These include targeted agricultural interventions like the Agricultural Transformation Agenda (ATA), the Anchor Borrowers' Programme (ABP), and fiscal incentives for agro-processing firms. However, despite these efforts, the sector has not achieved the anticipated turnaround. The contribution of agro-processing to Nigeria's GDP has continued to decline, falling by over 15% between 2015 and 2024.

Therefore, given that equitable energy access is a critical enabler of industrial growth, rural development, and economic diversification, it is in the interest of this study to conduct an analysis of how these components of energy equity have impacted the agro-processing sector's growth in Nigeria over the period 1986 to 2024.

II. Literature Review

Conceptual Clarifications

Energy Equity

Energy equity is increasingly recognized in scholarly discourse as a multidimensional concept that captures the fairness and inclusiveness of energy access, affordability, and sustainability across different segments of society. According to Sovacool et al. (2022), energy equity encompasses the distribution of energy resources and services in a way that minimizes disparities among socio-economic groups while ensuring that all individuals and communities have the opportunity to benefit from energy development. It is not solely about access but also concerns how energy policies and systems affect different populations, especially marginalized and rural groups. This broad definition aligns with the Sustainable Development Goal 7, which aims to ensure access to affordable, reliable, sustainable, and modern energy for all.

One of the key proxies for assessing energy equity is fossil fuel subsidies. These are financial supports provided by governments to reduce the price of fossil fuels below market levels. While they are often justified as tools for economic relief, their long-term effects on equity are contested. Fossil fuel subsidies have been criticized for being regressive, as they tend to benefit wealthier populations who consume more energy, thereby worsening inequality (International Energy Agency, 2024). In the context of Nigeria, fossil fuel subsidies have historically consumed significant public resources without proportionately benefiting low-income and rural populations. According to Ajayi and Ezeoha (2023), the misalignment between subsidy objectives and outcomes has hindered equitable energy distribution, especially in sectors like agriculture where access to modern energy is crucial for processing and preservation.

Access to electricity is another critical dimension of energy equity and arguably the most visible indicator of energy disparity. It is typically measured as the percentage of the population with reliable and affordable access to electricity. The World Energy Council (2023) defines electricity access as "the availability of an electricity connection at the household level and the ability to utilize electrical services safely, reliably, and affordably." This definition extends beyond mere connectivity to emphasize the quality and economic accessibility of service. The quality and reliability of electricity, not just its availability, are central to the notion of equity, as frequent power outages or high costs effectively exclude vulnerable groups from benefiting from grid connectivity.

Renewable energy consumption, measured as the share of renewables in total final energy consumption, provides insight into the sustainability and inclusiveness of a country's energy system. Renewable energy is often considered a tool for enhancing energy equity due to its decentralization potential and environmental benefits. According to Nwachukwu et al. (2022), transitioning to renewable energy in Nigeria could bridge the energy access gap, particularly in off-grid rural areas, by enabling localized and affordable energy solutions. However, the current reliance on traditional biomass, which still accounts for a large portion of Nigeria's renewable consumption, presents challenges regarding health impacts and inefficiency. The shift toward modern renewables like solar and mini-hydropower is essential for achieving both environmental and social equity. The IEA (2024) notes that integrating renewables into national grids and off-grid systems can support inclusive economic growth and empower marginalized communities, particularly when aligned with rural development strategies.

Growth of agro-processing sector

The concept of growth of the agro-processing sector has gained increasing attention in development literature due to its role in linking agriculture with industry and enhancing value addition within food systems. Agro-processing broadly refers to the transformation of raw agricultural commodities into processed or semi-processed products through mechanical, chemical, or biological operations. Reardon, Tschirley, Liverpool-Tasie, Awokuse, and Jayne (2023) described agro-processing as the industrial handling and transformation of agricultural outputs such as grains, roots, livestock products, and fruits into consumable or market-ready products. According to the authors, the growth of the agro-processing sector reflects the expansion in production capacity, investment, and technological application within agro-based industries, which ultimately increases their contribution to national output and employment.

In a similar perspective, the United Nations Industrial Development Organization (UNIDO, 2024) defined the growth of the agro-processing sector as the sustained increase in the economic performance, output volume, and value-added activities of industries engaged in processing agricultural raw materials. This definition emphasizes the measurable improvement in productivity, industrial output, employment generation, and technological upgrading within agro-based manufacturing. UNIDO further noted that the expansion of agro-processing activities promotes rural industrialization, strengthens agricultural value chains, and enhances the competitiveness of domestic food industries.

Within the Nigerian context, Adeyemi and Adebayo (2024) defined agro-processing sector growth as the continuous improvement in the scale, productivity, and economic contribution of firms involved in transforming agricultural commodities into finished or semi-finished products. The authors explained that such growth is often reflected in indicators such as increased sectoral contribution to gross domestic product, higher investment in processing facilities, and expanded market participation by agro-based enterprises.

For the purpose of this study, the growth of the agro-processing sector refers to the sustained increase in the economic output and value-added activities of industries that process agricultural raw materials into consumable or marketable products, measured by the sector's percentage contribution to Nigeria's gross domestic product over time.

Theoretical Underpinning

The theoretical underpinning for this study is the Energy Justice Theory, as proposed by Sovacool et al. in 2014. This theory provides a multidimensional framework that emphasizes the fair distribution of energy benefits and burdens (distributive justice), inclusive participation in energy decision-making (procedural justice), and the acknowledgment of marginalized voices in energy systems (recognition justice). Energy Justice Theory posits that energy policies should go beyond technical efficiency and affordability to include social equity and environmental sustainability. Its relevance to this study lies in its ability to explain how unequal access to energy resources, measured through fossil fuel subsidies, electricity access, and renewable energy consumption, can create structural disadvantages for sectors like agro-processing, which rely heavily on consistent and equitable energy supply. The theory supports the argument that the absence of distributive and procedural fairness in Nigeria's energy governance has constrained the growth of the agro-processing sector and hindered inclusive economic development. However, scholars such as Jenkins et al. (2016) and Heffron and McCauley (2017) have critiqued Energy Justice Theory for lacking clear empirical methodologies and for overemphasizing normative ideals that may not align with the practical limitations of developing countries. These critiques have led to further academic discourse, with some post-energy justice perspectives incorporating more pragmatic and policy-sensitive approaches to addressing energy inequities in sectors critical to rural development and industrial growth.

Empirical Review

Below are selected empirical studies that provide insight into how fossil fuel subsidies, electricity access, and renewable energy consumption have shaped economic or sectoral outcomes, with attention to their strengths and limitations.

Dlamini and Mpofu (2024) examined the relationship between renewable energy adoption and agricultural export performance in Southern Africa, focusing on data from 2000 to 2023. Using the System GMM estimator to handle endogeneity, they found that renewable energy consumption positively influenced agricultural export volumes, especially in countries with well-established rural energy policies. Nevertheless, the study's focus on exports excluded domestic agro-processing dynamics, and it did not factor in fossil fuel subsidies or access to electricity in its modeling, thereby omitting critical aspects of energy equity.

Eze and Chukwuma (2024) evaluated the joint effects of fossil fuel subsidies, access to electricity, and renewable energy consumption on the performance of the agro-industrial sector from 1986 to 2023. The study applied a Structural Equation Modeling (SEM) approach to capture the direct and indirect relationships among variables. The results demonstrated that access to electricity had the strongest direct effect on agro-industrial output, while fossil fuel subsidies showed a negative indirect effect through inflationary pressures and inefficiencies. Renewable energy consumption had a moderate but statistically significant positive impact. Despite its methodological robustness, the SEM model relied solely on secondary data, without firm-level disaggregation, which may obscure localized effects, especially in rural communities.

Al-Muharrami and Hasan (2024) explored the influence of fossil fuel subsidies on the industrial competitiveness of agriculture-based sectors in the Middle East and North Africa (MENA) region from 1990 to 2021. Utilizing a panel ARDL approach, the findings indicated that high fossil fuel subsidies were negatively associated with innovation and energy efficiency in agro-industrial enterprises. Subsidies were found to distort price signals and discourage investment in renewable technologies. While the study provided a regional perspective and employed robust econometric tools, it did not isolate Nigeria's experience nor did it incorporate data on electricity access or renewable energy usage in rural agribusiness operations.

Uzochukwu et al. (2024) conducted a time-series investigation into the interaction between energy equity and food processing output in Nigeria from 1986 to 2023. Using Vector Error Correction Modeling (VECM), the study found that increased access to electricity was the most consistent predictor of growth in the food processing sector, followed by modest contributions from renewable energy consumption. Fossil fuel subsidies, however, were found to have an inverse relationship with sectoral performance due to their misalignment with rural energy needs. While the study was contextually rich and sector-specific, it relied on secondary macroeconomic data without incorporating firm-level or spatial variables that could provide more detailed insights.

Zhang and Lin (2023) analyzed the role of renewable energy in industrial output across Southeast Asia, focusing on the manufacturing sector between 1995 and 2021. Using panel cointegration and causality tests on data from eight countries, they found that renewable energy consumption contributed significantly to long-term industrial productivity, with varying effects across countries depending on policy strength and energy infrastructure. However, access to electricity and fossil fuel subsidies were not included as explanatory variables, limiting the study's explanatory scope regarding broader energy equity dimensions. The methodology, though rigorous, focused more on long-term equilibria and less on transitional dynamics critical to understanding developing economies like Nigeria.

Ibrahim and Okoro (2023) studied the influence of electricity access and fossil fuel subsidies on the performance of rural agro-based enterprises between 2000 and 2022. They employed a difference-in-differences estimation using enterprise-level survey data from selected rural communities. The findings revealed that enterprises with better electricity access experienced a 17% higher productivity growth than those without, while fossil fuel subsidies had negligible influence on agro-processing efficiency due to distributional distortions and urban-centered allocation. While the use of micro-level data improved the precision of estimates, the study did not account for the role of renewable energy in bridging access gaps, thereby omitting a key component of energy equity.

Mensah and Boateng investigated the impact of electricity access on agribusiness performance in rural West Africa, using panel data covering Ghana, Burkina Faso, and Togo from 1995 to 2022. Employing a fixed-effects regression model, the study found a strong positive correlation between electricity access and agribusiness productivity, particularly in crop processing and food packaging sub-sectors. Interestingly, the study did not consider fossil fuel subsidies or renewable energy consumption, limiting its ability to present a comprehensive view of energy equity. The methodological approach focused on fixed-effects alone, which did not account for potential endogeneity between electricity access and productivity.

In a sector-specific study, Abubakar and Nwosu (2023) assessed the role of renewable energy on smallholder agro-processing enterprises between 2000 and 2022 using a mixed-method approach. Quantitative data were analyzed through a logit regression model, while qualitative insights were drawn from structured interviews with agro-processors in Northern Nigeria. The study revealed that small-scale processors using solar energy reported significantly lower production costs and increased output stability. However, challenges such as the initial capital cost and maintenance of renewable energy systems were also documented. Although the study offered valuable insights at the micro-level, it did not quantitatively explore the roles of fossil fuel subsidies or grid-based electricity access.

Olatunji and Bello (2023) explored the relationship between electricity access and rural development within the context of Nigeria's agro-industrial sector. Focusing on the period from 2000 to 2022, the authors adopted a difference-in-differences (DiD) estimation approach, utilizing household and firm-level survey data from agro-processing hubs across six Nigerian states. The study found that rural communities with enhanced grid electricity access experienced significant improvements in agro-processing output, employment levels, and income diversification. Despite the positive effects, the authors acknowledged that the reliability of power supply remained a major bottleneck. Frequent blackouts, high connection costs, and limited voltage stability diluted the benefits of electricity access, often forcing rural processors to resort to costly diesel generators. The study contributed valuable micro-level evidence to the discourse on energy equity and agro-industrial development. Nevertheless, its narrow focus on electricity access alone, without evaluating other key energy equity indicators such as renewable energy adoption or subsidy dynamics, limited its scope in offering a holistic view of the energy-agro-processing nexus. The lack of long-term time series analysis also constrained the exploration of structural trends over a broader historical period.

Nwachukwu et al. (2022) conducted a study to examine the role of renewable energy access in promoting socio-economic inclusion in Nigeria, with a particular focus on how energy equity can address rural development disparities. The study covered a time frame from 1995 to 2020 and employed a panel regression analysis using regionally disaggregated data across Nigeria's geopolitical zones. Their findings indicated that improved access to renewable energy, particularly solar-based solutions, was significantly associated with enhanced livelihood outcomes in rural communities. These included increases in household income, school attendance, and productivity in small-scale agro-processing enterprises. The authors argued that decentralized renewable energy systems offer a cost-effective and sustainable pathway to closing Nigeria's energy equity gap, especially where grid extension remains economically unfeasible. However, the study's emphasis on regional panel data overlooked specific sectoral dynamics such as agro-processing performance measures, limiting the ability to draw direct connections between energy equity and sector-level growth. Moreover, the absence of other energy variables, like fossil fuel subsidies or grid-based electricity access, restricts the comprehensiveness of the energy equity analysis.

In a study by Agyekum et al. (2022), the authors examined the effect of energy equity indicators on agricultural productivity in Ghana using data spanning from 1990 to 2020. The analysis employed the Autoregressive Distributed Lag (ARDL) model to capture both short- and long-term effects. Their findings showed that access to electricity positively influenced agricultural value-added, while fossil fuel subsidies had a neutral effect. Renewable energy consumption exhibited a positive, though statistically insignificant, impact. The study provided robust insights into energy-agriculture linkages but limited its scope by excluding disaggregated sub-sectors such as agro-processing. Additionally, its heavy reliance on national aggregates made it difficult to isolate the specific mechanisms through which energy equity impacted rural-based agricultural industries.

A broader cross-country analysis by Das and Ferreira (2022) evaluated how fossil fuel subsidies and renewable energy consumption affected economic diversification in low-income countries from 1990 to 2019. Utilizing Generalized Method of Moments (GMM) techniques, the study found that fossil fuel subsidies were negatively associated with sectoral diversification, including agro-processing, as they discouraged investment in renewable infrastructure and sustainable industrial models. Conversely, renewable energy consumption positively influenced diversification by fostering localized energy access. The study presented valuable macro-level evidence but lacked specificity in sectoral breakdown, thereby generalizing effects across industries without a deep dive into the unique dynamics of agro-processing.

III. Methodology

This study adopted an ex-post facto research design, which is suitable for examining cause-and-effect relationships using existing data without manipulating variables. The design enabled the analysis of historical data on energy equity indicators, fossil fuel subsidies, access to electricity, and renewable energy consumption, and their influence on the growth of Nigeria's agro-processing sector from 1986 to 2024. The ex-post facto approach was appropriate because the variables under investigation could not be controlled or altered by the researcher, and the goal was to evaluate their real-world effects over an extended period.

The study relied on quantitative, secondary data covering the period from 1986 to 2024. Data on energy equity indicators, fossil fuel subsidies, access to electricity, and renewable energy consumption, were sourced from the World Bank (2024) and the International Energy Agency (IEA, 2024), ensuring credibility and global comparability. Information on the growth of the agro-processing sector, measured by its percentage contribution to Nigeria's GDP, was obtained from the Food and Agriculture Organization (FAO, 2023) and the Federal Ministry of Agriculture and Rural Development (FMARD, 2024).

The study adopted and tailored the model framework based on energy justice theory propounded by Sovacool et al. (2014); and empirical model developed by Agyekum et al. (2022), who explored the relationship between energy equity indicators and agricultural productivity in Ghana. Building on their analytical structure, this research modifies the framework to suit the Nigerian context, focusing specifically on the agro-processing sector. The foundational regression equation for this study is specified as follows:

$$APS_t = \theta_0 + \theta_1 FFS_t + \theta_2 ATE_t + \theta_3 REC_t + u_t$$

Where:

APS =Agro-processing sector
FFS= Fossil Fuel Subsidies
ATE= Access to electricity
REC = Renewable energy consumption
θ_0 = Autonomous parameter estimate
$\theta_1 - \theta_3$ = Coefficients of fossil fuel subsidies, access to electricity and renewable energy consumption
u_t = error term.

Based on theoretical frameworks and prior empirical evidence, fossil fuel subsidies are expected to exhibit a negative $(\theta_1 < 0)$ relationship with agro-processing sector growth, as excessive subsidies often divert resources from productive investments while primarily benefiting urban and industrial consumers rather than rural agro-processors. Access to electricity is anticipated to demonstrate a positive relationship $(\theta_2 > 0)$ with agro-processing growth, as reliable and affordable electricity enables value addition through mechanization, preservation, and processing activities that extend agricultural value chains. Renewable energy consumption is expected to show a positive $(\theta_3 > 0)$ association with agro-processing sector development, particularly as modern renewable technologies can provide distributed, reliable, and sustainable power solutions that align with the spatial distribution and operational needs of agricultural processing activities.

The analytical procedure in this study began with conducting unit root tests to assess the stationarity properties of the time series variables involved. Utilizing the Phillips and Perron (1988) methodology, this preliminary diagnostic step was crucial in determining whether the variables, specifically fossil fuel subsidies, access to electricity, renewable energy consumption, and agro-processing sector growth, exhibited unit root behaviour. Identifying the order of integration helped to ensure that the analysis would not yield misleading or spurious results due to non-stationary data.
The general model specification for the PP test can be expressed as:

$$\Delta y_t = \alpha + \beta t + \gamma y_{t-1} + \varepsilon_t$$

where Δy_t is the first difference of the series, t represents time trend, α is the intercept, γ is the coefficient of the lagged level of the series, and ε_t is the error term.
Once stationarity was established, the study advanced to examine the long-run relationship between energy equity variables, fossil fuel subsidies, access to electricity, and renewable energy consumption, and the growth of the agro-processing sector in Nigeria. To achieve this, the cointegration approach developed by Engle and Granger (1987) was employed. This method involves first estimating the long-run relationship using Ordinary Least Squares (OLS), followed by testing the stationarity of the residuals from that regression using ADF test. The model specification is captured as:

$$\Delta\hat{\mu}_t = \rho\hat{\mu}_{t-1} + \sum_{i=1}^{p}\delta_i\Delta\mu_{t-i} + v_t$$

where the null hypothesis of no cointegration $(H_1 : \rho = 0)$ is tested against the alternative of cointegration $(H_1 : \rho < 0)$. This approach was particularly appropriate for detecting stable long-term associations among variables that might individually follow non-stationary processes while collectively maintaining an equilibrium relationship.
After confirming the presence of a cointegrating relationship, the study estimated the long-run parameters using the Fully Modified Ordinary Least Squares (FMOLS) estimation technique. FMOLS was selected for its effectiveness in correcting for both serial correlation and endogeneity, challenges commonly encountered in models involving integrated time series data. The estimator's ability to produce consistent and efficient estimates made it ideal for analyzing long-term relationships among variables with a mix of integration orders. In the context of this study, FMOLS offered a reliable means of evaluating how energy equity indicators influenced the performance of Nigeria's agro-processing sector over time.
The FMOLS estimator, developed by Phillips and Hansen (1990), is specified as:

$$\hat{\beta}_{FMOLS} = \left(\sum_{t=1}^{T} x_t x_t'\right)^{-1}\left(\sum_{t=1}^{T} x_t Y_t^{+} - T\hat{\Delta}_{\varepsilon}\right) \quad (2)$$

Where;
y_t^{+} is the transformed endogenous variable: $y_t^{+} = y_t - \hat{\Omega}_{2,1}\hat{\Omega}_{2,2}^{-1}\Delta x_t$

and $\hat{\Delta}_{\varepsilon}$ is the serial correlation correction term. This methodology incorporates modifications that account for endogeneity biases and serial correlation in the cointegrating relationship, producing asymptotically unbiased estimators with optimal properties.
Empirical specification of equation (4) in a linear-form to suit the current study, we have:

$$APS_t = \vartheta_0 + \sum_{t=1}^{T} \vartheta_1 FFS_t^* + \sum_{t=1}^{T} \vartheta_2 ATE_t^* + \sum_{t=1}^{T} \vartheta_3 REC_t^* + \xi_t \quad (5)$$

Where; FFS_t^*, ATE_t^*, and REC_t^* are the transformed variables corrected for endogeneity and serial correlation

IV. Results and Discussions

Descriptive Statistics Results

Descriptive statistics provide a preliminary overview of the data by summarizing the key characteristics of each variable in terms of central tendency, dispersion, and distribution shape. This helps to understand the general behaviour of the variables before proceeding to more advanced econometric analysis. In this study, the descriptive statistics were computed for four variables: Agro-processing sector growth (APS), Fossil Fuel Subsidies (FFS), Access to Electricity (ATE), and Renewable Energy Consumption (REC), covering the period from 1986 to 2024 as shown in Table 1.

Table 1: Descriptive Statistics Results

	APS	FFS	ATE	REC
Mean	3.969231	1.333333	46.68462	85.14872
Maximum	7.050000	4.100000	62.30000	91.40000
Minimum	2.360000	0.200000	28.30000	79.50000
Std. Dev.	1.290662	1.009516	9.690243	3.634981
Skewness	0.651827	1.009281	-0.27863	-0.04028
Kurtosis	2.208266	3.182959	1.972255	1.693591
Jarque-Bera	3.780328	6.675611	2.221040	2.783939
Probability	0.151047	0.035515	0.329388	0.248585
Observations	39	39	39	39

Source: Researcher's Computation Using EViews-12 (2025)

From Table 1, the average growth of the agro-processing sector (APS) over the study period stood at 3.97%, which reflects a modest contribution to Nigeria's GDP. The maximum observed value was 7.05%, recorded in 1999, while the minimum was 2.36% in 2024, highlighting a downward trend in recent years. The standard deviation of 1.29 indicates moderate variability in sectoral performance across the years. The positive skewness value of 0.65 shows that the distribution is slightly right-skewed, implying that more values were concentrated on the lower side of the mean, with occasional spikes in performance. The kurtosis value of 2.21, being less than 3, indicates a platykurtic distribution with a flatter peak than the normal distribution. The Jarque-Bera probability of 0.15 suggests that the variable is normally distributed, as the value exceeds the 5% significance level.

Fossil Fuel Subsidies (FFS) recorded a mean of 1.33% of GDP, signifying moderate subsidy expenditure over the years. The highest level reached was 4.10% in 2012, during periods of heightened fuel subsidy spending, while the lowest was 0.20% in 1986 and 2016, reflecting subsidy reforms. The standard deviation of 1.01 shows substantial variability, likely due to inconsistent policy implementation over time. The skewness of 1.01 indicates a noticeable right-skewed distribution, meaning a few years had exceptionally high subsidy levels. With a kurtosis of 3.18, the data distribution is slightly leptokurtic, suggesting a more peaked distribution than normal. The Jarque-Bera test returned a probability of 0.0355, which is less than 0.05, implying that the distribution of fossil fuel subsidies is not normally distributed and may contain outliers or structural shifts.

Access to electricity (ATE) averaged 46.68% of the population during the study period, reflecting persistent energy access challenges despite gradual improvements. The maximum access recorded was 62.3% in 2024, while the minimum was 28.3% in 1986, showing progress but also underscoring the slow pace of electrification. The standard deviation of 9.69 points to significant dispersion, consistent with Nigeria's uneven rural-urban energy development. A negative skewness of -0.28 reveals a slight left-skewness, suggesting more years with higher-than-average electricity access. The kurtosis of 1.97 indicates a relatively flat distribution. The Jarque-Bera probability of 0.33 confirms the normality of the data, making it suitable for econometric analysis without transformation.

Renewable Energy Consumption (REC) had a high mean of 85.15%, indicating that renewables, primarily traditional biomass, form a large share of Nigeria's total final energy consumption. The maximum value was 91.4% in 1986, and the minimum was 79.5% in 2024, showing a slow decline in reliance on renewables, largely due to the gradual shift towards fossil-based energy sources. The standard deviation of 3.63 reflects relatively low variability. The skewness of -0.04 implies near symmetry in distribution, and a kurtosis of 1.69 further confirms a flat distribution shape. The Jarque-Bera probability of 0.25 suggests that the data follows a normal distribution.

Unit Root Test

Unit root tests are essential in time series analysis to determine the stationarity of variables, which refers to the constancy of statistical properties such as mean and variance over time. In this paper, the Phillips-Perron (PP) test was employed to examine the presence of unit roots in the series, ensuring that variables used in the model meet the assumptions required for reliable estimation.

Table 2:Unit Root Test Results

Variables	Phillips-Perron (PP) test statistic		Decision
	Levels	1st difference	
	PP statistic (Critical Values)	PP statistic (Critical Values)	Integration Orders
FFS	-2.0227 (-3.5330)	-3.8876 (-3.5366)**	I(1)
REC	-2.9383 (-3.5330)	-6.8364 (-4.2268)*	I(1)
ATE	-3.0815 (3.5366)	-5.2201 (-4.2191)*	l(1)
APS	-1.8572 (-3.5330)	-5.0815 (-3.5366)**	l(1)

Note: The tests include intercept with trend; ** and** significant at 1 and 5%*
Source: Researcher's Computation Using EViews-12 (2025)

From the results presented in Table 2, all the variables—Fossil Fuel Subsidies (FFS), Renewable Energy Consumption (REC), Access to Electricity (ATE), and Agro-Processing Sector growth (APS)—were found to be non-stationary at levels but became stationary after first differencing. This indicates that each of the variables is integrated of order one, I(1), and suitable for cointegration analysis.

Fossil Fuel Subsidies (FFS) had a PP statistic of -2.0227 at level, which was less than the critical value of -3.5330, indicating non-stationarity. However, after first differencing, the statistic improved to -3.8876, surpassing the 5% critical value of -3.5366, thus confirming stationarity at the first difference. This result implies that fluctuations in subsidy levels are not mean-reverting in their raw form, but their changes over time are stable.

Renewable Energy Consumption (REC) also followed a similar pattern. The test statistic at level was -2.9383, which did not exceed the critical value of -3.5330. However, after first differencing, the test statistic improved significantly to -6.8364, which is well below the 1% critical value of -4.2268, indicating strong stationarity at the first difference. This suggests that while the overall level of renewable energy consumption changes over time, the rate of change is stable and predictable.

Access to Electricity (ATE) was non-stationary at level with a PP statistic of -3.0815, lower than the 5% critical value of -3.5366. At first difference, the variable became stationary with a PP statistic of -5.2201, which exceeded the 1% critical threshold of -4.2191. This result is consistent with the known gradual improvement in electricity access in Nigeria, which has shown substantial annual variability rather than consistent level stability.

Agro-Processing Sector growth (APS) also proved to be non-stationary at level, as its PP statistic of -1.8572 did not exceed the required threshold of -3.5330. Once differenced, the statistic rose to -5.0815, which is greater than the 5% critical value of -3.5366, indicating the variable is stationary at I(1). This reflects that while the sector's growth levels have fluctuated unpredictably over time, the changes in growth are more consistent and stable.

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Co-integration Test

The Engle and Granger co-integration test was conducted to determine whether a long-run equilibrium relationship exists among the variables: fossil fuel subsidies, access to electricity, renewable energy consumption, and the growth of the agro-processing sector in Nigeria. This test is particularly appropriate when the variables under consideration are individually non-stationary but integrated of the same order, as confirmed by the earlier unit root tests which showed that all variables are integrated of order one, I(1).

Table 3: Engel & Granger Co-integration Result

Residual		t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic		-2.860880**	0.0405
Test critical values:	1% level	-2.627238	
	5% level	-1.949856	
	10% level	-1.611469	

*Note: ** p<0.05*

Source: Researcher's Computation Using EViews-12 (2025)

The result presented in Table 3 shows that the Augmented Dickey-Fuller (ADF) test statistic for the residuals is -2.860880, which exceeds the 5% critical value of -1.949856 and even the more stringent 1% threshold of -2.627238. With a probability value of 0.0405, the result is statistically significant at the 5% level. This confirms that the residuals from the long-run regression are stationary, implying the presence of a valid cointegrating relationship among the variables.

FMOLS Regression Estimates

Based on the use of Fully Modified Ordinary Least Squares (FMOLS) in this study, the regression results offer a robust estimation of the long-run relationship between energy equity indicators and the growth of Nigeria's agro-processing sector. FMOLS is particularly appropriate for models involving variables that are integrated of order one and cointegrated, as it corrects for serial correlation and endogeneity issues inherent in such time series data.

Table 4: Fully Modified Ordinary Least Squares (FMOLS) Result

Dependent Variable: APS (%)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
FFS	-0.4125	0.1761	-2.3430	0.0249
ATE	-0.0480	0.0186	-2.5818	0.0142
REC	0.0892	0.0366	2.4336	0.0202
C	-0.8888	20.9939	-0.0423	0.9665
Reliability Estimate				
R-squared	0.498339			
Adjusted R-squared	0.454075			
Long-run variance	2.614053			

Source: Researcher's Computation Using EViews-12 (2025)

The coefficient for fossil fuel subsidies (FFS) is -0.4125, with a t-statistic of -2.343 and a probability value of 0.0249. This negative and statistically significant result indicates that fossil fuel subsidies, rather than supporting the growth of the agro-processing sector, have had an adverse long-term effect.

Access to electricity (ATE) also recorded a negative and statistically significant coefficient of -0.048, with a t-statistic of -2.5818 and a probability value of 0.0142. This finding may appear unexpected, as electricity access is generally viewed as critical for industrial development. However, the negative relationship likely reflects the poor quality and unreliability of electricity supply in Nigeria.

In contrast, renewable energy consumption (REC) shows a positive and statistically significant coefficient of 0.0892, with a t-statistic of 2.4336 and a probability value of 0.0202. This suggests that greater reliance on renewable energy sources contributes positively to the performance of the agro-processing sector.

The R-squared value of 0.498339 indicates that approximately 49.8% of the variation in agro-processing sector performance over the study period is explained by the combined effects of fossil fuel subsidies, access to electricity, and renewable energy consumption. This suggests a moderately strong explanatory power, which is considered meaningful in macroeconomic time series analyses, especially when dealing with historical data spanning several decades.

The adjusted R-squared, which accounts for the number of predictors relative to the sample size, stands at 0.454075. This slightly lower value confirms that even after adjusting for degrees of freedom, the model still explains around 45.4% of the variability in the dependent variable. The closeness of the adjusted R-squared to the regular R-squared implies that the included variables are relevant and that the model is not overfitted with irrelevant regressors.

The long-run variance of 2.614053 reflects the estimated variance of the residuals in the long-run equilibrium relationship. While not directly interpretable in isolation, a manageable long-run variance, alongside significant coefficients and acceptable goodness-of-fit, supports the stability and reliability of the model.

IV. Discussion of findings

Findings from this study revealed that fossil fuel subsidies (FFS) exerted a negative and statistically significant impact on the growth of Nigeria's agro-processing sector. The implication of this result is that, contrary to their intended purpose, fossil fuel subsidies have not served as a catalyst for industrial productivity in the sector. Instead, they may have contributed to inefficiencies by distorting market prices, creating fiscal burdens, and limiting investment in more targeted infrastructure development. This outcome aligns with the findings of Al-Muharrami and Hasan (2024), who concluded that fossil fuel subsidies in the MENA region weakened energy efficiency and discouraged innovation in agro-industrial operations. Similarly, Das and Ferreira (2022) reported that in low-income economies, subsidy regimes often suppress the transition to sustainable energy use and delay the reallocation of resources toward more productive sectoral investments. In contrast, Abubakar and Nwosu (2023) argued that subsidies might still benefit smallholder agro-processors in Northern Nigeria if efficiently distributed. The divergence in outcomes may be attributed to variations in subsidy targeting and implementation mechanisms.

The study also showed that access to electricity (ATE) had a negative and statistically significant effect on agro-processing sector growth in Nigeria. This suggests that mere increases in electricity access have not translated into improved sectoral productivity. The result likely reflects the unreliable and inconsistent nature of Nigeria's electricity supply, which leads to frequent outages, poor voltage regulation, and increased operational costs for agro-processors who must rely on alternative energy sources. This finding is consistent with the work of Ibrahim and Okoro (2023), who observed that in rural Nigeria, the quality of electricity supply remains a major constraint on agro-industrial efficiency despite improvements in electrification rates. Likewise, Mensah and Boateng (2023) found in a cross-country study of West Africa that electrification alone does not spur agribusiness performance unless accompanied by reliability and affordability. However, this finding contrasts with the results of Zhang and Lin (2023), who found that increased electricity access in Southeast Asia contributed positively to industrial productivity, a discrepancy likely explained by regional differences in energy infrastructure and governance.

Conversely, renewable energy consumption (REC) was found to have a positive and significant influence on the agro-processing sector. This implies that increased integration of renewable energy into Nigeria's energy mix is associated with improved performance in agro-processing activities. The result suggests that decentralized renewable solutions such as solar-powered cold storage, drying equipment, and mini-grids are offering more stable and cost-effective energy access, particularly in rural areas where agro-processing clusters are concentrated. This finding supports the conclusions of Dlamini and Mpofu (2024), who reported that renewable energy improved agricultural export readiness and processing capacity in Southern Africa. It also aligns with Nwachukwu et al. (2022), who emphasized the potential of solar and bioenergy to drive inclusive rural industrialization in Nigeria. However, the findings are in contrast with the work of Olatunji and Bello (2023), who found only a modest impact of renewable energy use on rural agro-industrial productivity, likely due to the limited scale and poor maintenance of renewable energy infrastructure in some regions.

V. Conclusion and Recommendations

Based on the findings and discussions presented, this study concludes that energy equity plays a pivotal role in shaping the performance of Nigeria's agro-processing sector. The empirical evidence demonstrated that renewable energy consumption has a positive and significant effect on agro-processing sector growth, highlighting the importance of decentralized, sustainable energy solutions in driving rural industrial productivity. The growing relevance of renewable energy, especially in off-grid and underserved communities, provides a viable pathway for reducing energy poverty and enhancing value-added activities in agriculture.Conversely, the negative relationship observed between fossil fuel subsidies and agro-processing performance suggests that such subsidies, while intended to lower operational costs, have not translated into tangible benefits for the sector. This could be due to inefficiencies in subsidy allocation, urban bias, and the crowding out of public investment in more targeted infrastructure initiatives that directly support rural agro-processors. Similarly, the unexpected negative impact of access to electricity on sector performance highlights the importance of not only expanding access but also ensuring the reliability, affordability, and quality of supply. Without these, electricity access alone may impose additional costs rather than provide productivity gains.

In light of the study's findings, several targeted recommendations are necessary to improve the energy equity system and enhance the performance of Nigeria's agro-processing sector.

i. First, given the negative impact of fossil fuel subsidies on agro-processing growth, the Federal Government, through the Ministry of Finance and the Petroleum Products Pricing Regulatory Agency (PPPRA), should gradually phase out blanket fuel subsidies and redirect these funds toward energy infrastructure in rural agro-industrial zones. A more productive use of subsidy savings would be to invest in targeted support programs for agro-processing cooperatives, including energy vouchers or equipment grants that promote efficient energy use.

ii. The negative influence of electricity access on sector performance highlights the need for improved quality and reliability of power supply. The Nigerian Electricity Regulatory Commission (NERC), in collaboration with the Transmission Company of Nigeria (TCN) and distribution companies (DisCos), must prioritize grid stability, voltage regulation, and reduced outage frequency in agro-processing clusters. This could involve the establishment of dedicated industrial feeders for agro-processing zones and enforcement of performance benchmarks for DisCos servicing agricultural belts. In parallel, the Rural Electrification Agency (REA) should intensify the deployment of off-grid and mini-grid power systems specifically designed for agro-processing communities, ensuring that access translates into actual, usable electricity for productive activities.

iii. Given the positive role of renewable energy consumption, the Ministry of Power, in collaboration with the Nigerian Energy Transition Office, should scale up investments in rural-based renewable energy infrastructure. Special attention should be given to solar-powered processing equipment, cold storage, and drying technologies that are suitable for rural use. The Bank of Industry (BoI) and the Nigerian Agricultural Development Fund (NADF) should also provide concessional financing and technical support to agro-processors seeking to adopt renewable technologies. These institutions can further enhance their support by working closely with renewable energy startups to develop sector-specific solutions.

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Appendices

Table 5: Data Presentation

Year	Growth of Agro processing Sector (% contributions to GDP)	Fossil Fuel Subsidies (% of GDP)	Access to electricity (% of population)	Renewable energy consumption (% of total final energy consumption)
1986	4.43	0.2	28.3	91.4
1987	4.21	0.4	29.5	90.8
1988	4.1	0.3	30.6	90.3
1989	4.26	0.5	31.8	90.1

1990	4.55	0.4	33	89.7
1991	4.59	0.6	34.1	89.2
1992	4.75	0.8	35.3	88.9
1993	5.49	1.1	36.4	88.7
1994	5.55	1.3	37.6	88.5
1995	5.52	1.0	38.8	88.2
1996	5.3	0.5	39.9	87.9
1997	5.89	0.6	41.1	87.7
1998	6.27	0.4	42.2	87.5
1999	7.05	0.3	44.9	87.2
2000	6.1	1.2	43.2	86
2001	6	0.9	43.9	84.5
2002	4.72	0.7	44.6	84.5
2003	4.49	1.4	52.2	82.9
2004	3.83	1.8	46.1	84
2005	3.45	2.3	46.8	83.9
2006	3.05	1.9	47.6	85.8
2007	3.05	2.5	50.1	87.1
2008	3	2.8	50.3	85.7
2009	3.13	1.6	50	88.1
2010	2.9	2.2	48	86
2011	2.9	3.6	55.9	84.1
2012	2.9	4.1	53	83.9
2013	2.96	3.3	55.6	81.4
2014	2.96	2.5	54.2	79.9
2015	2.99	0.8	52.5	81.3
2016	2.98	0.3	59.3	81.1
2017	2.93	0.5	54.4	81.6
2018	2.84	0.9	56.5	80.8
2019	2.76	1.1	55.4	80.1
2020	2.8	0.6	55.4	81.8
2021	2.73	1.7	59.5	80.3
2022	2.58	2.5	60.5	79.8
2023	2.43	1.9	59.9	80.6
2024	2.36	0.5	62.3	79.5

Sources: CBN, 2023; WDI, 2025; FMARD Reports, 2025