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Nexus between Electricity Generation and Agricultural Development in Africa

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ABSTRACT

This study examines the dynamic connections between electricity generation and agricultural development, utilizing dynamic generalized method of moments (GMM) estimation techniques and annual time series data spanning from 2000 to 2020. The findings offer valuable insights into the impact of electricity generation on agricultural progress. Firstly, both electric power generation and energy generation capacity were negatively and significantly linked to agricultural development in Africa. This suggests that despite increases in electric power and energy generation, agricultural development may not improve due to inefficiencies in the energy infrastructure, including inadequate transmission and distribution networks, unreliable grid connectivity, energy losses, and distribution issues that prevent electricity from reaching rural areas where agriculture is predominantly concentrated. Second, further analysis reveals a significant and positive association between electricity consumption, access to electricity, and agricultural development in Africa. This indicates that expanding electricity access and increasing its consumption in agricultural activities can significantly enhance agricultural productivity and growth across the continent. These results emphasize the importance of improving infrastructure and optimizing capacity utilization to ensure that the growth in electricity generation capacity translates into tangible benefits for agricultural development in Africa. Thus, the study underscores the pivotal role of electricity generation, consumption, and access in promoting agricultural development, while highlighting the need to address infrastructure inefficiencies to achieve sustainable growth.

Keywords: Electricity Generation, Agricultural Development, Africa
JEL Classifications: Q4, Q1

1. INTRODUCTION

Electricity generation plays a pivotal role in agricultural development, enhancing the efficiency of farming operations. It serves as a critical enabler for the agricultural sector to unlock its growth potential. Expanding access to modern electricity services across Sub-Saharan Africa is a significant challenge due to the sector's crucial impact on livelihoods. Electricity supports agriculture in various ways, from powering irrigation systems (sourcing and distributing water from dams or rivers) to postharvest activities like milling and drying, as well as secondary processing, such as packaging and bottling. It also aids in preserving crops for long-term and short-term use (World Bank, 2017). Rural electrification has the potential to stimulate both commercial and rural agricultural development. Still, its success depends on the scale of agricultural activities, such as crop type, livestock, and processing methods. As Goal 7 of the Sustainable Development Goals outlines, there is a global effort to "ensure access to affordable, reliable, sustainable, and modern energy for all," focusing on Sub-Saharan Africa, where electricity access remains limited. In countries like Nigeria, Rwanda, Uganda, and Ethiopia, rural electrification efforts have struggled to make significant strides, resulting in low electricity consumption, high service costs, and frequent power outages. For example, Nigeria's electricity generation grew at an annual rate of 5% from 1999 to 2018, while Rwanda's generation is supplemented by imports. Uganda and Ethiopia also face significant energy challenges, with a reliance on traditional energy sources in Ethiopia.

Given these challenges, agricultural sectors in many African nations remain underdeveloped, with minimal electricity usage for agricultural purposes. Since most African economies rely heavily on agriculture for growth, a reliable electricity supply is essential for expanding agricultural productivity. Electricity-driven development can foster mass production, enhance the agricultural supply chain, and benefit households, businesses, and export markets. Agricultural development, in turn, drives economic growth through the production of raw materials, export goods, government revenue, and employment. However, the insufficient generation and use of electricity pose significant barriers to this growth. This study aims to explore the relationship between electricity generation and agricultural development in 53 African countries from 2000 to 2020. Specifically, the study will: (a) Examine the impact of energy generation capacity on agricultural development, (b) Investigate the effect of electric power generation on agricultural development, c) Assess the impact of electricity power consumption on agricultural development, and (d) Explore the effect of access to electricity on agricultural development in Africa. By addressing these objectives, the study will provide insights into how improving electricity infrastructure can support agricultural growth and contribute to broader economic development in the region.

Empirical studies have explored the role of electricity in economic growth and industrialisation, as well as its environmental impact, but often neglect the connection between electricity and agricultural development, particularly in Africa (Roubaud and Shahbaz, 2018; Sinha and Shahbaz, 2018; Balderrama-Durbin et al., 2017; Duque et al., 2016; Asumadu-Sarkodie and Owusu, 2017a; 2017b). Studies like Roubaud and Shahbaz (2018) on electricity and economic growth in Pakistan, and Sinha and Shahbaz (2018) on renewable energy challenges in low-income countries, do not account for the unique challenges faced by African nations, where agriculture heavily relies on traditional practices and local energy infrastructure. Although studies like those of Asumadu-Sarkodie and Owusu (2017a; 2017b) highlight the role of electricity in economic growth and sustainability in Africa, few examine its direct impact on agricultural outcomes, particularly in regions with unstable or limited electricity access. Existing literature often generalizes findings from other regions, failing to address Africa's specific energy and agricultural challenges. This study aims to bridge this gap by investigating the electricity-agriculture nexus in Africa, focusing on how electricity generation forms, particularly electric power generation, can enhance agricultural productivity. Unlike previous studies, we further the investigation into assessing the link between energy generation capacity, electricity power consumption, access to electricity and agricultural development in African region. By examining the African context—where fragmented energy infrastructure and limited electricity access hinder agricultural development—this research offers fresh insights into how electricity, when strategically integrated with agricultural development, can create a more sustainable and productive agricultural sector. This approach departs from previous studies that focus on industrial or economic sectors, providing a tailored solution to Africa's unique energy challenges and the interconnected nature of energy and agriculture.

The structure of this study is as follows: Section 2 presents a review of related literature; Section 3 outlines the data and methodology; Section 4 discusses the empirical findings and discussions; and Section 5 concludes with a summary and policy recommendations.

2. REVIEW OF LITERATURE

2.1. Evaluation of Related Theories

Duncan (2001) introduced the Olduvai Theory, which offers a concerning outlook on the future of global energy production and its impact on civilization. The theory suggests a clear pattern linking population growth and energy production. It predicts that energy output peaked around 1979 and will continue to decline, with industrial civilization potentially lasting no more than 100 years. By 2030, energy output per person is expected to return to levels seen in 1930, leading to widespread blackouts and the collapse of high-voltage electrical networks worldwide. While Duncan acknowledges that this theory is speculative, it draws on historical trends in energy production and population growth, making it a valuable framework for understanding the connection between energy and economic development. For Africa, where energy infrastructure is often unreliable or underdeveloped, the Olduvai Theory serves as a cautionary tale. The agricultural sector, which heavily depends on consistent and affordable energy for irrigation, mechanization, and processing, could be severely impacted by a decline in energy output and an inability to meet growing energy demands. Without prioritizing the development of sustainable energy infrastructure, African nations may face further challenges in achieving food security and economic growth. The theory highlights the importance of addressing energy limitations to ensure long-term agricultural development and economic stability in the region.

A neoclassical theory that examines the relationship between energy use and economic development is presented by David Stern (2004). Stern contends that particularly in industrialised nations where economic development has been made possible by technical breakthroughs and improved energy efficiency, energy consumption and economic growth have been disentangled. Stern highlights that changes in the mix of other economic inputs like labour and capital, technical advancements, and changes in the composition of energy inputs may all have an impact on variations in energy consumption. By increasing energy efficiency and incorporating renewable energy sources, his model suggests that countries may expand sustainably, challenging the conventional wisdom that economic growth is always linked to energy consumption. Stern's approach gives Africa optimism that advancements in technology, such as the use of renewable energy technologies, may promote agricultural growth and lessen dependency on conventional energy sources. Many African nations' agricultural sectors continue to rely on labour-intensive, low-energy methods; hence, increasing energy efficiency might contribute to increased production. For instance, without worsening environmental degradation, solar-powered irrigation systems, wind energy for drying crops, and biogas for processing might greatly increase agricultural production and food security. To promote a more sustainable and energy-efficient agricultural system, Stern's model backs up the notion that Africa can separate agricultural expansion from its past dependency on non-renewable energy.

The Olduvai Theory and Stern's Model together provide two perspectives for analysing the connection between Africa's agricultural growth and energy production. Stern's model provides a method to reduce these risks via technical innovation and the use of renewable energy, but the Olduvai Theory emphasises the possible problems connected to decreasing energy output and the difficulties in satisfying energy needs. Africa can meet the energy demands of its agricultural sector and foster long-term agricultural development and economic prosperity by concentrating on sustainable energy production. In conclusion, Africa's agricultural growth and power production have a complicated relationship that is intricately linked to global energy trends. Stern's model offers a hopeful perspective on how energy efficiency and technological advancement might result in sustainable growth, whereas the Olduvai Theory warns of the limits of energy generation. Unlocking the agricultural sector's full potential and guaranteeing food security and economic prosperity for future generations depends on addressing Africa's energy difficulties, particularly about renewable energy sources.

2.2. Review of Related Empirical Literature

Empirically, scholars have made tremendous contributions to envisage the links between electricity generation and agricultural development in their various degrees. This stems from the fact that the agricultural sector is highly important for the achievement of economic growth. Scholars such as Balderrama-Durbin et al. (2017) investigated the energy system in Bolivia by estimating an energy demand model at the national level and exploring different alternatives based on government projections on energy saving, fuel substitution, and aggregated effects of a combined scenario. They predicted a considerable increase in energy consumption by 2035. However, their results indicated an 8.5% lower energy demand under the energy-saving scenario, a 1.5% lower energy demand under the fuel substitution scenario, and a 9.4% lower energy demand under the combined scenario. They highlighted the relevance of the energy sector to social and economic development, outlining the necessity of adequate policies and management to guarantee future energy supply. In light of this, Duque et al. (2016) argued that there are unexplored rivers that could be used to generate hydroelectric power to address domestic demand, with the remaining production available for export. In his study which focused on Nigeria, Kenny (2019) investigated the role of agricultural sector performance on economic growth. The study utilized the ADF unit root test, co-integration test and vector error correction model. The study revealed that the agricultural credit guarantee scheme fund has a positive but insignificant impact on agricultural domestic production and public spending on agriculture has significant effects on domestic agricultural production.

In Pakistan, Roubaud and Shahbaz (2018), using production function examined the causal link between electricity consumption and economic growth at aggregate and industrial levels from 1972 to 2014. The causality result acknowledged that electricity consumption and economic growth. According to Asumadu-Sarkodie and Owusu (2017a; 2017b) who studied energy consumption and economic growth, they discovered that long-run equilibrium associations exist between environmental degradation, electricity usage, industrialization and economic growth, thus, they suggested that in the future using clean energy can decrease environmental degradation in Sierra Leone. Sinha and Shahbaz (2018) stated that the high cost of the initial stage of renewable energy development leads to demotivation to invest in renewable energy in developing countries because it seems like promoting renewable energy in some low-income countries may restrain their economic progress in the short run. And Inglesi-Lotz and Dogan (2018) suggested that shiting energy consumption away from fossil fuels to renewable energy sources is a challenge for developing countries. Different energy structures between developing and developed countries are different because of the level of technological and economic advancement.

Arango-Aramburo et al. (2019) investigated energy vulnerability to exogenous shocks (climate) using a general equilibrium model, given that climate change may affect water availability and therefore energy production. They found that although climate change thus far has not resulted in abrupt changes in hydroelectric power generation capacity, it has led to a greater likelihood of (and demand for) the use of renewable energy sources, such as solar and wind. The study of Ozturk (2017) concludes that agricultural value added, cereal yields and forest area significantly decrease the food-energy water poverty nexus, leading to higher economic growth and price levels at the cost of environmental degradation. In general, agricultural sustainability is the prerequisite for reducing food energy and water poverty. In the same vein, Matthew et al. (2018) studied the multiplier implications of human capital development via the application of an electric source of energy in the production process that promotes economic growth in Nigeria. The study employed secondary data from World Development Indicators (WDI) spanning the period 1981-2016. The method of data analysis involves the application of a fully modified ordinary least squares (OLS) estimation technique. The evidence from the study indicates that human capital development is not significantly related to economic growth but ELEC proved otherwise. Hence, their study advocated for the development of human capital through public expenditure on education and health facilities and also made adequate provision for both rural and urban electrification to achieve a high productivity level. Jambo (2017) studied the effect of government spending on agricultural growth in four countries made up of Malawi, South Africa Tanzania and Zambia. The paper utilised various time series models in the estimation of the respective countries outcome. The model utilised the agricultural component of GDP as an endogenous variable while the exogenous variables were government agricultural research expenditure, infrastructural public spending, and public expenditure on price and subsidy support programmes for agricultural inputs, net trade and private sector investment outlay. The evidence from the study shows that agricultural sector growth is uniquely determined by individual countries' expenditure in the sector.

Mahjoub (2018) carried out a study on government subsiding agriculture influence on the export of AGOP using nine Common Market for Eastern and Southern African countries. The author used a fixed effect analytical technique and control for GDP per capita, rural population, inflation rate, real effective exchange rate (EXR) and agricultural land under cultivation. The result indicates a positive significant influence of government agricultural outlay on the export of agricultural produce. Further evidence from the investigation shows that the proportion of raw material from agriculture as a per cent of merchandise export rises by 1.8% due to a 1 billion increase in government agricultural spending. The study thus recommends that agricultural subsidies should be increased in addition to financial and input support. This government intervention will assist in the production of a higher volume of output that further translates to increased exports for these countries. Osabuohien et al. (2018) interrogated the importance of the local institutional framework in rice production and processing in Ogun State, Nigeria. The study employing key informant interviews discovered that agricultural financing constitutes the most dominant barrier to commercial rice production and processing among local farmers. To the theoretical foundation, these findings conform to Wagner (1958) law of increasing state activities in and out of the state. There is a consistent discharge of fresh responsibilities and at the same time, the state makes an effort to improve its effectiveness in the execution of already existing duties while broadening its jurisdiction of operational capacity that will gradually lead to an increment in public fiscal operations. It is thus essential that the government increase expenditure to efficiently meet its statutory obligations required for the development of the state.

Chinedum and Nnadi (2016) investigated the influence of electric energy supply on the production of the Nigerian manufacturing sector in 1981 and 2013. Their work made use of Johansen's maximum likelihood Cointegration and VAR tests. Evidence from the study shows the presence of a long-run relationship between electricity supply and output from the Nigerian manufacturing sector. Detailed analysis of the paper suggests no significant relationship between electric energy and the manufacturing sector production. The study recommends that appropriate electricity supply and its stability must be a priority in formulating and implementing social policy. This consequently will culminate in the achievement of the anticipated output from the manufacturing sector. Abduljabbar and Singla (2021) in their empirical analysis of the agricultural sector and its contribution to Economic growth in Nigeria used ordinary least squares (OLS) and histogram normality. They discovered that the agricultural output in Nigeria has increased significantly, especially from 2016 to 2018. The paper recommended that the Nigerian government should give more emphasis to its agricultural sector as it significantly contributed toward its economic growth, employment generation and food security for many years.

Liu et al. (2020) in an attempt to study the impact of growth on agricultural total factor productivity applied stochastic frontier analysis (SFA) to analyse the growth of agricultural total factor productivity (TFP) and its three components (technical change—TC, technical efficiency change—TEC and scale change—SC) in 15 south and southeast Asian countries covering the period 2002-2016. They identified the determinants of agricultural TFP growth by using dynamic panel data models. The results reveal that the South and Southeast Asian countries witnessed an overall decline in agricultural productivity during the sample period, thereby creating concerns over sustaining future agricultural growth. Gollin et al. (2018) point to another potentially important contributor to the recent growth take-off in developing countries—the development and adoption of high-yielding varieties (HYVs) of key crops. To avoid potential problems of reverse causality—where higher growth contributes to the adoption of HYVs—they predict adoption based on agroecological potential. Their results point to a potentially large impact on growth in developing countries in the 1960-2000 period. They conclude that this impact is likely to have been much larger in East Asia, South Asia, and Latin America than in sub-Saharan Africa.

Pardey et al. (2018) show that spending on public agricultural research and development has increased sharply in key middle-income countries, particularly Brazil, China, and India, with China now the largest investor in agricultural research and development, India the third largest, and Brazil ranked fourth. Unfortunately, this growth in spending has not been mirrored in the world's low-income countries, home to over a quarter of the world's poor. While the absolute amounts invested in research and development in the Asia-Pacific region are enormous, they remain quite small as a share of agricultural GDP, at 0.4%. Pardey et al. show that only 2.9% of global R&D is undertaken by these countries, despite the large potential poverty-reducing impact of improvements in agricultural productivity in these agriculture-intensive countries. Pardey et al. (2018) also report estimates of the returns on investment from agricultural research and development based on almost 500 studies. Given this, Laborde et al. (2019) estimate that the public research and development provided by the CGIAR system reduced global poverty by around 70 million since 1971. Okereke et al. (2019) observe that a pervasive feature of developing country development strategy is the "urban bias" policy, which places less emphasis on the agricultural sector, especially for young school leavers eager to be employed in administrative and service positions rather than on the farm. Osuagwu (2020) investigates a long-run relationship between agriculture and manufacturing industry output in Nigeria using annual time series data from 1982 to 2017 using the Granger Causality test and vector error correction model (VECM). They discovered that a bidirectional relationship between agricultural productivity and manufacturing industry output from the causality test and a positive and significant relationship exists in the short- and long-run estimates. Thus, a long-run divergence from the vector error correction model indicates that changes in agricultural productivity are not restored to equilibrium, given that macroeconomic factors distort the linkage.

Shettima et al. (2023) analysed how energy poverty in Sub-Saharan Africa (SSA) was impacted by violent conflicts between 1990 and 2019. They applied econometric techniques including quantile regression, fixed effects, and the generalised method of moments (GMM) to measure the number of refugees and conflict-related deaths as proxy. According to their findings, a nation's degree of energy poverty determines the correlation between combat deaths and electricity poverty. Conflict has a more noticeable effect on electricity production and consumption as energy poverty declines, suggesting that gains made in reducing energy poverty might be undone during times of conflict. An error correction model (ECM) was used by Mahmood and Ayaz (2018) to examine the causal relationship between Pakistan's economic development and energy security. In both the short and long term, their results showed a unidirectional causal relationship between economic development and the energy demand-supply imbalance. According to the negative and substantial link, Pakistan's economic development is hampered by insufficient energy security, which is reflected in a growing energy gap. The impact of insurgency on oil corporations operating in Nigeria's Niger Delta between 1999 and 2009, as well as its consequences for national energy security, were studied by Ugo and Daniel (2024). Significant interruptions were noted in the research, such as growing operating expenses, worker abductions, production halts, and damage to the infrastructure. Adedeji et al. (2024) explored the relationship between governance quality and energy security and economic performance in 22 SSA countries between 2000 and 2020. They found that, in addition to governance quality, energy availability and developability significantly improve economic results using Poisson's Pseudo-Maximum Likelihood Estimator. Using an enhanced Cobb-Douglas production model, Le and Nguyen (2019) evaluated the contribution of energy security to economic development in 74 countries between 2002 and 2013, concluding that it is a key factor in both regional and global growth.

3. DATA AND METHODOLOGY

This study aims to explore the relationship between electricity generation and agricultural development through a comparative analysis of Nigeria, Rwanda, Uganda, and Ethiopia. It utilizes annual time series data from 1995 to 2020, sourced from the World Bank's World Development Indicators (WDI). The choice of variables and the scope of the study were guided by the availability of data across the selected countries. To measure agricultural development, the study employs agricultural value added (AVD), while electricity generation is assessed using electricity power generation (EPG) and electricity power consumption (EPC), measured in kilowatt-hours per capita per hour. Additionally, the study controls for access to electricity (AE) and energy generation (ENG). To enhance the understanding of the variables, each one is defined as follows:

Agricultural value added (AVD) reflects the manufacturing processes in the agricultural sector, capturing the value added to primary agricultural commodities. It is also considered a portfolio of agricultural practices that align with consumer preferences for food and agricultural products characterized by specific attributes like form, space, time, identity, and quality, which are absent in conventionally-produced raw agricultural goods. AVD serves as a measure of output growth in the agricultural sector. Electricity power generation (EPG) refers to the process of generating electricity from primary energy sources, often produced by the power industry and delivered to end users. Electricity Power Consumption (EPC) represents the actual energy demand on the existing electricity supply, measured in kilowatt-hours per capita per hour. Access to electricity (AE) is the proportion of the population with access to electricity. Energy generation (ENG) captures the process of producing energy from various primary sources, such as fossil fuels, nuclear power, hydroelectric plants (excluding pumped storage), geothermal systems, solar panels, biofuels, and wind energy. Additionally, the study considers a sample of 53 African countries, chosen based on the availability of data, which are presented in Table 1 below.

A list of a few chosen African nations and the accompanying average mean values are shown in Table 1, which provides information on the distribution and variations throughout the continent. In contrast to countries like Guinea-Bissau (0.485491) and Gambia (0.607628), which display substantially lower averages, countries like Rwanda (1301.012) and Senegal (1537.96) show significantly higher average means, indicating a relatively greater measure of the variable under consideration. A wide variety of values are seen, with some countries showing different levels of the examined metric, such as South Africa (28.34336), Ethiopia (23.41616), and Nigeria (86.77011), falling in between. The table illustrates the disparities in average performance between the nations, pointing to possible regional variations or differences in economic and developmental aspects that would be worth investigating further.

3.1. Dynamic GMM Model

The study utilized the Generalised method of moments (GMM) model as its analytical framework, aiming to resolve potential endogeneity difficulties in econometric analyses involving dynamic relationships and panel data. The GMM model was chosen for its ability to resolve potential endogeneity difficulties in dynamic relationships and panel data. The study conceptualized and defined the relationship between power generation and agricultural development in a structured functional format, laying the groundwork for investigating how enhanced energy infrastructure contributes to agricultural value addition. The functional specification also allowed for the incorporation of control variables, ensuring the model reflects both direct and indirect effects. Establishing this relationship in a functional form allowed for the discovery of testable hypotheses and established the framework for a thorough GMM study. The GMM framework quantifies the strength and direction of the link while accounting for factors like unobserved heterogeneity, simultaneity, and potential measurement errors. Thus, the functional form of the model is shown below.

$$AVD = f(EPG, C) \tag{1}$$

Table 1: List of selected African Countries

S/N	Countries	Average mean	S/N	Countries	Average mean
1	ANGOLA	7.502625	28	MADAGASCAR	25.74137
2	BENIN	5.935777	29	MALAWI	18.75849
3	BURKINA FASO	0.927769	30	MALI	9.464873
4	BOTSWANA	1.873952	31	MAURITANIA	11.03659
5	BURUNDI	2.479051	32	MAURITIUS	2.012697
6	CAMEROON	1.121344	33	MOROCCO	9.339684
7	CABO VERDE	0.61868	34	MOZAMBIQUE	6.201035
8	CENTRAL AFRICAN REPUBLIC	1.046841	35	NAMIBIA	20.72244
9	CHAD	2.644765	36	NIGER	59.48406
10	COMOROS	2.760198	37	NIGERIA	86.77011
11	REPUBLIC OF CONGO	1.352578	38	RWANDA	1301.012
12	DR EPUBLIC OF CONGO	57.75732	39	SAO TOME AND PRINCIPE	4.007694
13	DJIBOUTI	5.919715	40	SENEGAL	1537.96
14	EGYPT	7.059016	41	SEYCHELLES	1290.394
15	EQUITORIAL GUINEA	4.215736	42	SIERRA LEONE	580.7379
16	ERITREA	15.26531	43	SOMALIA	731.1503
17	ETHIOPIA	23.41616	44	SOUTH AFRICA	28.34336
18	GABON	14.61721	45	SOUTH SUDAN	94.7541
19	GAMBIA	0.607628	46	SUDAN	48.7814
20	GHANA	0.904866	47	SWAZILAND	3.074463
21	GUINEA	0.656219	48	TANZANIA	2.243965
22	GUINEA-BISSAU	0.485491	49	TOGO	6.74416
23	IVORY COAST	4.334186	50	TUNISIA	7.551487
24	KENYA	4.807538	51	UGANDA	431.2829
25	LESOTHO	5.139951	52	ZAMBIA	1102.765
26	LIBERIA	7.898616	53	ZIMBABWE	12.27682
27	LIBYA	12.72363			

Source: Authors concept

Agricultural development (AVD) is defined as being influenced by Electric Power Generation (EPG) and a collection of contextual variables known as C. This approach captures the relationship between energy availability and the structural elements that influence agricultural outcomes. To achieve a thorough analysis, we included major control variables that are important in mediating the relationship between power generation and agricultural progress. These controls include electricity power consumption (EPC), which is measured in kilowatt-hours per capita per hour, access to electricity (AE), which is the percentage of the population who has consistent access to electricity, and energy generation capacity (ENG), which indicates the overall efficiency and scope of energy production. By incorporating these variables, the model accounts for both direct and indirect paths in which electricity influences agricultural development. For example, increased electricity consumption per capita may assist mechanised agricultural and irrigation systems, whilst enhanced access to electricity guarantees rural people benefit from energy-driven advancements. Furthermore, energy generation capability demonstrates the promise of sustainable and scalable energy solutions to alter agricultural methods. Building on the theoretical and empirical framework laid by Manasseh et al. (2024), the basic functional form was transformed into a dynamic panel model to capture the relationship's temporal dynamics. This transformation acknowledges that present agricultural development is influenced not just by current energy variables, but also by previous states, reflecting the long-term and cumulative character of agricultural investments and energy infrastructure. To estimate this dynamic relationship, the Generalised method of moments (GMM) framework was used, which effectively resolves endogeneity problems, unobserved heterogeneity, and model dynamic structure. The new functional form is shown below in equation (2), which presents the GMM specification customised to the study's objectives.

$$AVD_{i,t} = \beta_0 + \beta_{1i}\, AVD_{i,t\text{-}1} + \beta_{2i}\, EPG_{i,t} + \beta_{3i}\, EPC_{i,t} + \beta_{4I}\, AE_{i,t} + \beta_{5i}\, ENG_{i,t} + \mu_I + \varepsilon_{i,t} \quad (2)$$

Where $AVD_{i,t}$ denote the Agricultural Development (AVD) at time t. $AVD_{i,t-1}$ is the lagged dependent variable, capturing the persistence of agricultural development over time. $EPG_{i,t}$ define the Electric Power Generation at time t*t* for entity i*i*. $EPC_{i,t}$ represent the Electricity Power Consumption (kWh per capita per hour) at time t. $AE_{i,t}$ is the Access to Electricity at time t. $ENG_{i,t}$ denote the electricity power consumption at time t. In addition, μ_I measures the individual specific effect which captures unobserved heterogeneity across entities (e.g., countries), such as differences in baseline agricultural policies or geographic factors, while $\varepsilon_{i,t}$ is the stochastic disturbance term capturing random shocks or noise at time t. In line with Hansen (1982), the lag AVD_{t-1} by AVD_{t-2} shown in eqn. (4) resolves any earlier noted problems and produces an unbiased estimate by eliminating α_i and θ_i from the eqn. (3).

$$\widehat{AVD}_{iv} = \frac{\sum_t^T \sum_i^N AVD_{i,t-2} AVD_{i,t-1} - \widehat{AVD}_{i,t-2}}{\sum_t^T \sum_i^N AVD_{i,t-2} AVD_{i,t-1} - AVD_{i,t-2}} \quad (3)$$

$AVD_{i,t-2}$ is used as an instrument of ($AVD_{i,t-1}$-$AVD_{i,t-2}$). The GMM techniques involve the most efficient instrument, P_i:

$$Y_{GMM} = \sum_{i=1}^{N} \Delta AVD_{i,t} P_i L_N \sum_{i=1}^{N-1} P_i^{'} \Delta AVD_{i,t}$$
$$\times \sum_{i=1}^{N} \Delta AVD_{i,t} P_i L_N \sum_{i=1}^{N} P_i^{'} \Delta AVD_{i,t} \quad (4)$$

4. EMPIRICAL RESULTS AND DISCUSSION

4.1. Empirical Results

The empirical findings from the examination of the connections between the major factors affecting agricultural development—with an emphasis on the production of electricity —are presented and discussed in this section. The descriptive statistics and correlation matrices, which provide preliminary insights into the distribution and correlations between the variables under research, are presented at the beginning of the empirical investigation. These preliminary analyses, which include measures of central tendency, variability, and possible relationships, are essential for comprehending the fundamental properties of the data. To ascertain whether the time series data is stationary, we then go on to unit root testing. The existence of unit roots would suggest that the variables are not stationary and might need to be transformed before the analysis can continue. Time series modelling relies heavily on the assumption of stationarity; if non-stationary data is ignored, the findings may be erroneous. We perform cointegration tests after the unit root tests to see whether there is a long-term equilibrium relationship between agricultural development and electricity generation. Cointegration tests are essential because they show whether the variables move in tandem over time, indicating a solid long-term link despite possible short-term variations. These tests serve as the basis for choosing suitable econometric methods to model the variables' dynamic connection. To evaluate the effects of energy policy, agricultural development, and electricity generation in the context of African economies, the outcomes of these tests will guide the choice of future modelling methodologies. The analysis will conclude with a summary of the main conclusions and policy suggestions for promoting sustainable development via better agriculture and energy practices.

Table 2 summarises descriptive statistics and presents a correlation matrix for the key variables examined in the study: Agricultural value added (AVD), electricity power generation (EPG), electricity power consumption (EPC), access to electricity (AE), and energy generation. The mean values for the variables reflect their basic trends, with AVD at 1.166, EPG at 0.922, EPC at 0.233, AE at −0.336, and ENG at −0.667. Notably, the data's maximum and minimum values differ greatly, particularly for AVD (ranging from −7.397 to 10.618) and EPG (ranging from −6.296 to 10.618), showing considerable differences in agricultural development and energy generation among the analysed countries. The standard deviations reflect this variability, with AVD having the greatest dispersion (3.115), followed by EPG (2.744), showing that the values of these variables are widely dispersed around their mean.

The skewness and kurtosis values offer valuable insights into the distribution patterns of the variables. AVD shows a mild positive skew (0.147), indicating a fairly symmetrical distribution, while

Table 2: Summary of descriptive statistics and correlation matrix

Variable	AVD	EPG	EPC	AE	ENG
Mean	1.166	0.922	0.233	−0.336	−0.667
Median	1.592	0.353	0.581	−0.082	−0.512
Maximum	10.62	10.62	4.149	2.175	6.611
Minimum	−7.397	−6.296	−7.002	−5.764	−6.296
Std. Dev.	3.115	2.744	1.366	1.009	1.907
Skewness	0.147	0.4889	−0.719	−1.948	−0.247
Kurtosis	2.618	3.565	4.852	9.079	3.160
Jarque-Bera	10.47	59.04	163.8	2341.7	12.47
Probability	0.005	0.000	0.000	0.000	0.002
Observations	1083	1112	715	1078	1107
AVD	1				
EPG	−0.851	1			
EPC	0.943	−0.399	1		
AE	−0.588	−0.354	0.038	1	
ENG	−0.603	−0.003	0.025	0.030	1

Source: Author's concept. AVD: Agricultural value added, EPG: Electricity power generation, EPC: Electricity power consumption, AE: Access to electricity, ENG: Energy generation

EPC and AE display negative skewness, suggesting that outliers are present on the lower end of the distribution. The kurtosis values, especially for AE (9.080), point to leptokurtic distributions, meaning these variables have more extreme values (outliers) compared to a normal distribution. The results of the Jarque-Bera test, which assesses normality, indicate that all variables, except EPG, reject the null hypothesis of normal distribution at standard significance levels (with P-values significantly below 0.05). This suggests that, except for EPG, the data for the other variables do not follow a normal distribution, which could influence subsequent analyses and may require data transformation or the use of robust estimation methods.

The correlation matrix provides further insights into the relationships between the variables. AVD exhibits a strong positive correlation with EPC (0.943), suggesting that higher electricity consumption per capita is associated with improved agricultural development. However, there is a significant negative correlation between AVD and EPG (−0.851), implying that in this dataset, increased electricity generation is linked to a decrease in agricultural value-added. Similarly, AE and ENG both show negative correlations with AVD, indicating that neither access to electricity nor energy generation is strongly associated with agricultural development in this context. These initial correlations suggest complex interrelationships between energy-related variables and agricultural outcomes. The descriptive statistics reveal considerable variability in the data, while the correlation matrix uncovers intricate connections between energy generation, consumption, and agricultural development. These findings point to the need for deeper exploration, particularly with regard to potential policy interventions and their implications for energy access and agricultural growth in the studied regions.

A crucial prerequisite for reliable econometric modelling is the variables' stationarity, which is revealed by the unit root test findings in Table 3. The stationarity of each variable was evaluated using a variety of tests, such as Levin-Lin-Chu (LLC), Im-Pesaran-Shin (IPS), Fisher-ADF, and Fisher-PP. According to the results, all test statistics produced extremely significant P-values (P < 0.01), and Agricultural Value Added (AVD), Electricity Power Generation (EPG), Electricity Power Consumption (EPC), and Access to Electricity (AE) are all stationary at level, indicated as I(0). Accordingly, these variables can be directly included in models that assume stationary variables, like ordinary least squares (OLS) or other regression techniques, because they do not have unit roots at their levels.

On the other hand, energy generation (ENG), represented by I(1), shows non-stationarity at level but attains stationarity following initial differencing. This suggests that ENG has a unit root at level, necessitating the use of differencing in order to remove random walk behaviour or stochastic trends. Its dynamic aspect is highlighted by the integration order of I(1) for ENG, which calls for the employment of models capable of handling variables with varying degrees of integration. Autoregressive distributed lag (ARDL) models, for instance, are especially well-suited for these datasets since they can account for both I(0) and I(1) variables. Strong evidence of the variables' stationarity features is ensured by the results' constant significance across all tests, which boosts trust in the variables' dependability for further analysis. These results highlight how crucial it is to specify econometric models that take into consideration the various integration orders of the variables when designing models to prevent erroneous correlations and skewed estimations. ARDL and related frameworks are ideal for this study because of the dataset's combination of stationary and non-stationary variables, which provides a chance to investigate both short-term dynamics and long-term correlations.

After determining the variables' integration orders and stationarity characteristics, we investigate the possibility of a long-term cointegrating relationship between Africa's agricultural development and electricity generation. This was accomplished by using the Pedroni (2004) panel cointegration test as the main technique and the Kao (1999) cointegration test as a robustness measure. Table 4 provides a summary of the results from this analysis.

Table 4's cointegration test results offer important information about whether or not the variables under investigation have a long-term equilibrium relationship. Other test statistics provide a different result, even if the Pedroni test's Panel-v statistic is insignificant (P = 0.9987), suggesting no indication of cointegration. In particular, the Panel-PP and Panel-ADF statistics are both highly significant (P = 0.0000), providing strong evidence of cointegration, and the Panel-rho statistic exhibits significance at the 5% level (P = 0.0285). The existence of the long-term connection is also supported by the group statistics Group-rho, Group-PP, and Group-ADF, all of which exhibit statistical significance at the 1% level. These results are consistent with the robustness check of the Kao (1999) test, which yielded a highly significant statistic (P = 0.0000), supporting the evidence of a consistent, long-term relationship between electricity generation and agricultural development in Africa. The validity of these findings is highlighted by the high degree of agreement across the majority of statistical measures. The presence of cointegration between the variables has significant ramifications for developing models and formulating policies. Despite brief oscillations, it shows that the variables move in tandem over time, indicating a solid relationship. Cointegration suggests to policymakers that decisions pertaining to electricity generation have long-term impacts on agricultural development and vice versa. Long-term agricultural growth could be supported by investments in energy infrastructure, while agricultural production could suffer long-term effects from interruptions in electricity generation. Thus, in order to achieve sustainable development in Africa, comprehensive policy measures that address the interaction between electricity supply and agricultural outcomes are essential.

Table 5 summarises the findings from the estimation of the dynamic panel Generalised Method of Moments (GMM) model to investigate the connection between agricultural development and electricity generation in Africa. The dynamic panel GMM approach was chosen for this investigation because it has a number of significant advantages over other approaches, like the

Table 3: Unit root test results

Variable	LLC	IPS	Fisher-ADF	Fisher-PP	Integration order	
					Level	First Diff.
AVD	−925.028*** (0.0000)	−339.366*** (0.0000)	1407.02*** (0.0000)	743.871*** (0.0000)	I (0)	_
EPG	−4.35844*** (0.0000)	−5.24077*** (0.0000)	218.410*** (0.0000)	240.333*** (0.0000)	I (0)	_
EPC	−11.0688*** (0.0000)	−11.2682*** (0.0000)	330.449*** (0.0000)	357.641*** (0.0000)	I (0)	_
AE	−9.94235*** (0.0000)	−10.6722*** (0.0000)	303.335*** (0.0000)	310.119*** (0.0000)	I (0)	_
ENG	−37.4197*** (0.0000)	−31.9197*** (0.0000)	1010.27*** (0.0000)	2457.34*** (0.0000)	_	I (1)

Source: Authors' Concept. *** represents 1% level of significance; I (0) and I (1) represents order level; and first difference. (.) denote probability value. LLC: Levin-Lin-Chu, IPS: Im-Pesaran-Shin, AVD: Agricultural value added, EPG: Electricity power generation, EPC: Electricity power consumption, AE: Access to electricity, ENG: Energy generation

Table 4: Cointegration test results

Panel-v	Panel-rho	Panel-PP	Panel-ADF	Group-rho	Group-PP	Group-ADF	Kao test (robust check)
−3.0018 (0.9987)	−1.9674** (0.0285)	−15.197*** (0.0000)	−13.347*** (0.0000)	16.8139*** (0.0000)	−21.824*** (0.0000)	−15.989*** (0.0000)	−8.1185*** (0.0000)

Source: Authors' Concept. ***, and ** represents 1% and 5% levels of significant. (.); represents probability value

Table 5: Estimated dynamic GMM results

Variable	Diff. GMM	System GMM
AVD (-1)	0.5958*** (0.000)	−0.581*** (0.000)
LnEPG	−0.878*** (0.000)	−0.166* (0.056)
LnEPC	0.128* (0.079)	0.876*** (0.000)
LnAE	−0.869*** (0.000)	0.864** (0.041)
LnENG	−0.103** (0.021)	−0.856*** (0.000)
Obs.	1007	913
PMG	0.681	
FE	0.612	
AR1	2.799 (0.036)	
AR2	0.625 (0.532)	
Hansen J-Stat.	56.78 (0.155)	81.33 (0.462)

Source: Authors' Concept. ***, **, and * represents 1%, 5% and 10% level of significance. Ln is the natural Logarithm. (.); probability value

Autoregressive Distributed Lag (ARDL) model. Datasets with a high number of cross-sectional units (such as countries) and brief time periods are ideal for dynamic panel GMM, which fits the design of this investigation. Furthermore, GMM successfully handles endogeneity problems that can result from omitted variable bias or reverse causality, which are frequent in research examining the relationship between energy and development. For example, while the generation of electricity may have an impact on agricultural development, it is also possible that agricultural productivity will have an impact on energy demand. GMM reduces these biases by using lagged variables as tools, guaranteeing accurate and consistent parameter estimates.

Dynamic panel GMM (GMM) is a statistical model that considers unobserved heterogeneity among units, unlike ARDL (Analytical Regression Linear Model), which is better suited for examining correlations in small panels or single time series. It includes lagged dependent variables, capturing the dynamic nature of the connection and considering persistence or inertia in agricultural development over time. This is particularly important for industries like agriculture and energy, where previous performance significantly impacts present results. GMM ensures efficiency and consistency when heteroskedasticity or serial correlation are present, which are common issues in panel data analysis. It is a popular choice for researching the complex and changing link between agricultural development and electricity generation, providing valuable insights for policy suggestions and enabling policymakers to create plans that consider both short-term demands and long-term viability.

Additionally, a significant degree of persistence in the dependent variable is shown by the PMG estimate (0.681) being higher than the Fixed Effects estimate (0.612). This persistence implies that the dependent variable's lagged values have a substantial impact on its current values, raising the possibility of bias or inefficiency in standard estimators. The rule of thumb is that System GMM is the best estimation method in these circumstances. Because System GMM combines equations in levels and first differences, it successfully handles persistence and endogeneity difficulties. This method increases productivity and yields more accurate estimates, especially when the data show significant persistence.

Table 5 results show a positive coefficient of 0.5958, significant at the 1% level (see diff. GMM), which suggests past agricultural development continues to influence current agricultural outcomes. This highlights how historical factors, such as infrastructure, investments, and agricultural policies, shape present agricultural systems. In Africa, colonial-era farming methods and historical inefficiencies continue to impact modern farming practices. Mahmood and Ayaz (2018) emphasize that outdated farming techniques and inadequate infrastructure in countries like Nigeria and South Africa still hinder agricultural productivity, despite modernization efforts. These historical constraints restrict the sector's structural capacity to evolve. Conversely, the System GMM's negative coefficient of −0.581, also significant at the 1% level, indicates that external shocks, such as policy changes or fluctuations in global commodity prices, disrupt the path-dependent nature of agricultural growth. This finding suggests that Africa's agricultural development is vulnerable to external forces. Le et al. (2019) argue that African economies, particularly those dependent on commodity exports, are highly susceptible to such shocks. For example, changes in global oil prices have significantly impacted oil-dependent African nations, disrupted agricultural growth and often led to sectoral contraction. This dynamic demonstrates how global economic changes can override the historical continuity of agricultural development in the region, showing that while path dependence exists, external factors can reshape agricultural outcomes in Africa.

Further investigation revealed that the difference GMM model's negative coefficient of −0.103 (significant at the 5% level) suggests that although certain African nations may be increasing their capacity for electricity generation, the impact on agricultural productivity is negligible. This can be the result of ineffective energy distribution systems, inefficiencies, or a mismatch between the demands of agriculture and energy production. Many Sub-Saharan African countries, for example, suffer from antiquated energy infrastructure and insufficient transmission networks, which hinder energy from reaching rural farming areas (Adedeji et al., 2024). For instance, many farmers in Nigeria lack the electricity necessary for basic tasks like irrigation and mechanised planting due to significant transmission losses and unstable grid networks. The crucial role that energy generation capacity plays in agricultural development is further supported by the System GMM model's negative coefficient of −0.856, which is significant at the 1% level. Nonetheless, it emphasises how the beneficial effects on agriculture are severely hampered by inefficiencies in the energy sector, such as underutilisation of energy supplies and delays in project execution. For example, in South Africa, energy-intensive sectors frequently displace the agricultural sector's energy requirements, making it more difficult for farmers to implement cutting-edge methods like precision farming. These results demonstrate how urgently strategic investments in energy infrastructure that is suited to agricultural requirements are needed. As demonstrated by Kenya's renewable energy projects, which have increased the availability of energy for farming activities, decentralised energy solutions such as solar mini-grids and off-grid renewable systems can be implemented to target underserved rural areas. To fully realise the sector's potential in Africa, energy efficiency must be increased and energy generation must be matched with agricultural priorities.

The negative coefficient of −0.878 (significant at the 1% level) as shown in the difference GMM model indicates that higher power generation has a detrimental effect on agricultural productivity. Inefficiencies in energy generation and distribution networks, which disproportionately impact rural areas where agriculture is most popular, are probably the cause of this discovery. For example, Ugo and Daniel (2024) draw attention to how Nigeria's energy problems, including inadequate transmission infrastructure and significant energy losses, limit access to dependable electricity for processing, storage, and irrigation. These inefficiencies support the relationship between energy and agriculture, which holds that a lack of energy lowers agricultural production and, in turn, deters investment in contemporary farming practices. However, the System GMM model's lesser negative value of −0.166 (significant at the 10% level) indicates that, within this framework, the negative impact of electricity generation on agricultural output is less pronounced. This might be a reflection of the possibility of long-term improvements in energy infrastructure to lessen negative consequences. Decentralised renewable energy systems and other more efficient energy technologies have shown promise in tackling these issues. Examples of how focused investments in energy infrastructure might start to buck these tendencies and provide sustainable energy for agricultural expansion include Ethiopia's Grand Ethiopian Renaissance Dam project and Kenya's adoption of solar-powered irrigation equipment. These results highlight how urgently African countries must invest in dependable and just energy distribution networks to reduce energy inefficiencies. Agriculture might transform by incorporating renewable energy sources and bolstering rural electrification, which would promote resilience and production.

In addition, we observed a positive coefficient of 0.128, which is significant at the 10% level (see diff. GMM model). This indicates a minor correlation between increased agricultural output and higher power use. Even though this effect is small, it emphasises how crucial energy availability is to sustaining agricultural activity. This result is consistent with the findings of Adedeji et al. (2024), who emphasise how electricity use supports value-added operations such as crop drying, refrigeration, and milling as well as agricultural mechanisation. In rural Nigeria, for example, farmers who use electricity to store perishable items or turn cassava into flour have shown modest production increases; nevertheless, these improvements are frequently constrained by unreliable energy supply. A significantly higher positive coefficient of 0.876 (significant at the 1% level) is found in the System GMM model, suggesting that electricity use significantly contributes to increased agricultural productivity. This outcome demonstrates the revolutionary potential of dependable energy in updating farming methods. Agro-industrial development, precision farming, and increased irrigation coverage are all made possible by sustainable energy infrastructure, as demonstrated by projects like Ethiopia's Grand Ethiopian Renaissance Dam and Kenya's solar-powered irrigation systems. Shettima et al. (2023) point out that by lowering energy costs and improving rural farmers' access to electricity, renewable energy projects in Kenya have greatly increased agricultural production. These results underline the necessity of policies that give greater access to and use of electricity in Africa's agriculture sector top priority. By enabling smallholder farmers to use mechanised farming practices, investments in sustainable energy solutions—like decentralised solar grids—can boost productivity and promote rural economic development.

Also, we observed that agricultural development is constrained by the lack of adequate or effective electrical availability, especially in rural areas as indicated by a negative coefficient of −0.869 (significant at the 1% level). The inability of electricity infrastructure to satisfy the needs of rural populations is a recurring issue in many regions of Sub-Saharan Africa. For example, Shettima et al. (2023) discuss how mechanisation, irrigation, and storage capabilities are hampered by inadequate energy access in rural areas, which lowers output. For instance, farmers frequently use costly and unreliable fuel-powered generators in Nigeria, which raises output costs and reduces competition in agricultural markets. On the other hand, the System GMM model's positive coefficient of 0.864 (significant at the 5% level) shows that when power is made available, increased access to it significantly boosts agricultural productivity. This research demonstrates how electrification in rural areas may revolutionize agricultural practices. In nations like Ethiopia and Kenya, where solar-powered irrigation systems and electrified agro-processing units have greatly increased productivity, Ugo and Daniel (2024) demonstrate the advantages of rural electrification programs. Ethiopia's initiatives to increase grid connectivity, for instance, have made it possible for farmers to use contemporary storage facilities, which has improved market accessibility and decreased post-harvest losses. These findings underscore how urgently specific policies are needed to increase and enhance rural electrification in Africa. Investing in off-grid solar arrays and other decentralised energy solutions can solve inefficiencies and offer dependable electricity for agricultural operations. To promote productivity growth and guarantee food security throughout the continent, it is imperative to expand access to reasonably priced and sustainable energy.

In Africa, the dynamic link between agricultural development and energy generation is intricate and situation-specific. The results of the GMM models show that inefficiencies and unequal access to energy continue to be major obstacles, even though improvements in energy infrastructure can aid in agricultural development. Research such as that conducted by Mahmood and Ayaz (2018) and Shettima et al. (2023) highlights the significance of filling in infrastructure and energy access gaps to guarantee sustained agricultural expansion in the area. Furthermore, to address the ongoing issues facing African agriculture, the findings emphasise the necessity of customised energy policies that give priority to renewable energy sources and focused investments in rural electrification. The AR1 statistic, a significant 5% level value, indicates the validity of a model's autoregressive structure and first-order serial correlation in the differenced equation's residuals. This is common in dynamic panel data models, as first-order serial correlation is often introduced when variables are changed to eliminate unobserved heterogeneity. However, if there is no second-order serial correlation, the model is not invalid. This result is particularly relevant to Africa, as it emphasizes the dynamic nature of the linkages under study, such as agriculture development and electricity generation's contribution to economic growth. The existence of AR1 suggests that authorities should consider the time-lag impacts of investments and policies, such as mechanisation or rural electrification when planning for growth. To verify the model's validity and guarantee trustworthy policy conclusions, additional robustness tests, such as the Hansen J-statistic and the AR2 statistic, should be employed. The AR2 test evaluates second-order autocorrelation in residuals, indicating the model's reliability in handling higher-order autocorrelation. The J-statistic tests the validity of instruments in the GMM estimation, ensuring they are uncorrelated with errors and correctly excluded from the equation.

4.2. Discussion

The study examines the connection between electricity generation and agricultural development in Africa, emphasising the role that electricity generation plays in determining agricultural development. The study identifies historical persistence and adaptability potential in African agricultural systems using the System GMM and Difference GMM models. Lagged agricultural outcomes and current productivity were positively associated, according to the Difference GMM model, suggesting that past difficulties still influence the present. This supports the idea of path dependence, according to which the productivity of African agriculture is currently constrained by inefficiencies from previous policies, such as land distribution and agricultural techniques from the colonial era. These issues are still present, especially in rural areas where infrastructure—especially the energy supply—is still insufficient. The results are consistent with the larger story of Africa's sluggish agricultural modernisation, where historical inefficiencies have hindered the region's capacity to realise its full agricultural potential. Unlocking the region's agricultural potential requires addressing these past inefficiencies. African economies are sensitive to exogenous shocks, such as changes in global commodity prices, policy changes, or technical breakthroughs, according to the System GMM model's negative coefficient for the lagged dependent variable. In the context of Africa's global integration, this adaptability is essential, particularly as agricultural systems face mounting pressure from global markets and climate change.

The study reveals significant inefficiencies in Africa's energy systems, particularly in electric power generation and energy generation capacity, and their impact on agricultural development. The negative coefficients indicate that despite increases in electricity generation, the actual benefits to agriculture remain minimal due to systemic challenges such as inadequate distribution networks, frequent transmission losses, and unreliable supply. These infrastructural shortcomings prevent the full utilization of available electricity in the farming sector. Infrastructure improvements over time could alleviate these inefficiencies, as seen in Kenya, where decentralized renewable energy projects like solar-powered irrigation systems have shown promise in enhancing agricultural productivity. The energy generation capacity coefficients also highlight the inefficiencies in Africa's energy systems, with the −0.103 coefficient in Difference GMM and −0.856 in System GMM suggesting that increased energy capacity has not led to effective utilization, especially in agriculture. In Ethiopia, inadequate rural distribution networks hinder the practical use of electricity for farming, while the larger negative coefficient in the System GMM highlights long-term structural challenges such as poor planning, operational inefficiencies, and corruption. The findings emphasize the critical importance of addressing energy infrastructure inefficiencies to boost agricultural productivity in Africa. The disconnect between energy generation and agricultural needs exacerbates challenges such as post-harvest losses, limited mechanization, and insufficient irrigation systems, stifling the potential for growth in the agricultural sector.

Despite these challenges, the study reveals that increased electricity power consumption can significantly improve agricultural development, especially in Africa where many countries rely on limited energy supply. Successful examples of renewable energy projects, such as Kenya's solar and geothermal projects, demonstrate the potential of affordable, sustainable energy for agriculture. These projects have enabled farmers to access consistent and affordable energy for irrigation and mechanized farming, leading to increased productivity. Large-scale projects like the Grand Ethiopian Renaissance Dam have facilitated irrigation and the adoption of modern farming techniques, fostering agro-industrial growth. However, the study also highlights the challenges posed by insufficient infrastructure, with a negative coefficient for access to electricity (LnAE) indicating difficulties in accessing modern farming equipment due to outdated energy infrastructure. This infrastructure deficit is a key barrier to agricultural modernization, as farmers cannot invest in modern irrigation systems, mechanized equipment, or other technologies that could boost productivity. The study suggests significant investments in energy infrastructure, particularly in renewable energy sources like solar and wind, are essential for overcoming these barriers.

The study highlights the ongoing electricity generation-agriculture dilemma in African countries, highlighting inefficiencies and unequal distribution of electricity. Limited access to reliable energy for critical agricultural operations, such as irrigation, processing, and storage, significantly hampers productivity. Poor transmission networks and insufficient rural electrification prevent farmers from accessing consistent and affordable energy supply. Over-reliance on fossil fuels exacerbates energy shortages in rural areas, raising costs and discouraging investment in modern farming technologies. Energy systems in many African countries are fragmented and inefficient, leading to frequent power outages and high electricity costs. Farmers often rely on costly and unsustainable energy sources, such as diesel generators, which not only increases production costs but also limits the ability of farmers to scale up operations or adopt more efficient farming techniques. Poor energy policy frameworks prioritize large-scale industrial users over small-scale agricultural producers, limiting access to affordable energy for the rural sector.

This study's findings have a number of significant implications for future research and policy formation in African economies. In order to boost agricultural development, policymakers should concentrate on enhancing energy efficiency, guaranteeing fair energy distribution, and encouraging renewable energy sources. Large-scale investments in decentralised renewable energy systems, such wind and solar, could lessen farmers' dependency on expensive and environmentally harmful energy sources and assist alleviate rural energy shortages. Furthermore, it will be essential to combine energy policy with modernisation plans for agriculture. Enhancing agricultural extension services, encouraging the adoption of contemporary farming technologies, and making it easier to obtain reasonably priced finance for energy-efficient farming equipment are all part of this. A comprehensive strategy that integrates energy reform with agricultural development policies can aid in realising the full potential of the energy-agriculture nexus in Sub-Saharan Africa, as suggested by Shettima et al. (2023) and Mahmood and Ayaz (2018). In conclusion, African nations may overcome enduring obstacles in the interaction between energy and agriculture by resolving energy inefficiencies, encouraging renewable energy, and making infrastructural investments. In addition to increasing agricultural output, this will also help the region's overall economic growth, poverty alleviation, and food security. The intricate relationships among energy availability, agricultural growth, and economic outcomes in African economies should be further investigated in future studies, with an emphasis on finding long-term, locally relevant answers to these urgent problems.

5. CONCLUSION AND RECOMMENDATIONS

This study focuses on exploring the relationship between electricity generation and agricultural development in Africa over the period from 2000 to 2020. We employed annual time series data from 53 selected African countries, sourced from the World Bank's development indicators (WDI). Agricultural value added (AVD) served as the indicator of agricultural development, while electricity power generation (EPG) and electricity power consumption (EPC) were used to assess electricity generation. In addition, we controlled for factors such as access to electricity (AE) and energy generation (ENG). The cointegration analysis revealed a long-term relationship between electricity generation and agricultural development in Africa. To ensure the robustness of our model, we conducted pre- and post-OLS estimation tests to verify the assumptions of OLS. The results indicated that the error terms of the model are normally distributed, free from serial correlation, and homoscedastic, confirming the correct specification of the model.

The System GMM results provide valuable insights into the dynamics between electricity generation and agricultural development in Africa. A key finding is the negative coefficient of −0.581, which highlights the vulnerability of African agriculture to external shocks, such as global commodity price fluctuations and policy changes. These external forces disrupt the historically path-dependent growth of agriculture, emphasizing the importance of stabilizing factors in the agricultural sector. The results also show that energy generation capacity, while increasing in some African nations, has limited impact on agricultural productivity due to inefficiencies in energy distribution. Despite efforts to improve energy infrastructure, rural areas in countries like Nigeria and South Africa continue to face unreliable power supply, hindering modern agricultural practices. Additionally, the positive coefficient of 0.876 suggests that increased access to electricity significantly boosts agricultural productivity. However, the effect is constrained by inadequate infrastructure, particularly in rural regions. To address these challenges, the study emphasizes the need for targeted investments in decentralized renewable energy solutions, such as solar-powered irrigation systems, which have shown promise in improving energy availability and enhancing agricultural output. The findings underline the urgency of prioritizing energy policies focused on renewable energy sources and rural electrification to address energy inefficiencies. Moreover, the AR1 statistic confirms the autoregressive structure of the model, reinforcing the need to consider time-lag impacts of energy and agricultural policies. Overall, the study advocates for robust testing of models, including the Hansen J-statistic and AR2 statistic, to ensure reliable policy conclusions for sustainable agricultural development in Africa.

Based on the findings, several policy recommendations are put forward to strengthen the role of electricity generation in fostering agricultural development in Africa. First, African governments should prioritize investments in energy infrastructure, with a particular focus on renewable sources like solar and wind, to ensure a consistent and reliable electricity supply, especially in rural areas where agriculture is most concentrated. Second, there should be a concerted effort to develop decentralized energy systems that enhance energy access for smallholder farmers and rural communities. Third, policies must address the long-standing inefficiencies in agriculture by promoting modern farming practices, improving agricultural extension services, and facilitating access to advanced farming technologies. Finally, energy and agricultural development should be strategically integrated, ensuring that energy access is directly aligned with and supports the growth and productivity of the agricultural sector.

In conclusion, the study also points to the crucial role of energy infrastructure in agricultural productivity. The negative coefficient of −0.103 and −0.856 in both difference and system GMM suggests that increases in electricity generation have limited immediate effects on agricultural development, primarily due to inefficiencies in energy distribution and poor transmission networks. Inadequate access to energy, especially in rural areas where agriculture is concentrated, exacerbates this challenge. Despite this, the positive coefficient of 0.128 shows that access to electricity has a modest, yet important, role in supporting agricultural activities. These findings emphasise the need for targeted investments in energy infrastructure, such as decentralised solar systems, to enhance agricultural development. Therefore, improving energy access and infrastructure is critical for fostering sustainable agricultural development in Africa.

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