Indian Development Economics Review
Vol. 1, No. 1, 2025, pp. 85-104 • ISSN: 3049-1770
https://DOI:10.47509/IDER.2025.v01i01.05

ARF INDIA
Academic Open Access Publishing
www.arfjournals.com
https://arfjournals.com/isdr

Energy-Driven Pathways to Food Security: The Moderating Influence of Energy Consumption on Innovation, FDI, and Environmental Dynamics in Nigeria

Muhammed Shamwil[1], Aisha Adamu Hassan[2], Anas Muhammad Abubakar[3] and Bashir Bappayaya[4]

[1]*Department of Economics and Development Studies, Federal University of Kashere, Gombe state, Nigeria. E-mail: mohammedshamwil@fukashere.edu.ng*
[2]*Department of Economics, Gombe State University, Gombe, Nigeria. E-mail: Aishaadamu1043@gsu.edu.ng*
[3]*Department of Economics, Mewar International University, Nassarawa, Nigeria. E-mail: anas.muhd@miu.edu.ng*
[4]*Department of Economics, Gombe State University Gombe, Gombe State*

To Cite this Article

Muhammed Shamwil, & *et al.* (2025). Energy-Driven Pathways to Food Security: The Moderating Influence of Energy Consumption on Innovation, FDI, and Environmental Dynamics in Nigeria. *Indian Development Economics Review,* 1: 1, pp. 85-104.

Abstract

Despite its abundant potentials in agriculture, food security remains a major challenge for Nigeria, with food production and access mostly influenced by factors such as technological, socio-economic, environmental, and infrastructure. This study empirically examined the determinants of food security in Nigeria by utilizing Fully Modified Ordinary Least Square (FMOLS) and Canonical Cointegrating regression (CCR) for robustness check. Annual time series data from 1990 and 2023 was used. The results revealed that technological innovation and economic growth promote food security significantly, while FDI inflows shows a positive but insignificant impact on food security, which may be associated with its high concentration in extractive sectors. Similarly, expansion in agricultural land has an insignificant impact on food security. On the contrary, CO_2 emissions significantly reduce food security in Nigeria, underscoring the negative environmental consequences of CO_2 emissions related climate change on food security. The effect of energy consumption as a moderator highlights that availability of energy access enhances the favorable roles played by technological innovation and economic growth in enhancing food security. However, energy moderated FDI inflows, agricultural land expansion, and CO_2 emissions are unfavorable to food security in Nigeria. These outcomes suggests that there is need for integrated policies aimed at promoting the

Received : 17 March 2025 • **Revised :** 22 April 2025 • **Accepted :** 11 May 2025 • **Published :** 30 June 2025

adoption of modern agricultural technologies, attract sustainable agriculture-centered foreign investments, expand rural infrastructure such as access road, and electricity, and promote climate-resistant agricultural practices to mitigate agricultural losses related to climate change environmental risks.

Keywords: Technological innovation, food security, energy consumption, Nigeria, environmental quality, agriculture

JEL Codes: O33, Q16, Q18, Q43, Q54

Introduction

Agriculture plays a crucial role in the economic and social development of many countries especially in Nigeria where it remains one of the major sources of livelihood for a large share of its population and contributes around 25% of its GDP, provide direct and indirect employment opportunities for over 70% of Nigerians mostly at subsistent level, underscoring the sector's role in improving rural incomes and food security (Food and Agricultural Organization [FAO], 2023; World Bank, 2024). Because of the underdevelopment and subsistent nature of agriculture in the country, the acute food insecurity has reached an alarming level, as demonstrated by recent reports from the United Nations and the World Food Programme (WFP) that about thirty (30) to thirty one (31) million Nigerians are facing acute hunger, primarily driven by persistent conflict, climate shocks, and rising prices of agricultural products, with the northeast and northwest regions significantly affected (WFP, 2025; FAO, 2024).

Moreover, technological innovation and foreign direct investments (FDI) are often viewed as major channels through which improved agricultural productivity and sustainable food security can be achieved in Nigeria. For instance, digital technologies like mobile phones, internet-related farm services, agricultural ICT applications, and Controlled Environment Agriculture (CEA) systems have the potential to significantly raise agricultural productivity, reduce post-harvest losses, and promote smallholder farmers into higher value chains (FAO, 2024). Meanwhile, FDI can play a transformative role by bringing in capital, advanced technologies, managerial skills, and value-chain investments that strengthen agricultural yields and provide market access, yet in Nigeria and Africa, FDI inflows have been broadly volatile as stated by United Nations Conference on Trade and Development (UNCTAD, 2024) that FDI inflows into the developing countries reduced in 2023, with African nations experienced mixed outcomes, while Nigeria recorded modest FDI inflows related to the capital requirements for largescale agricultural mechanization, which shows growing concerns about both the adequacy and composition of the needed investments towards achieving sustainable agriculture and food security (UNCTAD, 2024)

Furthermore, energy resources are one the central but often overlooked factor necessary for achieving the productive potentials of technological innovation and foreign direct investment in agriculture. Modern agricultural technologies such as irrigation pumps, cold chain storage facilities, processing plants, and CEA systems are highly energy-intensive, requiring reliable and often on-demand energy. However, energy supply system in Nigeria remains highly inefficient as reported by Energy for Growth Hub (2024) that as of 2023, only 61% of the Nigeria's population had access to electricity with chronic unreliability and frequent blackout, forcing many farms and agricultural product processors to rely on costly and environmentally-unfriendly diesel generators and small scale solar system, which significantly raise costs of production and undermine the viability and economic capabilities of many agricultural technologies. In the same vein, the use of fossil fuels and their attendant carbon intensity in Nigeria's electricity generation affect the sustainable agricultural practice, as the country emits over 100 million tonnes of CO2 annually, with agriculture contributing through its reliance on fossil fuel as the major energy source, underscoring the environmental trade-offs of agricultural practice and environmental sustainability (Worldometer, 2024).

Though there are many research studies that examine the nexus such as ICT and agricultural productivity, FDI and agricultural output, or energy consumption, CO_2 emissions, and agriculture, significant gaps exist in the literature that limit clear policy guidance for Nigeria. First, several of the prior empirical studies failed to treat these factors as part of an integrated system. Instead, they apply fragmented approach, leaving the moderating influence of energy consumption within the framework of technology, FDI, agricultural productivity and food security pathway which underexplore the relationship (Abdullahi *et al*., 2025; Chandio *et al*., 2024).

Therefore, this study addressed these shortcomings by exploring the role of technological innovation and FDI on food security in Nigeria, taking into account the moderating role of energy consumption in this relationship. In this regard, this study contributes to the literature in three ways. First, we construct an empirical model that integrate innovation, FDI inflows, agricultural land, economic growth to agricultural productivity and food security, accounting for the mediating role of energy consumption. Second, it highlights the role of energy resources to provide roadmap for policy guide in energy and agriculture policy coherence. Third, by incorporating CO_2 emissions into the model as a control variable, the study spotlights the tradeoff between high agricultural productivity and environmental quality, as well as the potential for decoupling productivity growth from rising emissions. The findings from this study will be a source of guidance to policymakers, agricultural investors, and development partners on where to focus their interventions in promoting agricultural productivity gains, sustainable food security, and achieving climate-sensitive agricultural advancement in Nigeria.

2. Literature review

2.1. Technological Innovations and Agricultural Productivity

Technological innovations have consistently influenced agricultural productivity by enhancing production efficiency, broadening market access, and addressing logistical and environmental challenges (Abdullahi *et al*. 2025). Chandio *et al*. (2024) suggested the use of Mobile phones and the Internet has a significant and favorable effect on grain food production across all quantiles. They arrived at this conclusion after investigating the impacts of ICT on grain food production in SAARC countries from 2002 to 2019 using the Method of Moments Quantile Regression. Domguia and Asongu (2025) revealed that ICT use measured by the internet, mobile and fixed-line telephone penetration boosts the agricultural sector enormously in 18 sub-Saharan African countries. Abdullahi *et al*. (2025) examined the dynamic effects of CO_2 emissions, and technological innovations on agricultural exports and imports across 41 African nations from 1990 to 2022 by utilizing the Method of Moments Quantile Regression (MMQR), and discovered that CO_2 emissions exhibit a dual effect, positively influencing exports in high-performing economies but negatively affecting imports in environmentally vulnerable regions like North and Middle Africa, while technological innovations enhance agricultural trade performance, and economic growth drives both export capacity and import demand. Danjuma *et al*. (2025) asserted that different machines and frameworks applied in agricultural farming can mitigate the CO2 emissions of the agriculture sector if renewable energy technologies (RETs) and renewable energy sources are organized with proper agrarian loads. Nwanojuo *et al*. (2025) assessed the adoption of controlled environment agriculture (CEA) in Nigeria focusing on its feasibility, benefits, environmental impact, and socio-economic implications, and discovered that While CEA technologies offer efficiency and yield improvements, their adoption faces challenges like high initial costs, technical knowledge gaps, unstable energy infrastructure, lack of localized research on resource utilization, crop profitability, and the scalability of these systems.

The farmers' adoption of green innovative technology in agriculture for mitigating climate change in Benue state has been investigated by Wombo *et al.* (2023) using descriptive statistics approach covering a sample of 182, selected using multistage sampling technique. Their results revealed that Green innovative technology in agriculture has significant influence in mitigating climate change in Benue State. Ali *et al.* (2021) modeled the effects of income, agricultural innovation, energy utilization, and biocapacity on Carbon dioxide in Nigeria from 1981 to 2014 by applying the novel dynamic autoregressive distributed lag simulations. The results confirmed the EKC hypothesis and found that agricultural innovation and energy utilization have an escalation effect on CO2 emissions whereas income and biocapacity have long-run emission-reduction effects. Olisah *et al.* (2025) concluded that adoption of renewable energy technologies, such as solar power, wind energy, and biogas, mitigate greenhouse gas emissions, reduce reliance on fossil fuels, and improve energy access for rural farmers. This results in enhanced irrigation systems, mechanize farming operations, and implement precision agriculture techniques, leading to increased productivity and resilience to climate change impacts.

2.2. Foreign Direct Investment, CO_2 emissions, energy use and agricultural trade

The complex and diverse nexus between foreign direct investments, energy consumption, carbon emissions and agricultural productivity has garnered notable interest in recent years. Ananwude and Nwobia (2025) examined the extent to which foreign direct investment affects crop production, livestock, forestry, and fishery real output by utilizing an ex-post facto research design and Ordinary Least Square regression technique and found that foreign direct investment has a significant positive effect on crop production, livestock, forestry, and fishery real output in Nigeria. Osabohien *et al.* (2022) that agricultural trade is significant in explaining the level of inclusive growth, while FDI is insignificant in explaining inclusive growth in West Africa. Okeke and Abu (2024) asserted that in the short run, foreign direct investment and export earnings are positive and statistically significant, while exchange rate and inflation were negative and statistically significant in Nigeria by using Autoregressive Distributed Lag Model (ARDL). Empirical results obtained using the PMG model by Abdulrazaq *et al.* (2025) demonstrated that Chinese Foreign direct investment inflows have a favorable impact on the growth rate of agricultural value added in Africa, suggesting that Chinese investments have a positive impact on the agriculture sector in Africa. Umoru *et al.*

(2024) investigated the dynamic adjustment between energy consumption and productivity growth in oil-importing countries using the quantile regression technique and the Markov-Switching regression. The findings confirmed that the quantile effects of productivity growth on energy consumption are positive and significant, with productivity growth having the biggest influence on energy demand at the 10th percentile. Segbefia *et al.* (2023) evaluated the influence of carbon emission, population growth, economic growth and human capital on food security in five selected African nations using cross-sectionally augmented autoregressive distributed lag (CS-ARDL), and the findings indicated that carbon emission and population growth have an inverse connection with food security, whereas, human capital and economic growth improve food security.

The role of food security on poverty reduction within the Visegrad communities (Czech Republic, Hungary, Poland, and Slovakia) was evaluated by Takyi and Gavurova (2025) using Cross-Sectional Augmented Distributed Lag (CS-ARDL) model, and the findings revealed that food security, FDI, population growth, and technological innovation contribute in poverty reduction. Kelechi *et al.* (2022) explored the link among energy poverty, environmental degradation and agricultural productivity in 35 SSA nations using generalized method of moment (IV-GMM). Findings from the study revealed that whereas the index of energy poverty has a significant positive influence, ecological footprint exhibited an inverse and significant impact on agricultural productivity. Chidiebere-Mark *et al.* (2022), using the panel autoregressive distributed lag model answered the question of whether agricultural production, the use of renewable energy, and FDI increase or reduce carbon emissions in thirty-one African countries. Their results showed that net FDI, fertilizer consumption, livestock production significantly increased carbon emissions, both in the short run and long run. Udemba (2022) explored how FDI and agricultural sector determine the position of Nigeria in climate change, building on the ecological footprint in accounting for environmental performance using two-stage analyses of ARDL regression. The study confirmed that positive relationship between economic growth and ecological footprint is established in both the short run and long run. On the contrary, negative and significant relationship is uncovered between FDI and ecological footprint, and between agricultural sector and ecological footprint in both long run and sort run.

Awunyo-vitor and Sackey (2018) assessed the effect of foreign direct investment on Ghana's agriculture sector and economic growth using Error Correction Model (ECM). The study revealed positive and significant relationship between economic growth and foreign direct investment flow to the agricultural sector and volume of trade respectively. Alhassan (2021) examined the effect of agricultural total factor productivity on carbon dioxide emissions using a panel of 38 sub-Saharan Africa (SSA) countries. The outcome from the Fully Modified Ordinal Least Square and Canonical Cointegration Regression models revealed that the link between agricultural total factor productivity and carbon dioxide emissions shows a U-shaped relationship, implying that agricultural productivity initially reduces carbon dioxide emissions to a certain point, beyond which higher agricultural productivity increases carbon dioxide emissions, contradicting the Borlaug hypothesis. Agba (2018) measured the impact of foreign direct investment on agricultural output in Nigeria using Error correction model. The study found an insignificantly positive effect of foreign direct investment on agricultural output in the short-run but found a significant effect on agricultural output in the long-run, and a significant effect of employment, exchange rate, and interest rates on agricultural output in the long-run. Adetunji and Liu (2013) evaluated the impact of FDI on agricultural productivity in Nigeria using Vector Auto Regression (VAR) environment. Results from the analysis revealed that FDI in the period under review had no significant impact on agricultural output, but have significant positive impact on employment generation.

3. Methodology

3.1. Study Series and Data Sources

This study employed time-series data spanning from 1981 to 2023 for Nigeria to examine the dynamic impact of technological innovations, foreign direct investment (FDI), energy consumption, and CO_2 emissions on food security. The dependent variable, food security (FOS), is proxied by the Food Production Index (FPI) sourced from the Food and Agriculture Organization (FAO) database. The FPI measures changes in aggregate food production relative to a base year, making it a widely accepted metric for evaluating food availability and overall food security outcomes (FAO, 2023). The selection of explanatory variables reflects their relevance to agricultural performance and food security in Nigeria and is grounded in extensive empirical literature that links technological, financial, environmental, and energy-related factors to productivity outcomes.

The independent variables are the technological innovation, measured using Total Factor Productivity (TFP) which captures the extent of technological diffusion and the adoption of innovations in agriculture that aids higher yields with fewer input resources, and reduced production costs (Chandio *et al.*, 2024; Liu *et al.*, 2024). Foreign Direct Investment (FDI) is measured as net inflows (BoP, current US$) from the World Bank, captures external capital inflows and technology transfers (Ananwude & Nwobia, 2025; Osabohien *et al.* (2022). CO_2 emissions, measured in kilotons from the World Development Indicators (WDI), are included to account for the environmental impacts of technology, FDI and agricultural intensification (Udemba, 2022; Kashem *et al.*, 2024).

Furthermore, agricultural land (AGL), measured in hectares from the WDI, is included as one of the major inputs in agricultural practice, as its availability determines the agricultural potentials of a country (Kazemi *et al.*, 2022). Similarly, economic growth (lnGDP), measured in constant USD from the World Bank, is added as a control variable as higher economic growth can be associated with increased higher investments in agricultural technologies, improved infrastructure and reduced poverty rates, which are essential in achieving food security (Osabohien *et al.*, 2022; Domguia & Asongu, 2025). Finally, energy consumption was included as moderating variable, distinguishing this study from the previous ones. Energy, (fossil fuel energy consumption, measured as a % of total energy consumption), plays a pivotal role in moderating the effectiveness of the key variables (both technological innovations and FDI) on agricultural productivity, as modern agricultural practices are highly energy-intensive, requiring reliable and affordable sources of energy (Umoru *et al.*, 2024; Energy for Growth Hub, 2023).

3.2. Model Specification

The study adapted the modeling framework employed by Abdullahi *et al.* (2024). While their study focused on carbon emissions, technological innovations, agricultural land, GDP, agricultural exports and imports, our study extends the model by removing some variables and incorporating the ones that are crucial for explaining food security dynamics in Nigeria. Specifically, this study incorporate food production index as a proxy for food security, technological innovation, foreign direct investment, energy consumption, economic growth, and CO_2 emissions to better understand the structural and environmental factors influencing agricultural production and food security in Nigeria. The modified model is therefore specified as follows:

$$\text{lnFOSt} = \beta_0 + \beta_1 lnTEI_t + \beta_2 lnFDI_t + \beta_3 lnRGDP_t + \beta_4 lnCO2_t + \beta_5 lnAGL_t + \beta_6 ENC_t + \mu_t \quad (1)$$

Here, β_o represents the constant, while β_1-β_6 are the parameter coefficients to be estimated, t is the time dimension, and μ_t denotes the error term in the model.

3.2.1. Moderating Effect of Energy Consumption

This study examines the moderating effect of energy consumption on food security through technological innovation, and foreign direct investment by adding interaction terms ($lnTEI_t \times ENC_t$, $lnFDI_t \times ENC_t$, $lnCO2_t \times ENC_t$, $lnRGDP_t \times ENC_t$ and $lnAGL_t \times ENC_t$) to the regression model. Thus, taking into account the work of Hunjra *et al.* (2020), the mathematical representation for all the constructs is presented in a single equation as follows:

$$lnFOS_t = \beta_0 + \beta_1\ lnTEI_t + \beta_2\ lnFDI_t + \beta_3\ lnRGDP_t + \beta_4\ lnCO2_t + \beta_5\ lnAGL_t + \beta_6\ (lnTEI_t \times ENC_t) + \beta_7\ (lnFDI_t \times ENC_t) + \beta_8\ (lnCO2_t \times ENC_t) + \beta_9\ (lnRGDP_t \times ENC_t) + \beta_{10}\ (lnAGL_t \times ENC_t) + \mu_t \quad (2)$$

3.3. Estimation Techniques

3.3.1. Unit Root Tests

This study adopts a multi-step estimation approach to ensure consistent, and robust outcomes. Before estimating the model, unit root tests were conducted using the conventional Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root procedures to determine the stationarity properties of the variables to avoid the problem of spurious regression.

3.2.2. Cointegration Test

Upon identifying the order of integration of the study variables, Johansen cointegration approach developed by Johansen and Juselius (1990) and further refined by Johansen (1995) was applied to examine the long-run relationship among the study variables. This methodology is more appropriate when the sample size is relatively small and there are multiple potential cointegrating vectors.

3.3.3. Fully Modified Ordinary Least Squares (FMOLS)

The study adopted the Fully Modified Ordinary Least Squares (FMOLS) estimator developed by Phillips and Hansen (1990) to estimate the long-run coefficients. The choice of FMOLS is because it effectively addresses several methodological challenges associated with time-series analysis such as correcting for potential endogeneity problem between the error term and regressors; it also adjusts for serial correlation in the residuals, and ensure unbiased and efficient estimates; and it has superior performance when the sample size is small compared to Ordinary Least Squares (OLS) and Dynamic OLS (DOLS) (Phillips & Hansen, 1990; Stock & Watson, 1993).

3.3.4. Canonical Cointegrating Regression (CCR) For Robustness Check

To confirm the validity and the robustness of the FMOLS results, this study further employed the Canonical Cointegrating Regression (CCR) technique developed by Park (1992) which has almost similar features as the FMOLS. The dual application of FMOLS and CCR strengthens the empirical results by providing cross-verification of the long-run results, minimizing the risks associated estimator specific bias. This enhances the overall validity and policy relevance of the findings.

4. Results and discussions

4.1. Descriptive Characteristics of Variables

The descriptive characteristics of the study variables in the models are presented in Table 1.

Table 1: Summary of descriptive statistics

Variables	*LFOS*	*LTEI*	*LFDI*	*LRGDP*	*LAGL*	*LCO2*	*ENC*
Mean	4.277547	-0.178320	21.41504	26.31078	13.39075	4.598477	50.15500
Median	4.321741	-0.187445	21.40745	26.30510	13.40271	4.610730	50.71500
Maximum	4.736725	0.091554	22.90267	26.95644	13.43486	4.865680	58.23000
Minimum	3.667400	-0.454132	19.51785	25.75487	13.28302	4.318918	42.39000
Std. Dev.	0.281378	0.178503	1.024119	0.461152	0.041242	0.145782	4.519633
Skewness	-0.248405	-0.016505	-0.191405	0.111360	-1.309324	0.071774	-0.075014
Kurtosis	2.323245	1.605584	1.884355	1.399239	3.726426	2.112228	2.033081
Jarque-Bera	0.881021	2.431856	1.739010	3.265052	9.231264	1.010932	1.196801
Probability	0.643708	0.296435	0.419159	0.195435	0.009896	0.603225	0.549690

Source: Authors' Computation using Eviews 12

The summary statistics of the variables of interest are shown in Table 1. The mean of FOS stands at 4.278 with a standard deviation of 0.281. This is an indication that food security varies less across space and time. The mean of technological innovation is approximately -0.178 with a standard deviation of 0.178. The average FDI is 21.42 with standard deviation of 1.024. The mean size of agricultural land is about 13.39 % and the actual value deviate from its mean by approximately 0.041. The mean of RGDP is approximately 26.31, and standard deviation of 0.46, implying that economic growth is less volatile across space and time. The mean of CO_2 emissions measured in metric tons stands at 4.60 with a standard deviation of 0.14. This is an indication that carbon emissions is less volatile across space and time. The mean of energy consumption is approximately 50.16 with a standard deviation of 4.52, implying that energy consumption varies greatly across time and space.

4.2. Unit root and cointegration tests

Table 2 presents the panel unit root tests of the model variables.

Table 2: Unit root tests

	ADF		*PP*		
Variables	*T-stat (Level)*	*1st Difference*	*T-stat (Level)*	*1st Difference*	*Remarks*
LFOS	-2.301859	-3.072941**	-1.388401	-9.299729***	I(1)
LTEI	-2.099035	-3.935335**	-2.457938	-3.900893**	I(1)
LFDI	-2.598126	-10.01394***	-2.421988	-10.01394***	I(1)
LRGDP	-1.935013	-4.035443**	-2.985234	-3.890907**	I(1)
LAGL	-2.080964	-4.560967***	-0.818132	-4.667190***	I(1)
LCO2	-3.154912	-7.227515***	-3.124163	-7.541934***	I(1)
ENC	-3.172593	-5.546221***	-3.172593	-6.771472***	I(1)

Source: Authors' Computation using Eviews 12

Note: ***, ** and * denote 1%, 5%, and 10% significance levels, respectively.

Table 2 presents the unit root tests of the model variables. The results reveal that all the variables become stationary after the first difference for all the two tests. Thus, it is concluded that since the model variables are integrated of order 1, there is a need for co-integration test which is presented in Table 3.

Table 3: Johansen cointegration test Outcomes

Hypothesized		*Trace*	*0.05*	
No. of CE(s)	Eigenvalue	Statistic	Critical Value	Prob.**
None *	0.970372	225.6340	125.6154	0.0000
At most 1 *	0.796495	127.1008	95.75366	0.0001
At most 2 *	0.655917	82.52301	69.81889	0.0035
At most 3 *	0.566068	52.65058	47.85613	0.0166
At most 4	0.537657	29.27429	29.79707	0.0573

At most 5	0.180832	7.673768	15.49471	0.5009
At most 6	0.071883	2.088727	3.841466	0.1484
Unrestricted Cointegration Rank Test (Maximum Eigenvalue)				
Hypothesized		Max-Eigen	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical Value	Prob.**
None *	0.970372	98.53320	46.23142	0.0000
At most 1 *	0.796495	44.57779	40.07757	0.0146
At most 2	0.655917	29.87243	33.87687	0.1397
At most 3	0.566068	23.37629	27.58434	0.1580
At most 4 *	0.537657	21.60053	21.13162	0.0430
At most 5	0.180832	5.585042	14.26460	0.6668
At most 6	0.071883	2.088727	3.841466	0.1484

Source: Authors' Computation using Eviews 12

The results based on the Johansen test of cointegration demonstrate that both the trace test and max-eigenvalue outcomes reveal 4 and 3 cointegrating equations respectively, at the 5% significant level, implying the rejection of the null hypothesis of no cointegration. This confirms the existence of a long- run relationship among the selected variables. With the validation of long-run relationship, the study proceeds to model the long-run relationship between technological innovations, foreign direct investment, agricultural land, energy consumption, CO_2 emissions and food security in Nigeria using the FMOLS and CCR.

4.3. FMOLS and the CCR regressions results

Table 4 and 5 presents the FMOLS and the CCR regressions results, respectively. The long-run estimations from FMOLS and CCR are similar and produce the same sign.

Table 4: FMOLS estimation results

Variables	*Coefficient*	*Std. Error*	*t-Statistic*	*Prob.*
LTECH	1.208393	0.290838	4.154860	0.0004
LFDI	0.007809	0.018891	0.413368	0.6833
LRGDP	0.945935	0.150436	6.287939	0.0000
LAGL	0.207160	0.956627	0.216552	0.8306
LCO2	0.125681	0.189877	0.661909	0.5149
ENC	0.000492	0.004731	0.104060	0.9181
C	-24.36917	9.328392	-2.612365	0.0159
Moderating Effect of Energy Consumption				

Variables	Coefficient	Std. Error	t-Statistic	Prob.
LTEI*ENC	0.004389	0.045684	0.096065	0.9245
LFDI*ENC	-0.012025	0.004648	-2.587104	0.0186
LCO2*ENC	-0.050374	0.023679	-2.127388	0.0475
LAGL*ENC	-0.018837	0.048553	-0.387968	0.7026
LRGDP*ENC	0.028443	0.028256	1.006619	0.3275
R-squared	0.973026			
Adjusted R-squared	0.965669			

Source: Authors' Computation using Eviews 12

Table 5: CCR estimation results

Variables	*Coefficient*	*Std. Error*	*t-Statistic*	*Prob.*
LTEI	1.287153	0.389487	-3.304740	0.0032
LFDI	0.012970	0.029706	0.436627	0.6666
LRGDP	0.965658	0.194182	4.972959	0.0001
LAGL	0.182718	1.420847	0.128598	0.8988
LCO2	0.144587	0.270243	0.535028	0.5980
ENC	0.000687	0.006401	0.107322	0.9155
C	-24.78342	13.67166	-1.812758	0.0835
Moderating Effect of Energy Consumption				
LTEI*ENC	0.007799	0.068081	0.114551	0.9101
LFDI*ENC	-0.013633	0.008769	-1.554714	0.1374
LCO2*ENC	-0.065728	0.059415	-1.106265	0.2832
LAGL*ENC	-0.019129	0.072794	-0.262776	0.7957
LRGDP*ENC	0.032645	0.043156	0.756435	0.4592
R-squared	0.977084			
Adjusted R-squared	0.964353			

Source: Authors' Computation using Eviews 12

The FMOLS results reveal that technological innovation (TEI) has a positive and significant influence on food security (lnFOS) in Nigeria, with a 1% increase in TEI associated with a 1.2% rise in food security, justifying proposition of the Solow Growth Model, which states that advancement in technology promotes productivity (Solow, 1956). FDI also exerts a positive but insignificant impact on food security, where 1% increase in FDI improves food security by 0.007%. This may be connected to the fact that the insignificant influence of FDI on food security in Nigeria arises from its concentration in the oil and gas sector rather than agriculture (UNCTAD, 2023). Economic has a positive and statistically significant impact, where a 1% increase in RGDP results in a 0.95% rise in food security. This is in line with the proposition of the Structural Transformation Theory, which asserts that economic advancement enhances the purchasing power of the household, allowing access to food and improved nutritional diet (Timmer, 2009). The results further revealed that agricultural land use (AGL) is positive but insignificant. 1% change in AGL raises food security by 0.21%, suggesting that increasing the size of farmland alone may not guarantee improved food availability in Nigeria, confirming the Boserup Hypothesis, which states that agricultural productivity growth depend more on technological innovation than on the expansion of land (Boserup, 1965). Furthermore, carbon dioxide (CO_2) emissions significantly reduce food security, with a 1% increase results in a 0.13% decline in food security, which confirm the assertion of Environmental Kuznets Curve (EKC), that early stages of economic progress are often associated environmental damage before improvements occur (Grossman & Krueger, 1995).

The impact of Primary energy consumption (ENC) alone is insignificant on food security, as 1% increase in ENC slightly reduces food security by 0.0005%. However, when ENC is introduced as a moderating variable, the interaction effects reveal more complex changes. The positive interaction between TEI and energy use (TEI*ENC) and between economic growth and energy use (RGDP*ENC) suggests that food security improved when technological advancement and economic expansion are supported by adequate energy access, supporting the proposition of Energy-Technology Complementarity perspective that mechanized agriculture require reliable energy infrastructure to give the desired outcome (Ali *et al.*, 2022). Conversely, the negative interactions of FDIxENC, AGLxENC, and CO_2xENC suggest that energy-intensive foreign investments, land expansion, and environmental degradation are detrimental to food security and agricultural practices in Nigeria.

4.4. Diagnostic Tests

Diagnostic tests in the form of normality, heteroscedasticity, and serial correlation tests were computed to validate the efficiency of the estimation. The results demonstrate that there is absence of auto-correlation and heteroscedasticity among the variables, and the model is well fitted.

Table 6: Diagnostics results

Diagnostic Statistics Tests	X^2 (*p Values*)	*Results*
Breusch Godfrey LM test	0.1088	No problem of serial correlations
Breusch Pagan Godfrey test	0.6907	No problem of heteroscedasticity
Ramsey RESET test	0.7461	Model is specified correctly
Jarque Bera Test	0.2590	Estimated residuals are normal

Source: Authors' Computation using Eviews 12

The stability tests using cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residuals (CUSUMQ) tests in Figures 1 and 2 reveal that the residuals' values are within the confidence lines at 5% significance level, which confirms that our model is stable.

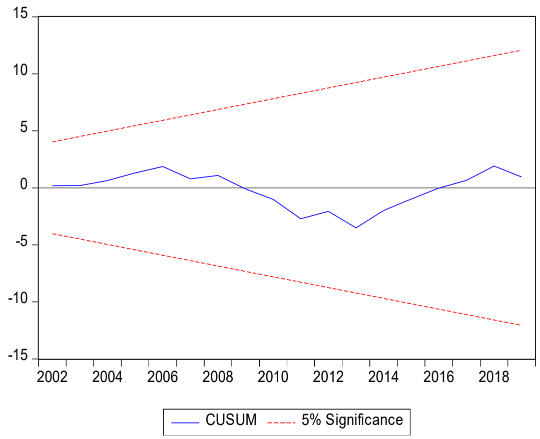

Figure 1: CUSUM Test

Source: Authors' estimation

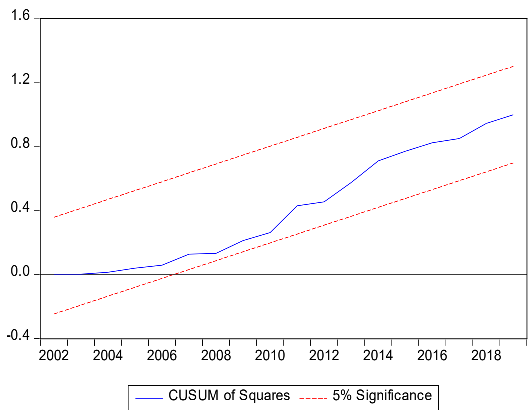

Figure 2: CUSUMQ Test

Source: Authors' estimation

5. Conclusion and policy implications

5.1. Conclusion

This study explored the determinants of food security in Nigeria using the FMOLS and CCR approaches. The results indicated that technological innovation and economic growth significantly improves food security, with the strongest been the economic growth. Again, foreign direct investment and agricultural land contributes positively, though insignificant. Conversely, CO_2 emissions significantly undermine food security, confirming that environmental degradation, and climate change are major threats to food security in Nigeria. From the moderating effects of ENC, it was revealed that energy consumption stimulates the positive impacts of technological innovation and economic growth on food security, However, energy-moderated foreign investments (energy-intensive), agricultural land expansion, and CO2 emissions affect food security negatively when energy consumption is poorly managed.

5.2. Policy Implications

The findings of this study have significant policy implications and made the following recommendations. First, policymakers in Nigeria should give special priority to investment in agricultural technologies to promote efficiency and high productivity among smallholder farmers, mostly located in rural areas. This should be complemented by improving rural infrastructure, particularly in energy access, roads, and irrigation, and systems to expand the benefits of technological adoption. Second, promoting the adoption of green and agriculture-centered FDI policies would of immense benefit in ensuring that foreign capital contributes directly to food production rather than extractive sectors of the economy. Third, climate-resistant agriculture such as promoting drought-resistant crops, soil restoration practices, and sustainable land management are crucial in reducing the negative consequences of CO_2 emissions on agriculture. Finally, renewable energy solutions should be integrated into agricultural practice in order to reduce over reliance on fossil fuels, thereby improving the ecosystem and food availability in the country.

References

Abdullahi, I., Usman, M., & Ibrahim, S. (2025). Technological innovations, CO_2 emissions, and agricultural trade performance in Africa: Evidence from MMQR analysis. *Journal of Agricultural Economics and Development*, 13(2), 44-62.

Abdullahi, B.N., Wang, H., Abdullahi, N.M., Baisheng, D., Yeboah, F.K. & Bah, A.S. (2025). Examining the dynamic effects of carbon emissions and technological innovations on agricultural exports and imports in Africa: a method of moments quantile regression approach. *Cogent Food & Agriculture*, 11(1), 2547313. DOI:10.1080/23311932.2025.2547313

Abdulrazaq, L.A., Huang, X. & Ukasha, Z. (2025). Foreign Direct Investment and Agricultural Growth: Panel Data Evidence on Chinese FDI Inflows in African Countries. Asian Journal of Agriculture and Development, 22(1), 38-56. https://doi.org/10.37801/ajad2025.22.1.3

Adetunji, A., & Liu, I. (2013). An evaluation and forecast of the impact of foreign direct investment in Nigeria's agriculture sector in a VAR environment. *International Journal of Business and Social Science*, 4(10), 17–29.

Agba, D. Z. (2018). Does foreign direct investment impact agricultural output in Nigeria? An error correction modelling approach. *International Journal of Economics and Financial Research*, 9(4), 67–77.

Alhassan, H. (2021). The effect of agricultural total factor productivity on environmental degradation in sub-Saharan Africa. *Scientific African*, *12*, 00740. https://doi.org/10.1016/j.sciaf.2021.e00740.

Ali, S., Khan, I., & Shahbaz, M. (2022). Energy-technology complementarity and sustainable agricultural development: Evidence from developing economies. *Journal of Cleaner Production, 368,* 133002. https://doi.org/10.1016/j.jclepro.2022.133002

Ananwude, A. C., & Nwobia, C. E. (2025). Foreign direct investment and agricultural sector performance in Nigeria: A disaggregated approach. *Journal of Research in Financial Studies*, 6(1), 1–31. https://doi.org/10.47509/JRFS.2025.v06i01.01

Awunyo-Vitor, D., & Sackey, R. A. (2018). Agricultural sector foreign direct investment and economic growth in Ghana. *International Journal of Economics and Financial Issues*, 8(3), 1–15.

Boserup, E. (1965). *The conditions of agricultural growth: The economics of agrarian change under population pressure.* London: Allen & Unwin.

Chandio, A. A. (2024). Can digitalization improve agriculture? Exploring the impact of ICT on grain food production in SAARC countries. *Information Development*. Advance online publication. https://doi.org/10.1177/02666669231225945

Chidiebere-Mark, N.M., Onyeneke, R.U., Uhuegbulem, I.J., Ankrah, D.A., Onyeneke, L.U., Anukam, B.N. & Chijioke-Okere, M.O. (2022). Agricultural Production, Renewable Energy Consumption, Foreign Direct Investment, and Carbon Emissions: New Evidence from Africa. *Atmosphere*, 13, 1981. https://doi.org/10.3390/atmos13121981

Domguia, E. N. (2025). ICT and agriculture in Sub-Saharan Africa: Effects and transmission channels. *Information Development*. Advance online publication. https://doi.org/10.1177/02666669251333759

Energy for Growth Hub. (2024). *Nigeria energy access and reliability report*. Retrieved from https://www.energyforgrowth.org

European Commission Joint Research Centre (EDGAR). (2024). *Global CO_2 emissions dataset*. Retrieved from https://edgar.jrc.ec.europa.eu

Food and Agriculture Organization (FAO). (2023). *Nigeria: Country overview*. Retrieved from https://www.fao.org/countryprofiles

Food and Agriculture Organization (FAO). (2024). *Hunger hotspots: FAO-WFP early warnings on acute food insecurity*. Retrieved from https://www.fao.org

FAO. (2023). Food production index (2014-2016 = 100). Food and Agriculture Organization of the United Nations. Retrieved from https://www.fao.org/faostat/en/#data/FPLI

FAO. (2024). State of food security and nutrition in Nigeria. Food and Agriculture Organization of the United Nations. Retrieved from https://www.fao.org/3/cc1160en/cc1160en.pdf

Food and Agriculture Organization. (2022). *The state of food security and nutrition in the world 2022.* FAO. https://www.fao.org/publications

Grossman, G. M., & Krueger, A. B. (1995). Economic growth and the environment. *Quarterly Journal of Economics, 110*(2), 353–377. https://doi.org/10.2307/2118443

Hayami, Y., & Ruttan, V. W. (1971). *Agricultural development: An international perspective.* Baltimore: Johns Hopkins University Press.

Intergovernmental Panel on Climate Change. (2021). *Climate change 2021: The physical science basis.* IPCC. https://www.ipcc.ch

Kazemi, M., Mohammadi, H., & Karimi, A. (2022). Agricultural land, productivity, and food security: Assessing the impact of land expansion versus intensification. *Land Use Policy*, 114, 105–125.

Kelechi, D.S., Ikechukwu, O.K., Chidinma, O.F. & Chukwunonso, E. (2022). Energy poverty, environmental degradation and agricultural productivity in Sub-Saharan Africa, AGDI Working Paper, No. WP/22/096, African Governance and Development Institute (AGDI), Yaoundé

Liu, X., Zhang, Y., & Kumar, N. (2024). Digital agriculture and productivity: Evidence from mobile advisory systems in sub-Saharan Africa. *Technological Forecasting and Social Change*, 185, 122–139.

Okeke, C.O & Abu, G.A. (2024). Impact of foreign direct investment on agricultural Growth in Nigeria (1990-2023): application of autoregressive Distributed lag model. *Journal of Agricultural Economics, Extension and Sciences*, 11(1), 16-33.

Romer, P. M. (1990). Endogenous technological change. *Journal of Political Economy, 98*(5), S71–S102. https://doi.org/10.1086/261725

Osabohien, R., Alam, B., Osabuohien, E. S., & Kaleem, M. (2022). Agricultural trade, foreign direct investment and inclusive growth in developing countries: Evidence from West Africa. *Transnational Corporations Review, 14*(3), 244–255. https://doi.org/10.1080/19186444.2021.1936986

Park, J. Y. (1992). Canonical cointegrating regressions. *Econometrica, 60*(1), 119–143.

Pedroni, P. (2000). Fully modified OLS for heterogeneous cointegrated panels. *Nonstationary Panels, Panel Cointegration, and Dynamic Panels*, 3, 69–115.

Pedroni, P. (2001). Purchasing power parity tests in cointegrated panels. *The Review of Economics and Statistics,* 83(4), 727–731.

Phillips, P. C. B., & Hansen, B. E. (1990). Statistical inference in instrumental variables regression with I(1) processes. *The Review of Economic Studies, 57*(1), 99–125.

Saikkonen, P., & Lütkepohl, H. (2000). Testing for the cointegrating rank of a VAR process with structural shifts. *Journal of Business & Economic Statistics, 18*(3), 451–464.

Solow, R. M. (1956). A contribution to the theory of economic growth. *Quarterly Journal of Economics, 70*(1), 65–94. https://doi.org/10.2307/1884513

Stock, J. H., & Watson, M. W. (1993). A simple estimator of cointegrating vectors in higher order integrated systems. *Econometrica, 61*(4), 783–820.

Timmer, C. P. (2009). *A world without agriculture: The structural transformation in historical perspective.* American Enterprise Institute.

Udemba, E. N. (2022). Moderation of ecological footprint with FDI and agricultural sector for a better environmental performance: New insight from Nigeria. *Journal of Public Affairs*, 22(2), 1–13. https://doi.org/10.1002/pa.2444

Umoru, D., Ekeoba, A. A., & Igbinovia, B. (2024). Dynamic adjustment between energy demand and productivity growth with exchange rate devaluation as a moderating variable. *Amity Journal of Management, 12*(2), 17–33. https://doi.org/10.31620/AJM.122318

Segbefia, E., Dai, B., Adotey, P., & Kwasi, A. (2023). Heliyon A step towards food security : The effect of carbon emission and the moderating influence of human capital . Evidence from Anglophone countries. *Heliyon*, *9*(12), Article 22171. https://doi.org/10.1016/j.heliyon.2023.e22171

Takyi, K. N., & Gavurova, B. (2025). Assessing the moderating role of technological innovation on food security in poverty reduction within the Visegrad region. *Discover Sustainability,* 6, Article 653. https://doi.org/10.1007/s43621-025-01545-7

Trading Economics. (2024). *Nigeria GDP from agriculture*. Retrieved from https://tradingeconomics.com/nigeria/gdp-from-agriculture

Umoru, D., Okorie, P., & Lawal, S. (2024). Energy consumption, productivity, and structural transformation in oil-importing economies: Evidence from quantile regression. *Energy Economics*, 128, 107-126.

UNCTAD. (2024). *World Investment Report 2024: Investment in sustainable agriculture*. United Nations Conference on Trade and Development. Retrieved from https://unctad.org

United Nations World Food Programme (WFP). (2025). *Nigeria: Food security outlook*. Retrieved from https://www.wfp.org/countries/nigeria

United Nations Conference on Trade and Development (UNCTAD). (2024). *World Investment Report 2024: Investing in Sustainable Value Chains*. Retrieved from https://unctad.org/topic/investment/world-investment-report

United Nations Conference on Trade and Development. (2023). *World investment report 2023.* UNCTAD. https://unctad.org/publications

World Bank. (2023). *Nigeria: Agriculture and rural development*. Retrieved from https://data.worldbank.org

World Bank. (2024). *World development indicators: Nigeria*. Retrieved from https://data.worldbank.org

World Bank. (2023). *World development report 2023: Investing in food systems.* World Bank. https://www.worldbank.org

World Bank. (2023). *Access to electricity (% of population) – Nigeria*. Retrieved from https://data.worldbank.org

Worldometer. (2024). *Nigeria CO_2 emissions*. Retrieved from https://www.worldometers.info/co2-emissions/nigeria