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Climate change, financial development and economic performance of the agricultural sector in Nigeria

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ABSTRACT

The study investigated the impact of climate change and financial development on the economic performance of Nigeria's agricultural sector. It highlighted the severe threat posed by climate change, primarily through greenhouse gas emissions (GHG), and the influence of financial development dynamics on agricultural productivity in developing countries. An ex-post-facto research design was employed, utilizing data from 1990 to 2023 sourced from the World Development Indicators and the Central Bank of Nigeria. The independent variables included greenhouse gas emissions carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Financial development variables encompassed inflation, exchange rate, and gross capital formation, while the dependent variable was agricultural value added. The Fully Modified Ordinary Least Squares (FMOLS) method was used as the analytical tool, along with other diagnostic tools. The findings indicated a significant negative relationship between carbon dioxide emissions (CO_2) and agricultural value added. Methane emissions (CH_4) showed no significant impact, whereas nitrous oxide (N_2O) positively affected productivity. These results underscore the complex dynamics between greenhouse gases, financial development, and agricultural productivity. The study emphasizes the need for targeted policies to mitigate GHG emissions by promoting sustainable agricultural practices to ensure long-term food security and resilience in Nigeria. The implications of financial development indicators—such as inflation, exchange rates, and gross capital formation—in climate change studies suggest that improving access to financial resources could facilitate investments in sustainable agriculture. Policymakers should consider enhancing financial infrastructure to support farmers in adopting environmentally friendly practices.

Contribution/Originality: This study contributes to the existing body of literature by examining the interplay between climate change, financial development, and the economic performance of the agricultural sector in Nigeria; an area that has been largely neglected in previous research.

1. INTRODUCTION

Climate change is believed to be caused by the greenhouse effect (GHE), which occurs when greenhouse gases (GHGs) are trapped in the atmosphere. These greenhouse gases include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), among others (Filonchyk, Peterson, Zhang, Hurynovich, & He, 2024; Nzuza, 2021). These GHGs cause the greenhouse effect when they are transferred into the atmosphere by flaring of fossil fuels (oil, natural gas, and coal), disposal of solid waste, burning of bushes, and wood products, among others (Nzuza, 2021). Climate change also results in severe economic damage and poses serious risks that affect everyone globally, as pollutant discharges from one country add to the build-up of greenhouse gases in the atmosphere, which in turn leads to global warming in every country (Nzuza, 2021). In Africa, Nigeria is the second-highest emitter of greenhouse gases (GHGs), after South Africa (Oyeranti, 2024).

Nigeria, therefore, as an integral part of the global community, faces significant challenges related to climate change, as the country is highly dependent on climate-sensitive sectors such as agriculture; and the economic structure suggests that more than 70 percent of Nigerians are employed in agriculture (Butu, Okeke, & Okereke, 2022; FAO, 2021; Ndubuaku, Okoro Okoro, & Kabiru, 2019). Agricultural productivity measured by agricultural value added remains a significant channel for enhancing food security and zero-poverty targets (Okeke & Okereke, 2022), but changing rainfall patterns, increased frequency of droughts, and changing pest dynamics negatively affect crop yields and livestock productivity and often worsen food insecurity, especially among rural communities that depend on subsistence farming (FAO, 2021).

Financial development refers to the intricate network of financial institutions, markets, policies, and relationships that shape the functioning of an economy, and it encompasses how financial resources are allocated, economic activities are organized, and social interactions occur within a community or country (Akintola, Amponsah-Dacosta, & Mhlongo, 2020; Lisbinski & Burnquist, 2024; Ndubuaku, Inim, Samuel, Rosemary, & Prince, 2021; Shaddady, 2023). Key proxies employed in this study for assessing financial development included gross capital formation, the inflation rate, and the exchange rate. The agricultural value-added approach addresses the economic performance of the agricultural sector of the economy by assessing the value created beyond the cost of capital used to generate it (Clark, Jablonski, Inwood, Irish, & Freedgood, 2021; Sharmiladevi, 2023). It is the difference between the value of goods and services produced in the agricultural sector and the cost of the inputs used in the production process, and it represents the true value created by the sector (Clark et al., 2021; Sharmiladevi, 2023).

Several studies in their methodological approach to the climate-agro-development concept often utilized traditional climatic indicators such as rainfall, temperature, and humidity (Tilahun, Bantider, & Yayeh, 2025); others investigated GHGs (Filonchyk et al., 2024), without incorporating the interplay of financial development and economic structure such as inflation, investment, broad money supply, exchange rate. Also, the combined variables of carbon dioxide, methane and nitrous oxide have been seldom used in the climate-agro-development debate (Amaefule, Shoaga, Ebelebe, & Adeola, 2023; Filonchyk et al., 2024; Oyeranti, 2024). Furthermore, though agricultural value addition is crucial for economic development (Dahal, Kimmerer, & Hailu, 2024; Mbotiji, Oumar, & Egwu, 2023; Sharmiladevi, 2023), it is often overlooked or not fully integrated into developmental studies. This oversight has led to missed opportunities for boosting incomes, creating jobs, and improving food security in developing regions. These issues further limit the understanding of how climate change affects true value creation in the agricultural sector and in the pursuit of food security.

Also, much of the existing research on climate-finance-agro development was concentrated in developed countries (*China:* Zhang and Diao (2020); *India:* Sharmiladevi (2023); *ASEAN-4:* Chandio, Shah, Sethi, and Mushtaq (2022)), with limited studies focusing specifically on developing countries like Nigeria and its unique socio-economic context (*CEMAC:* Mbotiji et al. (2023); *Nigeria:* Amaefule et al. (2023) and Oyeranti (2024)). This regional gap hinders the ability to draw relevant conclusions about the specific challenges and opportunities facing climate-finance-agricultural development in developing countries such as Nigeria. There is also a lack of comprehensive policy analysis that considers sectoral differences within Nigeria, particularly how climate change, finance and agricultural development across diverse regions.

While there is substantial empirical discourse on climate change, finance and agricultural development empirical results remain controversial as the literature pose opposing conclusions (Ani, Anyika, & Mutambara, 2022; Utuk, Udo, Akpan, Bassey, & Okon, 2024). Addressing these gaps is essential for developing effective strategies to mitigate the adverse impacts of climate change and to enhance the economic resilience of Nigeria. This study, therefore, seeks to research the impact of greenhouse gases (CO_2, CH_4, N_2O) and financial development on agricultural value added in Nigeria.

This study contributes to the existing body of literature by providing an in-depth examination of the interaction between climate change, financial development, and the economic performance of the agricultural sector in Nigeria. It addresses a significant gap in research by examining the intricate dynamics of greenhouse gas emissions specifically carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), and their direct impact on agricultural productivity.

Furthermore, the incorporation of financial development indicators, such as inflation, exchange rates, and gross capital formation, into the analysis highlights the importance of financial resources in facilitating the adoption of sustainable agricultural practices. This approach illustrates that financial infrastructure plays a critical role in mitigating the adverse effects of climate change on agriculture, thus enriching the discourse on climate-responsive economic policies.

By employing an ex-post-facto research design and robust analytical tools like the Fully Modified Ordinary Least Squares (FMOLS) method, the study provides empirical evidence that underscores the need for targeted interventions in policy frameworks. The findings not only reveal a significant negative relationship between CO_2 emissions and agricultural value added but also suggest that certain emissions can positively influence productivity. This differentiation provides a more comprehensive perspective on GHG impacts that can inform future research and policymaking.

Overall, the originality of this study lies in its holistic approach to linking environmental dynamics with financial development, paving the way for more effective strategies aimed at enhancing food security and economic resilience in Nigeria's agricultural sector. By emphasizing the interdependence of these factors, the study advocates for integrated strategies that can help mitigate climate change while promoting sustainable economic growth.

2. CONCEPTUAL REVIEW OF RELATED VARIABLES

Climate change poses a significant threat to food security, and understanding the combined interaction with financial development on the agricultural sector is crucial for developing effective strategies for mitigation and adaptation (Mirzabaev et al., 2023; Saleem et al., 2025). In addition, international cooperation is essential for addressing climate change and international agreements, such as the Paris Agreement, which can provide a framework for countries to collaborate on technology transfer, capacity building, and smart agriculture (CBN, 2023).

Greenhouse gases (GHGs) are gases that trap heat in the atmosphere, contributing to the greenhouse effect (World Bank, 2023). The major GHGs include carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and water vapor (H_2O) (World Bank, 2023). Carbon dioxide (CO_2) is a naturally occurring gas fixed by photosynthesis into organic matter; it is a by-product of fossil fuel combustion and biomass burning. It is also emitted from land use changes and other industrial processes, and it is the principal anthropogenic greenhouse gas that affects the earth's radiative balance (CBN, 2023; World Bank, 2023).

Methane (CH_4) is also a potent greenhouse gas that is emitted from various sources, including livestock farming, rice cultivation, fossil fuel production, and waste management, which is also closely related to the agricultural sector (CBN, 2023; World Bank, 2023). Nitrous oxide (N_2O) emissions mainly result from fossil fuel combustion, fertilizers, rainforest fires, and animal waste, primarily used in the agricultural and industrial sectors (CBN, 2023; Oyeranti, 2024). Nitrous oxide is a powerful greenhouse gas, with an estimated atmospheric lifetime of 114 years, compared with 12 years for methane and the global warming potential of nitrous oxide is nearly 310 times that of carbon dioxide within 100 years (CBN, 2023; World Bank, 2023).

Food security refers to a state where all people have, at all times, physical and economic access to sufficient and nutritious food that meets their dietary needs (World Food Programme, 2021). Nigeria's economy heavily relies on agriculture, making it particularly vulnerable to the impacts of climate change (World Food Programme, 2021). Figure 1, therefore, shows the diagrammatic flowchart of the relationship among the climate-finance-agro development concept.

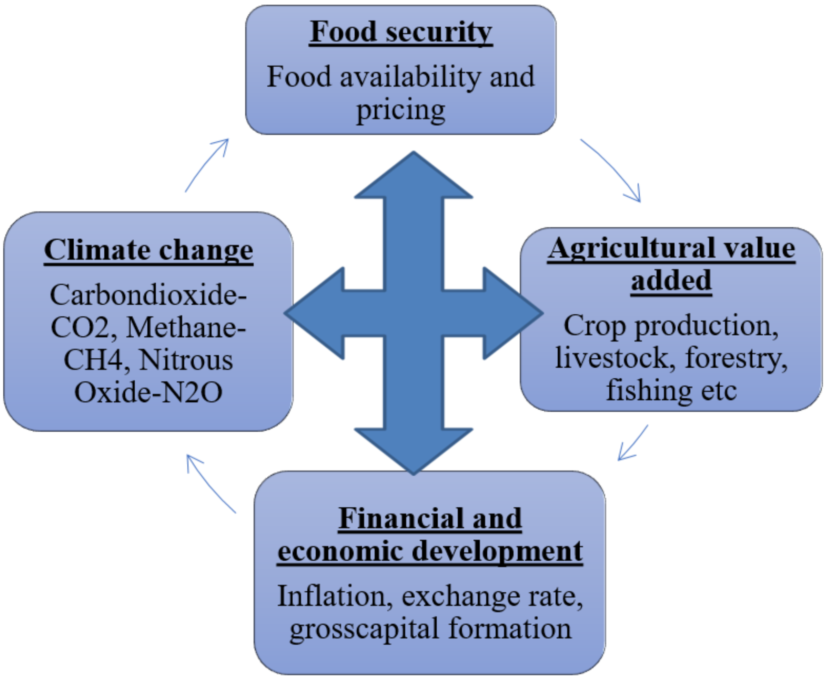

Figure 1. Climate-finance-agro development chart.

3. THE ENVIRONMENT KUZNET CURVE (EKC) AS THE THEORETICAL BACKGROUND FOR THE CLIMATE-AGRO-DEVELOPMENT CONCEPT

The EKC is a hypothesis that suggests an inverted U-shaped curve relationship between economic growth and environmental degradation (Almeida, Carvalho, Ferreira, Dionísio, & Haq, 2024). It can be related to the topics of climate change, financial development, and agricultural value added in Nigeria. The theory posits that in the early stages of economic development, environmental degradation tends to increase as countries prioritize economic growth. However, as countries reach certain levels of income per capita, environmental quality begins to improve, (Almeida et al., 2024; Oyeranti, 2024).

However, there is strong debate and no consensus regarding the EKC hypothesis among countries, regions, and different income groups (Almeida et al., 2024). The EKC has also suffered from criticism regarding the validity and applicability of the theory, as one school of thought called “the race to the bottom scenario” asserts that the EKC is inconsistent because of the outsourcing operations by developed countries, in which they outsource dirty production to developing countries, thereby making it increasingly difficult to reduce emissions (Amaefule et al., 2023; Ben Jebli, Madaleno, Schneider, & Shahzad, 2022).

For Nigeria, as a developing country that is in the early stages of the EKC, it suggests that economic growth is often driven by agricultural expansion and industrialization, which comprises an established financial system (Oniore & Ogheneogaga, 2025; Oyeranti, 2024). Therefore, climate change, in the form of deforestation, soil erosion, water pollution, and greenhouse gas emissions, could negatively impact the economic performance of the agricultural sector (Bhatti et al., 2024; Yuan et al., 2024).

Climate change driven by global greenhouse gas emissions can increase environmental challenges, including rising temperatures, erratic rainfall patterns, and extreme weather events, which could further reduce agricultural productivity (FAO, 2021; World Food Programme, 2021). The economic structure of the Nigeria economy, with a significant reliance on agriculture and natural resources, plays a crucial role in poverty reduction and food security. However, if agricultural practices are not sustainable and climate-resilient, they can aggravate poverty and food insecurity (Amaefule et al., 2023).

Unsustainable agricultural practices can lead to future problems, reducing future agricultural productivity and making it harder to achieve economic growth (Amaefule et al., 2023). Furthermore, the agricultural value-added concept, which measures the sector's contribution to the economy, can both be a driver and a victim of environmental degradation (Amaefule et al., 2023).

4. EMPIRICAL REVIEW ON CLIMATE-FINANCE-AGRO-DEVELOPMENT CONCEPT

The impact of climate change on agriculture in Nigeria has been a growing concern due to its potential effects on food security and rural livelihoods. A significant number of studies have presented contrasting results regarding the impact of climate change on agricultural development, which has strengthened the debate on the EKC hypothesis and its applicability. For some researchers, climate change has a negative and significant impact on agricultural productivity (Amaefule et al., 2023; Ani et al., 2022; Kralovec, 2020); others still posited a non-significant relationship (Utuk et al., 2024). Only a handful had investigated the concept of financial development in conjunction with climate change on agricultural development, especially in developing countries (Bagci, Sogut, Bozatli, & Degirmenci, 2025; Chandio et al., 2022).

Debates on climate-finance-agro development discourse were also divergent on methodological approaches. Most studies investigated carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) emissions individually (Amaefule et al., 2023; Oyeranti, 2024); some employed variables such as temperature, rainfall, and humidity (Utuk et al., 2024) with varying results. However, none presented a combination of the three major GHGs in conjunction with financial development variables, which presents a gap for investigation. Additionally, there have been varying analytical approaches to the discourse, as some studies employed robust least squares for analysis (Oyeranti, 2024), others used ARDL (Amaefule et al., 2023), and some utilized FMOLS (Utuk et al., 2024), often yielding different and contrasting results. This study, therefore, combines FMOLS, DOLS, and CCR methodologies to present a more robust result.

5. METHODOLOGY

This study used the *ex-post-facto* research design, complemented by other analytical research methods. The ex-post-facto design is often referred to as *"after-the-fact"* research, which focuses on analyzing past events, allowing the study to draw meaningful conclusions (Kinyua, 2023). Historical data sourced from the archives of the World Development Index and the Central Bank of Nigeria (CBN), related to the period 1990 to 2023, was employed for the study.

The datasets used were annualized time series that were secondary in nature, and the time frame was guided by the Kyoto Protocol assessment period of 1990-2023. The robustness of the results was analyzed using an array of pre- and post-estimation tests, which included the log transformation, unit root, and descriptive analysis. The model was analyzed using FMOLS, DOLS, and CCR, which provided better robustness techniques; efficient estimation in the long run and a better check for serial correlation and endogeneity in the model (Bansal, Sharma, Rahman, Yadav, & Garg, 2021).

5.1. Model Specification

The Environmental Kuznets Curve (EKC) created the theoretical context, and in an effort to relate the principles to the Nigerian perspective, Amaefule et al. (2023) and Oyeranti (2024) conceptualized the dynamics in their model, which was further adapted for this study. Therefore, the classical linear regression model (CLRM) was employed and expressed in its functional form as.

$$y_t = \delta_0 + \delta_1 X_{1_t} + \delta_2 X_{2_t} + \delta_3 X_{3_t} + \delta_4 X_{4_t} + \delta_5 X_{5_t} \dots\dots\dots\dots\dots. \delta_n X_{n_t} + \varepsilon_t \quad (1)$$

Where:

Y = Dependent variable (Explained variable); X = Independent variable (Explanatory variable); δ_0= Constant term (i.e., value of Y when X is zero); δ_1-δ_n= Coefficient of the parameter estimates; ε_t= error term (Residual term) The study models were restated in line with the objectives as follows;

$$AGRIVA_{it} = \beta 0 + \beta 1\, CO_{2it} + \beta 2_{it}\, CH_{4it} + \beta 3 N_2 0_{it} + \beta 4_t INFL_{it} + \beta 5\, REXR_{it} + \beta 6\, GCAP_{it} + \varepsilon_t \quad (2)$$

To address the exponential variances in the dataset, a log transformation was employed, and the model is reformulated as Equation.

$$InAGRIVA_{it} = \beta 0 + \beta 1\, InCO_{2it} + \beta 2_{it}\, InCH_{4it} + \beta 3\, InN_2 0_{it} + \beta 4_t InINFL_{it} + \beta 5\, InREXR_{it} + \beta 6\, InGCAP_{it} + \varepsilon_t \quad (3)$$

Where:

AGRIVA = Agric value added; Co_2= Carbon emission (kt); CH_4=Methane; N_2O=Nitrous Oxide; INFL= Inflation; REXR= Exchange rate; GCAP=Gross capital formation; $\beta 0$ = Intercept; $\beta 1$ -$\beta 6$ are the partial slope coefficients; andεt = stochastic error term.

Carbon emissions, methane, and nitrous oxide were employed as the primary climatic (independent) variables because they constitute the significant GHG pollutants (approximately 75% of greenhouse gas emissions) and are frequently utilized in the application of the climate-development concept and the Environmental Kuznets Curve (EKC) analysis.

5.2 Justification of Variables

Table 1 presents the justification of the variables used in the study, detailing their sources, periods of data collection, types, functions, associated theories, and empirical justifications, which effectively explain the rationale behind the selection of each variable and its significance within the context of the study.

Table 1. Justification of variables.

Variable	Source	Period	Type	Function of variable	Theory	Empirical justification
Agric value added (AGRIVA)	CBN Stat. Bulletin	1990-2023	Sectoral variable	Dependent Variable	EKC	Oyeranti (2024) highlights the relationship between agricultural productivity and economic growth.
Carbon emission (CO_2)	World dev. Indicators	1990-2023	Climatic variable	Independent Variable	EKC	Oyeranti (2024) indicates how carbon emissions influence environmental degradation and economic outcomes.
Methane (CH_4)	World dev. Indicators	1990-2023	Climatic variable	Independent Variable	EKC	Oyeranti (2024) supports the link between methane emissions and agricultural productivity impacts.
Nitrous oxide (N_2O)	World dev. Indicators	1990-2023	Climatic variable	Independent Variable	EKC	Oyeranti (2024) interconnects nitrous oxide emissions to soil health and agricultural yield variations.
Inflation (INFL)	CBN Stat. Bulletin	1990-2023	Macro-economic (Fin.	Moderating Variable	EKC	Empirical studies showed that inflation affects investment decisions and purchasing

			development) variable			power, affecting agricultural output (e.g., Ndubuaku et al. (2019)).
Exchange rate (REXR)	CBN Stat. Bulletin	1990-2023	Macro-econ. (Fin. development) Variable	Moderating Variable	EKC	Research indicates that exchange rate fluctuations influence trade and investment in agriculture (e.g., Butu et al. (2022)).
Gross capital formation (GCAP)	CBN Stat. Bulletin	1990-2023	Macro-econ. (Fin. development) variable	Moderating Variable	EKC	Studies demonstrate that higher gross capital formation leads to increased agricultural investments and productivity (Obe et al., 2024).

6. RESULTS AND DISCUSSION

The study showed the results presented in tables and analyzed using several analytical tools. A brief discussion of the results followed.

6.1. Descriptive Statistics

The descriptive statistics showed measures of central tendency of the data and the normality of the data.

Table 2. Descriptive statistics.

Stat	InCARBON	InMETHANE	InNITROUS_OXIDE	InREXR	InGROSSCAPITAL	InINFL
Mean	3.03	11.87	10.27	4.43	2.43	2.47
Median	3.02	11.88	10.29	4.85	2.49	2.32
Max	3.74	11.96	10.62	5.88	3.06	4.32
Min	2.36	11.72	9.91	2.08	1.69	-0.37
Std. Dev.	0.53	0.06	0.21	1.09	0.39	0.93
Skewness	0.03	-0.38	-0.01	-0.73	-0.04	-0.58
Kurtosis	1.30	2.38	1.89	2.24	1.65	4.34
Jarque-Bera	3.73	1.27	1.57	3.55	2.34	4.11
Prob	0.15	0.52	0.45	0.16	0.30	0.12

The data in Table 2 showed that the variables were log-transformed for linearity. The table also indicated that the mean and median values were fairly close for most variables, indicating a symmetric distribution. The Max-Min range of values indicated variability, with some variables like nitrous oxide showing a smaller range than others. The standard deviation signifies variability, with higher standard deviations indicating greater variability.

The statistics showed that most variables are negatively skewed, particularly the exchange rate, indicating a longer tail on the left, but carbon dioxide was skewed to the right. For kurtosis, inflation had a higher kurtosis, suggesting a more peaked distribution. Also, the kurtosis values for most variables are around 2, which indicates a mesokurtic distribution (for a normal distribution). For the Jarque-Bera test, the probabilities suggest that most variables do not significantly deviate from normality.

6.2. Cointegration Analysis

The Johansen test is a multivariate statistical method used to determine the number of cointegrating relationships among a set of non-stationary variables. Cointegration occurs when two or more variables are individually non-stationary but have a long-run relationship. To determine the number of cointegrating relationships, the test statistics are compared to their respective critical values.

Table 3. Cointegration analysis of agricultural value-added model.

No. of CE(s)	Eigenvalue	Trace statistic	Critical value (0.05)	Prob.
None *	0.89	192	126	0.00
At most 1 *	0.77	126	95.7	0.00
At most 2 *	0.68	83.2	69.8	0.00
At most 3 *	0.60	49.3	47.8	0.03
At most 4	0.38	22.3	29.7	0.28
At most 5	0.24	8.22	15.5	0.44
At most 6	0.00	0.00	3.84	0.95

Note: * presence of cointegration.

The output of the Agric Value Added model, as shown in Table 3, suggested that the trace statistic was greater than the critical value. Therefore, we rejected the null hypothesis and concluded that the trace test identified four cointegrating relationships at the 0.05 level, indicating that the model variables were cointegrated. This makes FMOLS an appropriate modeling tool.

6.3. Test of Unit Root

The data in Table 4 presents the results of unit root tests for various climatic and macroeconomic variables.

Table 4. Showing the ADF unit root analysis.

Variable	T test	1%	5%	10%	Prob	Order
Logcarbon	-5.12	-3.67	-2.96	-2.62	0.00	I(1)
Logmethane	-4.52	-3.67	-2.96	-2.62	0.00	I(1)
Lognitrousoxide	-6.64	-3.67	-2.96	-2.62	0.00	I(1)
Loginflation	-3.69	-3.67	-2.96	-2.62	0.00	I(0)
Logrexr	-5.06	-3.67	-2.96	-2.62	0.00	I(1)
Loggrosscapital	-5.27	-3.68	-2.96	-2.62	0.00	I(1)
Logagricva	-3.39	-3.67	-2.96	-2.62	0.02	I(0)

The unit root test is used to determine whether a time series variable is stationary, meaning it has a constant mean and variance, or non-stationary, indicating a time-varying mean or variance. The test results suggested that the variables of the log of inflation and the log of agricultural value added were stationary at levels, denoted as I(0). In contrast, other variables were stationary only after differentiation, indicated as I(1). This distinction is crucial for subsequent time series analysis, such as cointegration testing and model specification, to ensure valid inferences and avoid spurious results.

6.4. Result and Discussion of Model Estimation

The study employed the Fully Modified Ordinary Least Squares (FMOLS), a technique used to estimate cointegration relationships among non-stationary variables. It addresses potential biases arising from endogeneity and serial correlation.

Table 5. Result of model estimation of agricultural value added.

InAGRIVA: Dependent Var.	FMOLS			DOLS			CCR		
Variable	Coef.	t-Stat	Prob.	Coef.	t-Stat	Prob.	Coef	t-Stat	Prob.
$InCo_2$	-0.86	-3.92	0.00	-0.82	-2.84	0.01	-0.99	-3.2	0.00
$InCH_4$	2.61	1.67	0.10	2.76	1.55	0.13	2.48	1.16	0.25
InN_2O	4.23	3.69	0.00	4.43	4.77	0.00	4.11	2.26	0.03
InREXR	0.43	2.01	0.05	0.44	2.60	0.01	0.41	1.27	0.21
InGCap	-0.95	-4.47	0.00	-.92	-3.10	0.00	-0.98	-4.04	0.00
InInfl	-0.12	-1.54	0.13	-0.13	-1.44	0.16	-0.08	-0.59	0.55
C	-62.90	-4.24	0.00	-66.99	-3.29	0.00	-59.73	-3.5	0.00

R^2	0.97	0.97	0.97
Adj R^2	0.97	0.97	0.96
S.E. of regression	0.29	0.29	0.30
Long-run variance	0.07	-	0.07
Normality: JBera (Prob)	0.33 (0.84)	0.90 (0.63)	0.22 (0.89)
Hansen coin: LcStat (Prob)	0.74 (0.12)	0.22 (0.2)	0.52 (0.20)

The result from Table 5 showing the FMOLS estimation of Agricultural Value Added (AGRIVA) indicated the following.

a. Logcarbon: The coefficient: -0.86; $PV_{<0.05}(0.00)$ {FMOLS} indicated a negative and significant effect of CO_2 emissions on agricultural value added, which implied that a 1 unit increase in CO_2 emissions resulted in a 0.86 unit decrease in agricultural productivity. This agreed with the robustness regression test of DOLS and CCR, which confirmed the negative and significant relationship. This also aligned with several empirical studies that posited negative and significant relations among the variables (Amaefule et al., 2023; Ani et al., 2022; Chandio et al., 2022; Kralovec, 2020).

b. Log methane: The coefficient of 2.61 with a p-value of 0.10 indicates a non-significant relationship at the 5% significance level. This disagrees with Oyeranti (2024) and Utuk et al. (2024), which suggest that methane emissions (CH4) negatively affect agricultural productivity.

c. Log Nitrous Oxide: The coefficient: 4.23; $PV_{<0.05}(0.00)$ {FMOLS} indicated a positive and significant effect of N2O emissions on agricultural value added. It indicated that a 1 percent increase in N2O emissions resulted in a 4.23 percent increase in agricultural productivity. This robustness regression test of DOLS and CCR also confirmed the positive and significant relationship. This also aligns with empirical studies, which posit a positive and significant relationship between climate and development variables (see: Oyeranti (2024)).

d. Robustness Test: The R-squared and Adjusted R-squared values of 0.97 indicated that nearly 97.7% of the variability in LOGAGRICEVA was explained by the model, suggesting an excellent fit. The Jarque-Bera test evaluated whether the residuals followed a normal distribution by assessing skewness and kurtosis. The p-value of 0.84 was higher than the common significance level thresholds ($P > 0.05$). Therefore, we fail to reject (accept) the null hypothesis of normality and conclude that the residuals follow a normal distribution, which affirms the robustness of the model. The model appears to be good and fit for the data, with high R-squared values, low standard error, and normality of residuals, indicating that the model captured the basic relationship among the variables.

7. SUMMARY AND CONCLUSION

This analysis examined the effects of greenhouse gas emissions, specifically carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), and the economic structure on agricultural productivity. The findings revealed.

1. CO_2 emissions: A significant negative relationship was identified, with a 1-unit increase in CO_2 emissions resulting in a 0.86-unit decrease in agricultural value added. This result aligns with previous empirical studies that highlight the detrimental effects of CO_2 on agricultural productivity.

2. Methane emissions: The relationship between methane emissions and agricultural productivity was found to be non-significant at the 5% level, indicating that methane may not have a direct impact on agricultural output in the context studied.

3. Nitrous oxide emissions: A significant positive effect was noted, with a 1% increase in N_2O emissions leading to a 4.23% increase in agricultural productivity. This finding supports prior research suggesting that N_2O can enhance productivity, although it carries environmental implications.

The results underscore the complex relationship between greenhouse gas emissions, financial development, and agricultural productivity. While CO_2 emissions negatively impact agricultural value added, methane is non-significant; and N_2O emissions appear to positively and significantly enhance productivity. These findings highlight the need for targeted policies aimed at reducing harmful emissions while optimizing agricultural practices that promote productivity. This also diverges from various studies which often use a single proxy (e.g., CO_2) to represent climate change, as the results show that different gases interact differently with agricultural productivity.

Therefore, the policy implications suggest that to achieve sustainable agricultural development, it is crucial to balance productivity gains with environmental stewardship, and policymakers should prioritize strategies that mitigate CO_2 emissions, regulate N_2O emissions, and support sustainable agricultural practices through education, research, and financial incentives. By doing so, it is possible to foster an agricultural sector that is both productive and environmentally sustainable, ensuring long-term food security and resilience against climate change.

The policy implications further underscore the need for a comprehensive approach that ensures economic growth does not come at the expense of environmental sustainability through the mitigation of greenhouse gas (GHG) emissions. Therefore, policies aimed at reducing GHG emissions should be prioritized. This could include promoting sustainable agricultural practices, investing in renewable energy sources, and implementing carbon pricing mechanisms to incentivize reductions in emissions.

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