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RESEARCH ARTICLE

Impact of Carbon Emission and Population Growth on Agricultural GDP of Nigeria

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ABSTRACT

This study analytically examines the relationships between carbon emissions, population growth, and agricultural GDP in Nigeria from 1977 to 2022. The data were sourced from the World Bank and the Food and Agriculture Organization (FAO). The data were analyzed using econometric techniques (Ordinary Least Squares (OLS) regression, Johansen cointegration, and Granger causality tests). The results show a statistically significant positive relationship ($P<0.05$) between AGDP and population growth. A 1% increase in population growth could increase agricultural GDP by approximately 2.3%. In contrast, carbon emissions although positive but statistically shows insignificant impact on AGDP. The Cointegration analysis result shows a stable long-run equilibrium relationship among the variables in the model. Similarly, Granger causality tests reveal a unidirectional causal relationship from AGDP to carbon emissions, suggesting that economic growth in the sector enhance environmental pollution by increasing carbon emission, no other way round. Based on these findings, we recommend policy interventions focused on dissociating agricultural growth from its environmental impact through the adoption of climate-smart technologies and the incorporation of emission control strategy into national agricultural development plans.

Key words: Agricultural GDP, Carbon Emissions, Population Growth, Climate-Smart Agriculture.

INTRODUCTION

Climate change, driven mainly by greenhouse gas emissions, is a global concern, with developing countries bearing a disproportionate share of its adverse effects. Carbon dioxide (CO_2) is the major source of entire GHG emissions (IPCC, 2018). In Africa, CO_2 emissions from human activities grew by approximately 84% between 1970 and 2020 (Djido et al., 2021). This increase, signifies a serious environmental challenge to the achievement of sustainable development plans in the sub-Saharan African region (IPCC, 2013; Boateng et al., 2019). This is also particularly serious in Sub-Saharan Africa, where climate change and agriculture are posing additional threat (Robinson, 2020). The change in the land use, together with forestry and other land management changes, significantly affects atmospheric carbon levels (Praveen and Sharma, 2019; Leitner et al., 2020).

Nigeria has the largest population across African countries, the country is also among the fastest population growth rate estimated to be between 2.6 to 3.0 population growth rates. This rapidly growing population, together with agricultural expansion makes emission to be on increase since 1970. The growth in population amplifies by expansion of endogenous production system with low adoption to climate resilience practices positioned the country as one of the highest CO_2 emitter in the SSA (Liddle, 2015). The economic threat of increase in Co_2 emission is severe, for example, projections indicate that climate change could reduce Nigeria's GDP by 6% to 30% by 2050 if no measure is adopted to mitigate its impact. The agricultural sector, being the most sensitive and vulnerable to climate impacts is expected to bear the effect the most (Bannor et al., 2021). While Agricultural sector is vital for employment generation, reduces food insecurity, supplying raw materials, and contributing to foreign exchange earnings, Carbon emissions have a documented significant negative impact on the sector (Idris, 2020). Amaefule et al., (2023) claimed that climate change could result in decline in the yield of cereal and generate a dampening threat to the overall productivity of both crop and livestock particularly due

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to rice in temperature. This leads to climate vulnerability that disrupts economic activities, reduces productivity, and endangers food security (Ogundipe et al., 2020). Temperature increases to a certain threshold significantly reduce crop output and agricultural GDP (Ben Mariem et al., 2021; Bogale et al., 2022). While the link between population and Carbon emission is clear, the effect is ambiguous; While urbanization trigger activities like deforestation which contribute to emissions (Wang et al., 2021), unemployed population may not be directly engaged in high-emission activities thus Having less impact on the increase in the emission level (Omodero and Uwalomwa, 2021). Nonetheless, some studies (Sarkodie et al., 2020; Usman et al., 2022; Rehman et al., 2022) suggested that population growth is the major driver of increasing emissions over recent decades), as it influences production and consumption. Study by (Iwu, 2020; Yadav et al., 2021) showcased that growing population pressures triggers the agricultural sector to increase output which ultimately increased Co_2 level. Despite the risks, there is a dearth of combined empirical studies that investigate the interconnectedness between these three economic indicators (Carbon emission, population growth and carbon emission) for Nigeria, particularly those examining long-run and causal relationships. This study therefore aims to fill this critical gap. The findings will provide empirical evidence for policymakers to design integrated strategies for sustainable population control while improving food production and reducing carbon emission. Given these challenges, this study is designed to answer the following research questions:

1. What is the quantitative impact of carbon emission and population growth on Nigeria's Agricultural GDP?
2. Is there a long-term cointegrating relationship between carbon emission, population growth, and Agricultural GDP?
3. What is the causal relationship and the direction of causality between these variables?

How can policies be integrated to address both carbon emission and population growth to improve Agricultural GDP?

Ordinary Least Squares Model (OLS)

The OLS method was used to estimate the relationship between the variables in the model. The OLS approach reduced the sum of squared residuals between the regressors and regressand.

$Y = \beta_\circ + \beta_1 X_1 + \beta_2 X_2 + \epsilon$ …………………………………. (1)

Where:

Y: is the regressand

$\beta_\circ$: Is the intercept.

$\beta_{1-}\beta_2$: are the slopes

$X_1 - X_2$: Are the independents

ϵ: is the error term.

Explicitly

$AgGDP_{1=}\beta_\circ + \beta_1 CE_{it} + \beta_2 PG_{it} + \epsilon$ ……………..………….. (2)

Where:

Represents the Agricultural GDP at time (t), which was the dependent variable.

$\beta_{1-}\beta_2$ are the coefficient of the independent variable

CEt = Carbon Emission

PGt = Population Growth

ϵ Is the error term.

Johansen Cointegration

Johansen cointegration was a statistical strategy used to detect and estimate long-term links between various time series. It expanded on the notions of cointegration, which were important in econometrics and time sequence analysis, specifically when the data is not stationary.

$\Delta y_t = \mu + \pi_{yt-} + \sum_{i-1}^{p-1} \tau i \, \Delta y_{t-i} + \in_t$ …………………………………………………….. (3)

Where:

$\Delta y_t = y_t - y_{t-1}$ is the first difference of y_t

μ Is the intercept

π Is the k * k matrix of long-run relationship

τ_t Are the short run dynamic coefficient

$\in_t$ Is the error term.

Granger Causality (GC) Test

The bivariate GC test proposed by Granger (1969) was also adopted in this study. It had been referenced in the work of Sulaiman and Abdul-Rahim (2017) with some modifications, aiming to examine the causal relationships among the two outlined time series, with the objective of examining the direction of causality between the variables under study.

$y_t = \alpha_1 + \sum_{i=1}^{p} \beta_{1,i} Y_{t-1} + \sum_{i-1}^{p} Y_{1,i} X_{t-i} + \in_t^y$ …………….. (4)

$X_t = \alpha_2 + \sum_{i=1}^{p} \beta_{2,i} Y_{t-i} + \sum_{i=1}^{p} y_{2,i} X_{t-i} + \in_t^X$ …………. (5)

Where:

α_1 and α_2 are intercept

$\beta_{1,i}, y_{1,i}, \beta_{2,i}, y_{2,i}$ are the coefficient to be estimated

Y_t and X_t are the two series

P is the number of lags (lag length)

$\in_t$ error term

MATERIALS AND METHODS

Study Area

Nigeria is located in West Africa, the country is lower-middle-income country with diverse geographical features (National Bureau of Statistics (Adeleke et al., 2023). It spans 923,768 square kilometers and has a coastline of 853 km along the Gulf of Guinea. The country's terrain includes high plateaus and lowlands, with vegetation varying from tropical rainforests in the south to savannas in the north Udo (2023). As of 2020, Nigeria has an predictable populace of 206.14 million, with an annual growth rate of 2.6%. It has been the largest economy in Africa since 2012 (Udo, 2023). If this population continues the country population is estimated to be about 263m and 401m by 2030 and 2050 respectively (Udo, 2023).

Method of Data Collection

The study will primarily rely on secondary data.

For the purpose of this study, times series data of 3 variables (AGDP, Carbon emission, and population growth) was obtained from reputable sources such as; the WB data base, FAOSTAT, NBS, and other database sources covering the period of 1960-2023.The study will utilize the secondary source due to the nature of the study.

Data Types

Agricultural GDP Data: Time series data on Nigeria's agricultural GDP, segmented by different agricultural sub-sectors. Population Data: Historical and current data on Nigeria's population size, and growth rates. Carbon Emissions Data: Data on carbon emissions, including emissions from agricultural activities, deforestation, and other sources relevant to the agricultural sector.

Statistical Analysis

For stationarity test, the study used ADF and PP tests. The Ordinary Least Squares (OLS) model will be employed to assess the impact of CO_2 and population growth on AGDP. The Johansen cointegration test was used to test the long-term relationship among the variables. The Granger causality test will be employed to ascertain the direction of causality between the variables.

RESULTS AND DISCUSSION

Diagnostic and Stability Tests

Several diagnostic and stability tests were performed to assess the model's accuracy and consistency (Table 1). The Ramsey RESET test for error specification, the Jarque-Bera test for normalcy, the Variance inflation factor for multicollinearity, and the Breusch-Pagan Godfrey test for heteroscedasticity all have statistical probability larger than 5%. This shows that the residuals are regularly distributed, and our models do not suffer from serial correlation, heteroscedasticity, or error specification concerns. In addition, we used the cumulative total to ensure the structural integrity of our models. Table 1 displays alternative depictions of these tests. The CUSUM and CUSUMQ values fall within the 5% limitations, showing that the model is stable.

Table 1: Diagnostic and Stability Tests

Diagnostic and stability tests	Statistics	Probability
Jarque-Bera normality test	0.578	0.748
VIF	5	Normal
Breusch-Pagan Godfrey test for heteroskedasticity	23.45	0.175
Cusum	Stable	stable
Ramsey RESET test	0.029	0.976
Cusum of squares	Stable	Stable

Unit Root Test

The ADF and PP tests were used to ensure that the underlying variables in the current study were stationary (Table 2). The level and first difference unit root tests were first done using simply the intercept. Second, with the constant and trend terms; third, with neither term. ADF and PP tests were evaluated using the SC criterion at 1%, 5%, and 10% significant levels. Table 2 shows the output of the ADF and PP. The results show that the variables have distinct orders of integration. None of the variables are integrated at the level (Table 2). GDP and carbon emissions, on the other hand, are integrated at the first difference with intercept as well as with trend and intercept. The results show that all variables are integrated either in (1(1)) or (1(2)).

Effect of Carbon Emission and Population Growth on Agricultural GDP

To examine the relationship between the AgriGDP, population and carbon emission in Nigeria, the Ordinary Least Square Method (OLSM) was employed (Table 3).

The results reveal an R^2 value of 0.866, or 87 percent, and an adjusted-R2 of 0.86, or 86 percent. This finding implies that the model's independent variables (population and carbon emissions) account for around 86 percent of the entire change in agricultural GDP. The computed F-statistic value is 161.70 with a probability of 0.00, indicating that the model's overall fitness is significant.

The result of the OLS Table 3 shows that the coefficient of population growth was highly significant at $P < 0.01$, indicating a significant and positive correlation between agricultural GDP and population growth. The result could be interpreted to mean that a 1% increase in population could increase AGDP by 2.3% other variables held constant. This finding is similar with the findings of Ejenma et al. (2023), who reported that population growth is the primary driver of an increase in agricultural GDP. The study is also in line with the findings of Ugwuanyi 2018, who reported a significant and positive association between population growth and GDP growth rate. The results (Table 3) also revealed that the coefficient of carbo emission, although positive, was not statistically significant. This study slightly contradicts that of Appiah et al. (2018), who discovered a significant positive relationship between AGDP and carbon emissions. According to his findings, a 1% rise in economic development, crop production index, and livestock production index results in a proportionate increase in carbon dioxide emissions of 17%, 28%, and 28%.

Result of Cointegration

Two tests are employed to examine co-integration using the Johansen method: trace statistics and maximal eigenvalues (Table 4 and 5). The presence of cointegration suggests that agricultural GDP has a long-run equilibrium relationship with population and methane emissions in Nigeria. The values of the trace statistics (43.00608) and the max-eigen statistic (25.19368), which are greater than their critical values

Table 2: Unit root Test (at level)

	Augmented Dekey Fuller (ADF)			Philip Perron (PP)		
Variable	intercept	Intercept and trend	None	intercept	Intercept and trend	None
InGDP	0.87	0.31	0.84	0.94	0.35	0.95
InPP	0.99	0.99	0.80	1.00	1.00	0.99
InMETHANE	0.88	0.34	0.98	0.88	0.28	0.98
At First difference						
InGDP	0.00***	0.00***	0.00***	0.00***	0.00***	0.00***
InPP	0.97	0.89	0.00***	0.96	0.82	0.004***
InMETHANE	0.00***	0.00***	1.00	0.00***	0.00***	0.00***
At second difference						
InGDP	0.00***	0.00***	0.00***	0.01***	0.01***	0.00***
InPP	0.001***	0.007***	0.01***	0.01***	0.01***	0.05***
InMETHANE	0.00***	0.00***	0.00***	0.00***	0.01***	0.00***

Table 3: Regression Analysis of the effect of carbon emission and population growth on Agricultural GDP

Variable	Coefficient	Std. Error	t- Statistics	Prob.
LMETHANE	0.201361	0.650113	0.309732	0.7581
LPOPU	2.322773	0.366796	6.332608	0.0000
C	-9.721503	5.034193	-1.931094	0.0592
R-squared	0.866102			
Adjusted R-squared	0.860746			
Log likelihood	-24.90513			
F-statistic	161.7096			
Prob(F-statistic)	0.000000			

Table 4: Johansen co-integration test using trace statistics

Hypothesized No. of (CE)s	Eigenvalue	Trace Statistics	0.05 Critical Value	Prob.**
None *	0.389815	43.00608	29.79707	0.0009
At most 1 *	0.248984	17.81240	15.49471	0.0220
At most 2	0.060995	3.209655	3.841466	0.0732

Table 5: Johansen co-integration test Maximum Eigenvalue

Hypothesized No. of (CE)s	Eigenvalue	Max. Eigen Statistics	0.05 Critical Value	Prob.**
None *	0.389815	25.19368	21.13162	0.0127
At most 1 *	0.248984	14.60274	14.26460	0.0442
At most 2	0.060995	3.209655	3.841466	0.0732

Table 6: Pairwise Granger Causality Test

Null Hypothesis:	Obs	F-Statistic	Prob.
LMETHANE does not Granger Cause LAGRGDP	51	0.83501	0.4403
LAGRGDP does not Granger Cause LMETHANE		8.32847	0.0008***
LPOPU does not Granger Cause LAGRGDP	51	7.14807	0.0020***
LAGRGDP does not Granger Cause LPOPU		0.39767	0.6742
LPOPU does not Granger Cause LMETHANE	51	2.71676	0.0767*
LMETHANE does not Granger Cause LPOPU		0.95512	0.3923

(29.79707) and (21.13162), respectively, indicate that there is a long-term relationship between the dependent variable and the two independent variables, implying rejection of the null hypothesis of no cointegration. In both experiments, trace statistics and max-eigen statistics suggest two co-integrating equations at the 1% level.

The findings are consistent with recent research by Nilrit et al. (2018), which found that increasing energy consumption significantly increases METHANE emissions in various economic scenarios. The impact of per capita GDP on METHANE emissions is negative; for every 1% rise in GDP, METHANE emissions fall by -0.441% in the short run and -0.634% in the long run. Because an increase in GDP allows a country to maintain the same level of production while emitting less METHANE through the development of new low-carbon technologies. The results revealed that higher economic growth significantly reduces the country's high mass carbon emissions, making it critical for long-term economic growth. The findings are consistent with previous studies by Bannor (2021), which proved that the Pakistani economy's GDP helps to prevent environmental deterioration. The influence of population growth on METHANE emissions is positive, confirming that high population growth places a burden on the environment in the form of high mass METHANE emissions, hence it is preferable to limit population growth through the family planning process in a country.

Causality Analysis among the Variables (AGDP, Methane and POPU)

Table 6, present the result of causality between the two independent variables (Population growth and Carbon emission) and the dependent variable (Agricultural GDP).

The result indicates that LPOPU does Granger Cause LAGRGDP (p-value = 0.0020, $p < 0.01$). This means that past values of population size are a useful predictor for future agricultural GDP. Conversely, LAGRGDP does not Granger Cause LPOPU (p-value = 0.6742), indicating no evidence that agricultural output helps forecast future population size. This establishes a unidirectional causality from population to agricultural economic output. This finding strongly aligns with the Boserupian hypothesis, which posits that population growth acts as a driver for agricultural intensification and economic expansion (Boserup, 2014). This finding is supported by other studies, such as the work of Akombende & Chukwu (2024), who found a significant positive relationship between population growths on agricultural sector output in Nigeria. However, the result contradicts the Malthusian theory that view population growth only as a challenge to economic growth. In addition, the key finding show that LAGRGDP does Granger Cause

LMETHANE (p-value = 0.0008, p < 0.01). This provides evidence that agricultural GDP are useful for predicting future levels of methane emissions. On the other hand, LMETHANE does not Granger Cause LAGRGDP (p-value = 0.4403), showing no evidence that methane emissions predict agricultural economic performance. The result directly supports reports from the Intergovernmental Panel on Climate Change (Čengić-Džomba, 2025) and the Food and Agriculture Organization (Faizan, 2024), which identify agricultural economic activities specifically enteric fermentation from livestock and rice cultivation as primary anthropogenic sources of methane. This finding aligns with studies like Hanif et al. (2022), who found that Value added through agriculture Granger-causes methane emissions in developing economies. The unidirectional nature of the causality makes logical sense, as emissions are an outcome of production processes rather than a driver of them.

The result (Table 6) further indicates that LPOPU does Granger Cause LMETHANE at the 10% significance level (p-value = 0.0767). This suggests weak evidence that population size might have a direct predictive relationship with future methane emissions. Finally, LMETHANE does not Granger Cause LPOPU (p-value = 0.3923), confirming that emissions do not predict population trends. The weak direct causality from population to emissions is in line with studies that employ STIRPAT models**,** which often identify population size as a significant driver of environmental pressure, even after controlling for affluence (York, 2007). This link can be attributed to non-agricultural methane sources that scale with population, such as waste from landfills and wastewater, as noted by (Mohareb and Hoornweg 2017)**.** However, the weakness of this direct link, compared to the strong mediation through agricultural GDP, suggests that the affluence (type of economic activity) is a more critical mediator than population alone, a nuance highlighted in the work of (Jorgenson, 2006)**.**

The pathway Population growth → Agricultural GDP) → LMETHANE is supported by the literature many literatures. This finding is aligned with the wider description in environmental economics that economic structure is the foundation to understanding the environmental effect of population growth (O'Sullivan, 2020). The results suggest that any policy aimed at mitigating methane emissions should focus on modernizing agricultural practices for low carbon emission such as climate smart practice, rather than concentrating on population changes alone.

Conclusion

This study explains the relationships between population growth, agricultural GDP, and carbon emissions in Nigeria. The major finding shows that population growth is a primary driver of agricultural economic growth, with a 1% increase in population is associated with a 2.3% rise in agricultural GDP. This. However, this growth comes with an environmental cost. While carbon emissions themselves were not a direct, statistically significant driver of agricultural GDP in the short-term model, the Granger causality tests reveal a critical long-term relationship. The result indicates that Agricultural GDP growth is a significant detrminant of future increases in methane emissions**.** This result establishes a concerning outcome which shows that economic growth through agricultural sector involuntarily fuels the climate change that threatens future agricultural resilience.

Recommendations

1. Government and other stakeholders should invest in modern agricultural technology (efficient irrigation systems, and climate smart agriculture) that increase agricultural production while reducing carbon emission.
2. It is also essential that government should integrate climate adaptation strategies into agricultural policies. This will promote the adoption of climate resilience agriculture, there by mitigating and reducing emission of carbon and consequently reduce the impact of climate change
3. Government should create awareness on the implication of rapid population growth on food security and economic growth and the need for sustainable population growth for better society and economic expansion.

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