Agriculture and Climate Change: Assessing Carbon Emissions from Diverse Agricultural Activities in Nigeria

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Abstract

This paper examines the effects of diverse agricultural activities -crop production, fishing, livestock production and forestry- on carbon emissions in Nigeria. The study employs time-series data for the period 1990 to 2021 and applies Auto Regressive Distributed Lag (ARDL) estimation technique. The results reveal that agricultural activities significantly impact carbon emissions (CO_2) in Nigeria. The findings further reveal that livestock production and fishing activities increase CO_2 emissions. However, the results show that crop production and forestry activities reduce CO_2 emissions in Nigeria during the reference period. In the long run, a 1% rise in livestock production increases CO_2 emissions by 0.09% and a 1% rise in fishing activities increases CO_2 emissions by 0.57%. In contrast, a 1% expansion in crop production decreases CO_2 emissions by 0.31% while a 1% expansion in forestry decreases CO_2 emissions by 0.2%. Also, the estimates show that energy consumption has positive effect on CO_2 emissions. Further, the results reveal that trade openness and FDI have positive effects on CO_2 emissions while financial development reduces CO_2 emissions in the long run. Thus, agricultural policies and strategies that explicitly combine mitigation of CO_2 emissions with measures to improve food security and environmental outcomes in the agricultural sector should be promoted.

Keywords: Agriculture; Carbon emission; Environmental degradation; Climate change Nigeria

JEL Classification Codes: Q2; Q3; Q4

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1. Introduction

Enhanced productivity in the agricultural sector is pivotal to achieving food security, eliminating hunger, reducing poverty and promoting economic growth and development in developing countries, especially in Africa. Various measures, such as improved seed varieties and access to fertilizers and other farm inputs have been introduced to improve agricultural productivity in Africa. However, these measures to improve agricultural productivity have been found to be major contributors to rising greenhouse gases (GHGs) emissions as they utilize more non-renewable energy such as fossil fuels, induce encroachment of forest area and depletion of ground water sources (FAO, 2017). It is, therefore, a paradox that efforts to boost agricultural productivity and eliminate hunger in Africa may subsequently result in environmental degradation which furthers adversely affect the agricultural sector. Nzeh *et al*. (2016) and Opeyemi *et a*l. (2022) show that climate change adversely affects agricultural productivity in Nigeria. In Nigeria, agricultural sector is an essential component of the economy. About 78% of the country's total land mass, representing 708,000 km2, are suitable for agricultural purposes. Thus, the sector is the largest employer of labour and accounted for 25.1% of GDP (at constant basic price) in 2017.

According to Food and Agricultural Organization (2024), the agrifood systems account for about one-third of total anthropogenic greenhouse gas emissions (GHGs). The GHGs are generated within the farm gate, from crop and livestock production activities; by land-use change, caused by deforestation, biomass fires and degradation processes often linked to land clearing for agriculture; and in pre- and post-production processes, comprising the supply chain including food manufacturing, retail, household consumption and food disposal. The global agrifood systems emissions reached 16.2 billion tonnes of carbon dioxide equivalent (Gt CO2eq) in 2022. The emission intensity in Africa was above the world average (6.0 kg CO2eq/I$). .Striking a sustainable balance between improved agricultural productivity and reduction of GHGs emission is a task for policy makers in African countries. It has also been projected that by the year 2030, agriculture, forestry and other land use would contribute 33% of the total national emission in Nigeria.

The awareness of the current upsurge in climate change as a threat to the achievement of sustainable development goals has prompted scholars to investigate the determinants of CO_2 emissions in Nigeria. Studies have investigated the effects of energy and growth on CO_2 emissions (Akpan & Akpan, 2012; Saibu & Jayeola, 2013; Alege *et al*., 2016); financial development on CO_2 emissions (Oyinlola, 2020; Yahaya *et al*., 2021); GDP, trade integration and FDI on CO_2 emissions (Zubair *et al*., 2020); and sectoral output on CO_2 emissions (Rasaki, 2023) in Nigeria. However, none of the above studies has disaggregated the agricultural sector to examine the contributions of each sub-sector to CO_2 emissions in Nigeria. A number of studies have shown that agricultural sub-sectors activities have different impacts on carbon emissions (Appiah *et al*., 2018; Ayyildiz & Erdal, 2021). Despite these varying contributions of the agricultural sub-sectors to CO_2 emissions, scanty research attentions have been directed toward examining this in Nigeria. Hence, this study is motivated by the differing effects of agricultural sub-sectors on CO_2 emissions and lack of empirical studies assessing the impacts in Nigeria.

This study contributes to the existing literature by investigating the relative contributions of the four agricultural sub-sectors' activities to CO_2 emissions in Nigeria. Existing studies on agricultural sub-sectors contributions to CO_2 emissions have either considered one or two sub-sectors. Garnett (2009), Moran & Wall (2011) and Jessica (2012) examine the effects of livestock production on GHGs emissions. Hillier et al. (2009) evaluate the impacts of crop production on GHG emissions. Pearson et al. (2017), Nunes *et al*. (2020) and Li *et al*. (2021) investigate the impacts of forestry on GHGs emission. Devi et al. (2021) and Muñoz *et al*. (2023) assess the impacts of fishing on GHGs emissions. Havlik *et al*. (2012), Appiah *et al*. (2018) and Ayyildiz & Erdal (2021) examine the contributions of crop production and livestock on GHG emissions. This study is important as understanding the contributions of different agricultural activities to CO_2 emissions in Nigeria will assist policy makers to formulate policies that will increase productivity of the agricultural sub-sectors while reducing CO_2 emissions in Nigeria.

The research questions for this study include: (i) what are the effects of agricultural sector on CO_2 emissions in Nigeria? (ii) How does crop production affect CO_2 emissions in Nigeria? (iii) How does livestock farming affect CO_2 emissions in Nigeria? (iv) Does forestry activity impact CO_2 emissions in Nigeria? (v) How does fishing activity impact CO_2 emissions in Nigeria?

The remaining chapters are structured as follow: Section 2 reviews the related literature; section 3 is the data and method; section 4 analyses and discusses the results while section 5 concludes.

2. Review of literature

2.1 Theoretical literature

Theoretically, the environmental Kuznets curve (EKC) hypothesis illustrates the relationship between economic growth and environmental degradation. The EKC shows that growth has adverse effects on the environment at the early stage of economic development while at the later stage, growth improves the quality of the environment. This implies an inverted-U shape relationship between income growth and environmental degradation (Grossman & Krueger, 1991). After a threshold, a higher level of economic growth, will increase environmental awareness and demand for cleaner environment.

As a consequence, the EKC predicts that in the early stages of industrialization, a developing country will experience a deteriorating environmental quality and pollution because individuals are far more concerned with their income and their employment than with environmental quality - until a specific level of income per capita is met (Prieur, 2009). Once a country reaches a state of affluence, this trend will completely reverse. This emphasizes that once individuals feel economically secure, they will be in a position to concentrate extensively on responding to the environmental degradation that made their wealth accumulation possible. As such, the EKC posits that when an economy attains full maturity, the environmental damage that occurred during the developmental stages will fall dramatically (Stern, 2004).

Change in pollution can be decomposed into the scale effect, composition effect, and technique effect. At the initial stages of development, high level of pollution is generated due to the increased production and intensive usage of natural resources. This is termed the scale effect. The composition effect is associated with the change in production structure from more energy-intensive manufacturing sector towards more environmentally friendly sectors, which are less polluting (Bo 2011). Finally, technique effect demonstrates that trade introduces new technology which improves the environmental quality.

2.2. Empirical literature

Many empirical studies have been conducted to test the validity of EKC hypothesis. Apergis and Ozturk (2015), using GMM technique, evaluate the validity of EKC hypothesis in a panel of 14 Asian countries. The results support the validity of EKC hypothesis, indicating the existence of inverted-U shape relation between per capita income and CO_2 emissions. Ozturk and Al-Mulali (2015) adopt a GMM and 2SLS to ascertain the validity of EKC hypothesis in Cambodia. The results confirm the existence of EKC hypothesis in Cambodia. Solarin *et al*. (2017) apply an autoregressive distributed lag (ARDL) to investigate the existence of EKC in China and India. The findings lend credence to the existence of EKC hypothesis in China and India. Suki *et al*. (2020) investigate the presence of EKC hypothesis in Malaysia. Using the Quantile Autoregressive Distributed Lag (QARDL) estimation technique, the results confirmed the existence on an inverted U-shaped relationship in Malaysia.

In contrast, a few studies have rejected the validity of EKC hypothesis. Dogan *et al*. (2020) employ a STIRPAT model to determine the validity of EKC in BRICST –Brazil, Russia, India, China, South Africa and Turkey. The results reject the EKC hypothesis in these countries. Kilinc-Ata (2022) employs an ARDL model to examine the validity of EKC hypothesis in Russia federation. The findings do not support an inverted U-shaped relation but a U-shaped link. Baek (2015) employ an ARDL to evaluate the validity of EKC in Arctic countries. The findings indicate little evidence to support EKC hypothesis in Arctic countries. Beyene & Kotosz (2020) employ the pooled mean group (PMG) to examine the validity of EKC in 12 East Africa countries. The results do not support the EKC hypothesis.

As an extension of EKC hypothesis, a strand of literature has evaluated the contributions of agricultural sector to CO_2 emissions. The results have been quite inconclusive. For instance, Zhang *et al*. (2019) employ ARDL to examine the relationship between CO_2 emission and growth in the agricultural sector. The findings indicate that agricultural growth has positive effects on agricultural CO_2 emission in the short run and a negative effect in the long run. Aydoğan and Vardar (2019) apply fully modified ordinary least square (FMOLS) and dynamic ordinary least square (DOLS) to evaluate, among others, the role of agriculture on CO_2 emissions in E7 countries. The results show a positive impact of agricultural production on CO_2 emissions in E7 countries. Similarly, Adedoyin *et al*. (2021), employing ARDL, FMOLS and DOLS, investigate the effects of agricultural development on environmental pollution in E7. The findings reveal that value-added agriculture is one of the main drivers of CO_2 emissions in E7 countries. Han *et al*. (2024) examine the effects of agricultural production on CO_2 emissions across 29 Chinese provinces, using Logarithmic Mean Divisia Index (LMDI) method. The findings indicate that agricultural production has positive effects on CO_2 emissions in the provinces.

In contrast, other studies have reported negative impacts of agriculture on CO_2 emissions. For example, Balsalobre-Lorente *et al*. (2019) apply DOLS and FMOLS to investigate the impacts of agricultural activities on CO_2 emissions in BRICS counties. The findings reveal that agricultural activities exerts a negative impact on the environment in BRICS countries. Alhassan (2021) examines the effects of agricultural total factor productivity (ATFP) on CO_2 emission in Sub-Saharan African countries using FMOLS and canonical cointegration regression models. The findings indicate that agricultural productivity initially reduces CO_2 emission up to a point but beyond that point, it increases CO_2 emission. Raihan and Tuspekova (2022) employ DOLS to examine the dynamic impact of agricultural productivity and other variables on CO_2 emission in Kazakhstan. The results reveal that agricultural productivity reduces CO_2 emission in Kazakhstan. Few empirical studies have disaggregated agricultural sector output to examine the contributions of each sub-sector to CO_2 emissions. Appiah *et al*. (2018) employ FMOLS and DOLS to examine the contributions of crop and livestock production to CO_2 emissions in emerging economies. The findings indicate that crop and livestock production positively contribute to CO_2 emissions. Zhou *et al*. (2022) apply linear and non-linear ARDL to examine the contributions of China's agricultural sector to CO_2 emissions. The findings indicate that livestock production reduces CO_2 emissions while crop production deteriorates environmental quality.

Ridzuan *et al*. (2020) employ ARDL to investigate, among others, the effects of agricultural productivity on CO_2 emissions in Malaysia. The results reveal that crop production and fishery reduce CO_2 emissions while livestock have insignificant effect on CO_2 emissions. Chen *et al*. (2021), using Monte Carlo analysis, investigate the main crops determining the carbon footprint in China. The findings reveal that crop production generally exert negative impacts on the environment while vegetables and tea production contribute most to the deterioration of the environment. Li *et al*. (2024) examine the effects of crop farming on CO_2 emissions at regional level in China. The findings reveal that crop farming increase CO_2 emissions in China provinces. Li *et al*. (2021) employ dynamic spatial durbin model (SDM) to examine the effect of forest area and forest investment on CO_2 emissions in China. The findings show that forest area increase CO_2 emissions while forest investment reduces CO_2 emissions. Xing & Wang (2024) apply regression and spatial analysis to investigate variability in GHG emissions across different cropping systems in China. The results indicate that crop production increases CO_2 emissions in China.

Table 1. Summary of empirical literature

Author(s)	Country	Methodology	Findings
Aydoğan and Vardar (2019)	E7 countries	FMOLS and DOLS	Agricultural production has a positive impact on CO_2 emissions in E7 countries.
Balsalobre-Lorente *et al*. (2019)	BRICS Countries	FMOLS and DOLS	Agricultural activities exert negative impact on the environment.
Ridzuan *et al*. (2020)	Malaysia.	ARDL	Crop production and fishery reduce CO_2 emissions while livestock have insignificant effect on CO_2 emissions
Alhassan (2021)	Sub-Saharan Africa	FMOLS	Agricultural productivity initially reduces CO_2 emission up to a point but beyond that point, it increases CO_2 emission
Tuspekova (2022)	Kazakhstan	DOLS	Agricultural productivity reduces CO_2 emission in Kazakhstan.
Zhou *et al*. (2022)	China	ARDL	Livestock production reduces CO_2 emissions while crop production deteriorates environmental quality
Han *et al*. (2024)	China	LMDI	Agricultural activities increase CO_2 emissions
Xing & Wang (2024)	China	Spatial analysis	Crop production contributes positively to higher CO_2 emissions.
Li *et al*. (2024)	China	RMSE	Crop farming increases CO_2 emissions

From the above literature, it is obvious that the agricultural sector contributes to CO_2 emissions, though the evidence remains inconclusive. While studies have focused on the contributions of the sector to CO_2 emissions, only few studies have disaggregated the agricultural sector to examine the contributions of each agricultural sub-sector to CO_2 emissions. These few studies, however, have examined either one or two sub-sectors impact on CO_2 emissions. The gap that this study seeks to fill is to examine the contributions of 4 agricultural sub-sectors to CO_2 emissions in Nigeria.

3. Data and Method

3.1 Data

This study employs annual time-series data that cover the period 1990 to 2021. The variables used in the study are carbon emission, crop production, fishing, forestry, livestock, trade openness proxy by the sum of exports and imports as a ratio of GDP, financial development proxy as domestic loans to private sectors and foreign direct investment (FDI). The data were sourced from the World Bank Development Indicator (WDI), Central Bank of Nigeria (CBN) and the U.S. energy information administration. The data for energy consumption and CO_2 were sourced from the U.S. energy information administration. The functional form of the equation is written as:

Carbon emission = f (Energy, Crop production, Fishing, Forestry, Livestock) (1)

Hence, the econometric form of the model is stated as:

$$lCO_{2t} = \beta_1 + \beta_2 lEnergy_t + \beta_3 lcropproduction_t + \beta_4 lfishing_t + \beta_5 lforestry_t + \beta_6 llivestock_t + \omega D_{it} + e_{it} \quad (2)$$

Where β_1 is the intercept; β_2, β_3, β_4, β_5, and β_6 are the coefficient of explanatory variables and μ_t is the stochastic term. D_{it} denotes the control variables such as trade openness, financial development and foreign direct investment (FDI). The selected control variables are the macroeconomic variables that studies have shown can impact CO_2 emissions in Nigeria.

The study employs Autoregressive Distributed Lag (ARDL) technique developed by Pesaran and Shin (1999) and Pesaran *et al.* (2001) to investigate the short run and long run dynamics among the variables. ARDL is preferred to other cointegration technique due its flexibility, provision of unbiased estimates for long run relationship and parameters and its capacity to adequately address autocorrelation and endogeneity problems (Rahman & Kashem, 2017). Our approach is similar to Rahman and Kashem (2017) and Zubair *et al.* (2020). The model is specified as:

$$\Delta CO_{2t} = \beta + \sum_{i=1}^{n} \theta_1 \Delta CO_{2t-1} + \sum_{i=1}^{n} \theta_3 \Delta cropproduction_{t-1} + \sum_{i=1}^{n} \theta_4 \Delta fishing_{t-1} + \sum_{i=1}^{n} \theta_5 \Delta forestry_{t-1} + \sum_{i=1}^{n} \theta_6 \Delta livestock_{t-1} + \sum_{i=1}^{n} \theta_7 \Delta openness_{t-1} + \sum_{i=1}^{n} \theta_8 \Delta findev_{t-1} + \sum_{i=1}^{n} \theta_9 \Delta fdi_{t-1} + \delta_1 CO_{2t-1} + \delta_2 Energy_{t-1} + \delta_3 cropproduction_{t-1} + \delta_4 fishing_{t-1} + \delta_5 forestry_{t-1} + \delta_6 livestock_{t-1} + \delta_7 Openness_{t-1} + \delta_8 findev_{t-1} + \delta_9 fdi_{t-1} + \varepsilon_{it} \quad (3)$$

In eq. (3), the first-differenced variables represent the short run effects and are captured by the estimates assigned while the long run effects are denoted by the estimates of $\delta_2 - \delta_9$ normalized on δ_1. The existence of long run relationship and joint significance of lagged variable is evaluated by applying the $F-test$ (see Pesaran *et al.*, 2001). The hypotheses are specified as:

$$H_0: \delta_1 = \delta_2 = \delta_3 = \delta_4 = \delta_5 = \delta_6 = \delta_7 = \delta_8 = \delta_9 = 0 \quad (4)$$

$$H_1: \delta_1 \neq 0;\ \delta_2 \neq 0;\ \delta_3 \neq 0;\ \delta_4 \neq 0;\ \delta_5 \neq 0;\ \delta_6 \neq 0\ \delta_7 \neq 0;\ \delta_8 \neq 0;\ \delta_9 \neq 0 \quad (5)$$

If the estimated F-statistics is greater than the upper bound value, we reject the null hypothesis of no cointegration. But if the F-statistics is below the lower bound value, we do not reject the null hypothesis. Lastly, if the computed F-statistics fall between the upper and lower critical value, the test is regarded as inconclusive.

Table 2. Variables with their units and logarithmic forms

Variables	Units	Logarithmic form	Sources
CO_2	MMtonnes	lCO_{2t}	US EIA
Energy consumption	Quad Btu	$lenergy$	US EIA
Crop production	Nigerian currency	$lcropproduction$	CBN
Fishing	Nigerian currency	$lfishing$	CBN
Livestock	Nigerian currency	$llivestock$	CBN
Forestry	Sq. Km	$lforestry_t$	CBN
Trade openness	(Export + Import)/GDP	$lopenness$	WDI
Financial development	Credit to the private sector	$lfindev$	CBN
FDI	FDI as a % of GDP	$lFDI$	WDI

4. Results Estimation

4.1 Descriptive statistics

Table 3 presents the descriptive statistics for the variables employed in this study. The mean value for crop production is the highest with the standard deviation of 0.216, showing some degree of variability. This implies improved productivity in crop production over the sample period. The value of skewness is negative for all variables except CO_2, energy and livestock. The coefficient of variation (CV) which measures relative dispersion of variables is computed as the ratio of standard deviation to the mean values. It allows the direct comparison of relative volatility of our variables given the differences in mean values. The higher the CV, the greater the variability of the variable. The most volatile variable is energy followed by foreign direct investment (FDI). The CV also shows that the agricultural subsector is relatively volatile with forestry being the most volatile while livestock is the least volatile.

Table 3. Descriptive Statistics

Sectors	Mean	Std.	Min	Max	Skew.	Kurtosis	CV
CO_2	4.14	0.291	3.767	4.664	0.66	1.975	0.07
Crop production	8.134	1.755	4.465	10.41	-0.64	2.26	0.216
Fishing	4.506	1.767	1.166	7.413	-0.387	2.172	0.392
Forestry	3.816	1.567	0.854	5.656	-0.533	1.993	0.411
Livestock	6.595	0.366	6.12	7.117	0.099	1.442	0.055
Openness	3.591	0.245	3.031	3.976	-0.61	2.988	0.068
FDI	0.275	0.713	-1.694	1.756	-0.364	3.547	2.593
Financial development	7.593	2.155	3.513	10.276	-0.285	1.76	0.284

Source: Authors' Computation, 2024

4.2 Unit Root Tests

Table 4 shows the results for unit root tests for all the variables. We employ the unit root tests of Augmented Dickey Fuller (ADF) and Phillips Peron (PP) tests to carry out the stationarity tests of the variables. The variables are of mixed order of integration providing justification for the application of ARDL (Pesaran et al., 2001).

Table 4. Unit root test results

Variable	**Intercept**		**Trend & Intercept**	
	Level	1st difference	Level	1st difference
	Augmented Dickey Fuller (ADF)			
$lenergy$	-0.951	-6,695***	-2.564	-6.643***
lCO_2	-0.787	-6.438***	-2.396	-6.411***
$lcrop$	-3.269**	-3.48**	-1.743	-4.251**
$lfishing$	-1.352	-2.988**	-2.969	-3.093**
$lforestry$	-4.726***	-1.187	1.082	-6.226***
$llivestock$	-3.978***	-2.152	3.469	-4.721**
$lopenness$	-2.914*	-6.118***	-3.118	-5.996***
$lfdi$	-1.45	-6.802***	-2.429	-6.728***
$lfindev$	-2.392	-4.006***	-0.81	-4.662***
	Phillips-Peron (PP)			
$lenergy$	-0.827	-6.798***	-2.644	-6.773***
lCO_2	0.687	-6.480***	-2.481	-6.430***
$lcrop$	-6.146***	-3.48**	-1.875	-4.271**
$lfishing$	-1.451	-3.088	-1.719	-3.093
$lforestry$	-4.74***	-1.541	2.985	-16.197***
$llivestock$	-4.623***	-2.399	-1.359	-3.885**
$lopenness$	-2.955*	-8.635***	-3.099**	-9.297***
$lfdi$	-1.808	-6.785***	-2.064	-6.788***
$lfindev$	-2.449	-3.965**	-0.846	-4.635***

Source: Authors' Computation, (2024)

4.3 Bound test results

Table 5 presents the bound test results. The computed $F - Statistics$ is higher than the upper critical bound value at 5% significant level, using CO_2 emissions as the dependent variable. This implies the presence of cointegration among the variables over the sample period, indicating the existence of long run relationship among the variables in Nigeria.

Table 5: Bound tests

Critical values	Lower $I(0)$	Upper $I(1)$
1%	2.62	3.77
5%	2.11	3.15
10%	1.85	2.85
$F - Stat.$		163.55

4.4 Analysis of short and long run estimates

Table 6A shows the estimates for short run relationship with CO_2 as the dependent variable. The results show that energy consumption has significant positive impacts on CO_2 emissions in the short run. A 1% increase in energy consumption will increase CO_2 emissions by 0.848% The estimates indicate that agricultural subsectors contribute differently to CO_2 emissions. Crop production and forestry have significant negative effects on CO_2 emissions. A 1% expansion in crop production decreases CO_2 emissions by 0.18% while a 1 % increase in forestry decreases CO_2 emissions by 0.04%. However, the results reveal that fish and livestock production have significant positive effects on CO_2 emissions. A 1% expansion in fish farming increases CO_2 emissions by 0.08% and a 1% rise in livestock production causes an increase of 0.32% in CO_2 emissions. The estimates reveal that among the sub-sectors, livestock production has the greatest impact on CO_2 emissions in the short run. Also, the results reveal that trade openness has significant positive effect on CO_2 emissions in the short run. A 1% rise in trade openness causes 0.087% rise in CO_2 emissions. Moreover, the results show that financial development has significant negative effect on CO_2 emission in the short run. A 1% rise in financial development reduces CO_2 emissions by 0.094%. Lastly, the results reveal that FDI has significant positive effects on CO_2 emissions. An increase of 1% in FDI causes 0.8% rise in CO_2 emissions.

Table 6A. Short run estimates: Dependent variable- $\Delta \mathbf{lnCO_2}$

Variable	Coefficient	Std. error	t-statistics	Prob.
$\Delta lenergy$	0.848^{**}	0004	190.19	0.003
$\Delta lenergy_{(-1)}$	-0.034	0.019	-1.787	0.32
$\Delta lcropprod$	-0.183^{**}	-0.001	-18.78	0.03
$\Delta lcropprod_{(-1)}$	0.172^{**}	0.005	33.725	0.02
$\Delta lfishing$	0.078^{*}	0.009	8.269	0.08
$\Delta lfishing_{(-1)}$	-0.092^{*}	0.009	-10.318	0.06
$\Delta lforestry$	-0.004	0.026	-0.153	0.9
$\Delta lforestry_{(-1)}$	-0.241^{**}	0.014	17.748	0.04
$\Delta llivestock$	0.321^{**}	0.013	24.53	0.03
$\Delta llivestock_{(-1)}$	-0.054	0.015	-3.575	0.17
$\Delta lopenness$	0.087^{*}	0.009	-9.392	0.07
$\Delta lopenness_{(-1)}$	-0.046^{**}	0.003	-16.552	0.04
$\Delta lfindev$	0.04^{**}	0.002	16.983	0.04
$\Delta lfindev_{(-1)}$	0.099^{**}	0.002	43.811	0.01
$\Delta lfdi$	-0.027^{**}	0.002	-16.018	0.04
$\Delta lfdi_{(-1)}$	-0.057^{**}	0.002	-25.597	0.02
ECM	-1.093^{***}	0.003	404.38	0.002

***, **, and * denotes statistical significance at 1%, 5% and 10% respectively

Table 6B presents the long run estimates. The results show that energy has positive effect on CO_2 emissions. A 1 % rise in energy consumption leads to 0.762% in CO_2 emissions in the long run. The results show that crop production and forestry have negative effects on CO_2 emissions in the long run. A 1% expansion crop production leads to 0.311% decline in CO_2 emissions and a 1% expansion in forestry leads to a decrease of 0.2% in CO_2 emissions. The estimates, however, show that fishery and livestock production have positive effects on CO_2 emissions. A 1% rise in fishery production causes 0.571% increase in CO_2 emissions and a 1%` in livestock production leads to 0.097% increase in CO_2 emissions. Further, the results show that trade openness and FDI have positive effects on CO_2 emissions in the long run. A 1 % rise in trade openness leads to 0.137% increase in CO_2 emissions while a 1% increase in FDI leads to 0.08% rise in CO_2 emissions. Lastly, the estimates reveal that financial development has negative effect on CO_2 emissions. A 1% rise in financial development leads to 0.094% decline in CO_2 emissions.

Table 6B. Long run estimates: Dependent variable- $\Delta lnCO_2$

Variable	Coefficient	Std. error	t-statistics	Prob.
$lenergy$	0.762**	0015	50.66	0.01
$lcropprod$	-0.311**	0.013	-24.063	0.03
$lfishing$	0.571**	0.029	19.388	0.3
$lforestry$	-0.201*	0.017	-11.803	0.05
$llivestock$	0.097**	0.005	18.641	0.03
$lopenness$	0.137*	0.001	-13.914	0.05
$lfindev$	-0.094**	0.003	-28.675	0.02
$lfdi$	0.08*	0.006	12.857	0.05
Constant	5.427**	0.066	81.764	0.01

. ***, **, and * denotes statistical significance at 1%, 5% and 10% respectively

4.4 Discussion of results

The estimates indicate that agricultural subsectors contribute differently to CO_2 emission. Crop production and forestry have significant negative effects on CO_2 emission. This implies that expansions in cropland and forestry decrease CO_2 emissions. An increased productivity in crop production reduces the expansion of cropland into forest areas, thus decreases environmental degradation. Similarly, expansion in forestry reduces CO_2 emissions. This indicates that forestry mitigates CO_2 emission either by storing carbon in forest biomass and soil or by producing biomass fuel that can substitute fossil fuels. Forestry can also contribute effectively to carbon capture and sequestration. This is similar to the findings by Li *et al*. (2021).

However, the results reveal that fishery and livestock production have significant positive effects on CO_2 emissions. This indicates that expansion in fish production leads to rising consumption and combustion of fossil fuel and provisions of active gear that can increase to CO_2 emissions. This is similar to the findings by Devil et al. (2021) and Muñoz *et al*. (2023). Similarly, the results indicate that livestock production contributes positively to CO_2 emissions. The positive effect of livestock production on CO_2 emission implies that rising livestock production induces land clearance, land degradation, deforestation and expansion of pastures and arable farm lands which lead to a rise in CO_2 emission. This is in line with the findings by Moran and Wall (2011) and Appiah *et al*. (2018). The rising CO_2 emissions may also be due to the decomposition and mineralization of soil organic matter (Sakadevan *et al*., 2017).

Also, the results indicate that trade openness and FDI have significant positive effect on CO_2 emission in the long run. This suggests that as trade expands and FDI increases, the rate of CO_2 emissions increases. This indicates that deepening of trade and inflows of FDI lead to the production of pollution-intensive goods, reinforcing the pollution haven hypothesis. This is in line with the findings by Rasaki (2023) and Amoah *et al*. (2023). Lastly, the results show that financial development has significant negative effect on CO_2 emission in the long run. This implies that financial development leads to improved technology, lower energy consumption and declining CO_2 emissions. This is in contrast to the findings by Nyeadi (2023).

4.4 Diagnostic tests

Table 7 shows the results for the diagnostic tests. The Breusch–Godfrey Lagrange multiplier (LM) serial correlation test indicates absence of autocorrelation in the model as the probability value is higher than a 5% significance level. Further, the autoregressive conditional heteroscedasticity (ARCH), shows that the estimated residuals are homoscedastic. In addition, the Jarque-Bera (JB) normality test revealed that the error was normally distributed because the significance value is higher than the 5% significant level. Lastly, the Ramsey-Reset for model specification shows that model was correctly specified.

Table 7. Diagnostic tests

Tests	χ^2	Probability
ARCH	0.424	0.903
LM Test	4.166	0.327
JB	0.778	0.678
Ramsey-Reset	0.237	0.835

4.5 Stability Tests

In line with Pesaran & Shin, (1999), we examine the robustness and stability of our model, by employing the cumulative sum of recursive residuals (CUSUM) and cumulative sum of recursive residuals of squares (CUSUMSQ) tests. If the CUSUM and CUSUMSQ plots are within the 5 per cent critical bound, it signifies the parameter the model stability. The CUSUM test in figure 1 shows that the plots of the residuals lie within two pairs of straight lines at a 5% critical bound, confirming the model stability. Similarly, the CUSUMSQ in figure 2 also shows that the plots of the residuals lie within two pairs of straight lines at a 5% critical bound, confirming the model stability.

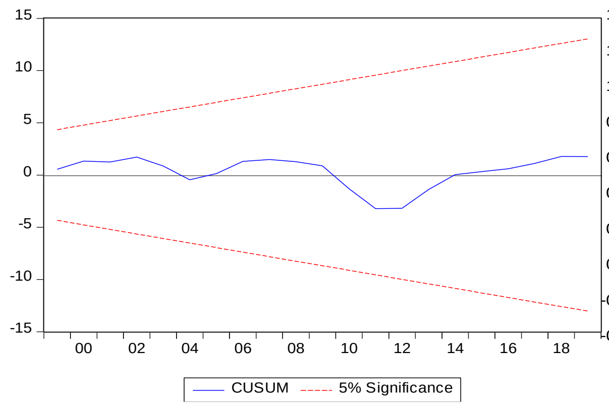

Figure 1: CUSUM Test

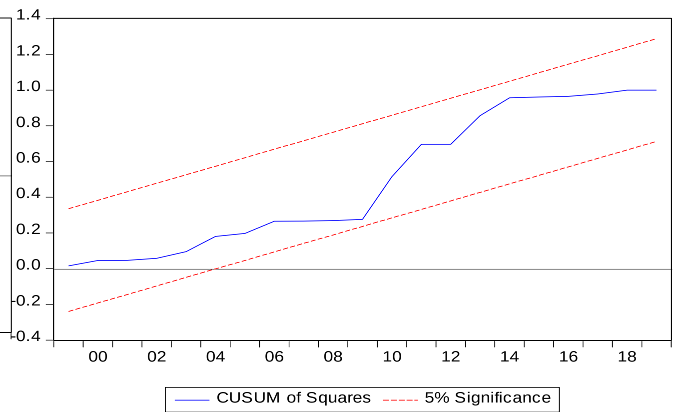

Figure 2: CUSUMQ Test

5. Conclusion

This study examines the effects of agricultural productivity on CO_2 emissions, focusing on the contributions of various agricultural sub-sectors on carbon emission in Nigeria. The study employs ARDL estimation technique. The findings show that agricultural production contributes to CO_2 emissions with differing contributions by the sub-sectors. The estimates reveal that crop production and forestry reduce CO_2 emissions in Nigeria. In contrast, fishery and livestock production increase CO_2 emissions in Nigeria. Further, the findings indicate that trade openness and FDI contribute positively to CO_2 emission while financial development contribute negatively to CO_2 emissions. Based on the findings of this study, we recommend that government should formulate agricultural policies and strategies that explicitly combine mitigation of CO_2 emissions with measures to improve food security and protect environmental outcomes. Government should promote the adoption of climate- smart and eco-friendly technologies. The method of irrigation should be shifted from fossil fuel sources to renewable sources such as solar. Also, government should invest in existing forests and plant more trees to mitigate rate of CO_2 emission in Nigeria.

Further studies should disaggregate each sub-sector to specifically highlight the particular activity contributing to CO_2 emission. Under livestock production, further studies can investigate whether it is cattle rearing or poultry farming that contributes to CO_2 emission. Further studies can also decompose crop production to investigate which types of crops can mitigate CO_2 emissions.

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