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Assessing the effect of carbon dioxide emissions on agricultural production in Nigeria (2010-2023)

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Abstract: This study examines the relationship between carbon dioxide equivalent (CO_2e) emissions and agricultural production (food, livestock, cereals, and crops) in Nigeria from 2000 to 2023, with a focus on trend analysis, long-run dynamics (Vector Error Correction Model - VECM), and short-run dynamics (Vector Autoregression - VAR). The study employs a quantitative approach, utilizing secondary data from the World Development Indicators (WDI) database. The trend analysis revealed a widening gap between CO_2e emissions and food production, indicating a potential threat to food security. Results indicated a significant positive relationship between CO_2e emissions and agricultural production at a 1% significance level, with coefficients of 0.937, 0.944, 0.957, and 0.519 for food, crop, cereals, and livestock production, respectively. Additionally, findings showed that a 1% increase in livestock and cereal production decreases CO_2e emissions by 0.668% (p-value=0.040) and 77.99% (p-value=0.019), respectively. The results suggest a CO_2 fertilization effect, particularly for food (t-stat=2.393, p-value=0.05) and cereals production (t-stat=4.284, p-value=0.05). Although contradicting general expectations that emissions would negatively impact agricultural productivity, these findings contribute significantly to the literature on climate change and agriculture, emphasizing the need for sustainable agricultural practices, climate-resilient crop varieties, and environmentally friendly incentives to mitigate climate change impacts on agricultural production.

Keywords: *Agricultural production, Carbon dioxide equivalent (CO2e) emissions, Climate change, Food security, Vector autoregression (VAR), Vector error correction model (VECM).*

1. Introduction

The impact of agricultural production (crop, livestock, food, and cereal production) on carbon dioxide equivalent (CO_2e) emissions in Nigeria has been a growing concern over the past decade. Nigeria, one of Africa's largest economies, is heavily reliant on agriculture, which accounts for approximately 25% of its GDP [1]. Climate change, primarily caused by increasing CO_2e emissions, has been identified as a major threat to agricultural production globally [2].

Nigeria is particularly vulnerable to climate change due to its geographical location, agricultural dependence, and limited adaptive capacity. Nigeria is located in the tropics, making it prone to extreme weather events and temperature fluctuation [3]. Agriculture is a significant contributor to Nigeria's economy, and climate change can have devastating impacts on agricultural productivity [4]. Also, Nigerian farmers often have limited access to resources, technology, and information, making it difficult for them to adapt to climate change [5]. Previous studies have investigated the impacts of climate change on agricultural production in Nigeria, taking into consideration crop yield reductions, variations in growing seasons, as well as increased pest and disease pressure [6]. However, despite the growing body of research on the impact of carbon dioxide equivalent (CO_2e) emissions on agricultural

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production, Nigeria has a significant research gap, particularly regarding an up-to-date study on the trend relationship between CO_2e emissions and agrarian production [1] short-run and long-run dynamics of this relationship [5] as well as crop-specific impacts on the different types of agricultural production [3] which informed this study.

2. Conceptual and Theoretical Framework

The conceptual framework for this study is grounded in the Environmental Kuznets Curve (EKC) hypothesis, which posits an inverted U-shaped relationship between environmental degradation (greenhouse gas emissions) and economic growth (agricultural production). This framework suggests that as Nigeria's economy grows, greenhouse gas emissions will initially increase but eventually decrease as the country reaches a threshold level of economic development. This study draws on the following theoretical frameworks:

- Climate Change Impact on Agriculture (CCIA) Framework: This highlights climate change's direct and indirect effects on agricultural productivity [7]:
- Ricardian Model: This model assesses the impact of climate change on agricultural productivity by analyzing the relationship between climate variables and agricultural output [8].
- IPCC's Fifth Assessment Report (AR5) Framework: This framework emphasizes the importance of understanding the impacts of climate change on agricultural productivity and food security [9].

3. Methodology

3.1. Study Area

Nigeria, located in West Africa, spans an area of approximately 923,768 square kilometers. The country's geography is characterized by a latitude of 4° to 14° N [10] Longitude of 2° to 15° E, annual temperature of 22°C to 32°C (average), rainfall of 600 mm to 4,000 mm (annual average), with two main seasons: wet (April to October) and dry (November to March) [5]. Nigeria's CO_2e emissions have been increasing steadily, primarily due to fossil fuel combustion, land use changes, and agriculture. In 2020, Nigeria's CO_2e emissions reached approximately 150 million metric tons, with a growth rate of 3.5% per annum [4].

3.2. Method of Data Collection

The data for this study were obtained from secondary sources (World Development Indicators). The data covered the period from 2000 to 2023, including annual data on carbon dioxide equivalent emissions, crop, livestock, cereal, and food crop production.

3.3. Model Specification

Trend Relationship Model:

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \beta_4X_4 + \varepsilon$$

Where:

Y = CO_2e emissions at time t

X = Agricultural production parameter (cereal, crop, food, or livestock production) at time t

β_0 = Intercept

β_1 = Coefficient of Slope

ε = Error term, representing the random variation in Y not explained by X

Long-Run Relationship Model:

A Vector Error Correction Model (VECM) can be used to determine the long-run dynamics of CO_2e emissions and agricultural production parameters (food, crop, livestock, and cereal production).

Model Equation:

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$\Delta Y_t = \alpha + \beta_1\Delta X_t + \beta_2\Delta Y_{t-1} + \ldots + \beta n\Delta Y_{t-n} + \gamma 1ECT_{t-1} + \varepsilon t$
Where:
Y_t = CO_2e emissions at time t
X_t = (Food, Crop, Livestock, Cereal) production at time t
Δ = First difference operator
α = Constant term
$\beta_1, \beta_2, \ldots, \beta n$ = Short-run coefficients
$\gamma 1$ = Error correction term (ECT) coefficient
ECT_{t-1} = Error correction term at time t-1
εt = Error term at time t

Long-Run Relationship:
The long-run relationship can be represented by the cointegrating equation:
$Y_t = \alpha + \beta X_t + \varepsilon_t$
Where:
Y_t = CO_2e emissions at time t
X_t = (Food, Crop, Livestock, Cereal) production at time t
α = Constant term
β = Long-run coefficient

Short-Run Relationship Model:
A Vector Autoregression (VAR) model can be used to determine the short-term dynamics of CO_2e emissions and agricultural production parameters, including food, crop, livestock, and cereal production.
Model Equation:
$\Delta Y_t = \alpha + \Sigma\beta i\Delta Y_{t-1} + \Sigma\gamma i\Delta X_{t-1} + \varepsilon t$
Where:
Y_t = (Food, Crop, Livestock, Cereal) production at time t
X_t = CO_2e emissions at time t
Δ = First difference operator
α = Constant term
βi = Coefficients of lagged Y_t terms
γi = Coefficients of lagged X_t terms
εt = Error term at time t

4. Results and Discussion

4.1. Trend Relationship Between the Variables

4.1.1. CO_2e emissions and food production

Food production specifically refers to the processing and preparation of raw materials from the primary sector into consumable food products. As presented in Figure 1, CO_2e emissions have been increasing steadily since 2010, with a growth rate of 2.5% per annum. Food production has also been growing, but at a slower rate of 1.5% per annum. The gap between CO_2e emissions and food production is widening, indicating a potential threat to food security. Similarly, the trend resulting from food production over the years indicates consistent growth in food production from 2000 to 2023, indicating that efforts to boost agricultural output are yielding positive results. This study is in line with studies carried out by Weber and Matthews [11]. Lal et al. [12] in their separate studies, report that CO_2e emissions from agricultural production have been increasing at a rate of 2.7% per annum since 2010, while food production has been growing at a rate of 1.8% per annum.

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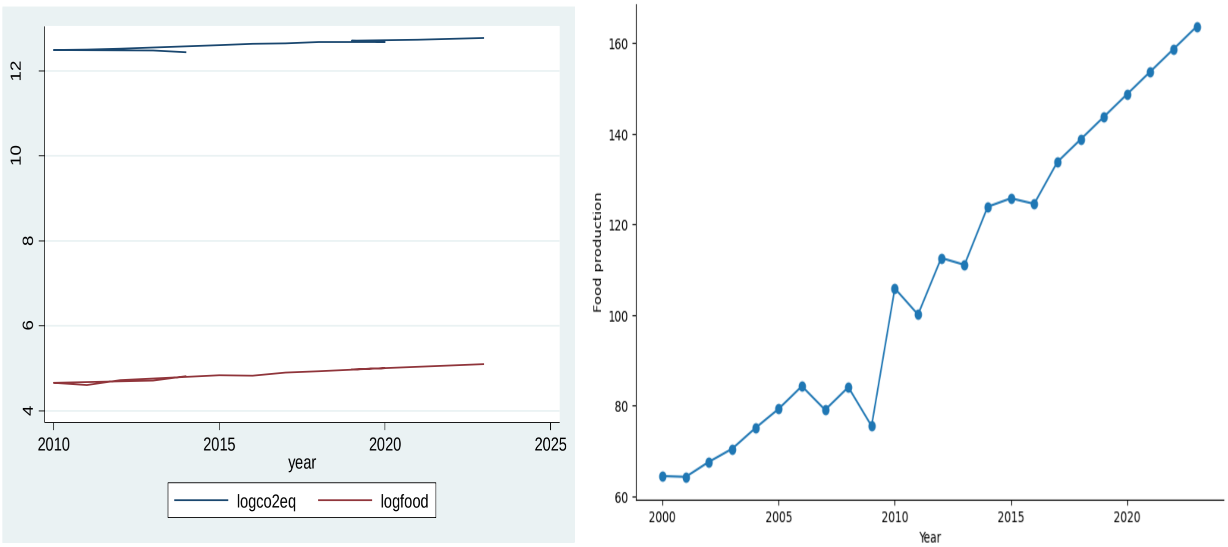

Figure 1.
Trend of CO_2e and food crop production over the years.

4.2. CO_2e Emissions and Crop Production

Crop production concerns crop cultivation. As presented in Figure 2, CO_2e emissions have been increasing, while crop production has fluctuated due to climate change and pests. The trend shows an increase in crop production over the years and a slight increase in crop production, but at a slower rate than CO_2e emissions. This indicates a potential impact of climate dynamics on farm yields, which boosts agricultural output. This study aligns with studies carried out by Ray et al. [13], who found that climate change has resulted in a 1.8% decline in global crop yields since 1960, with the largest impacts seen in wheat and maize.

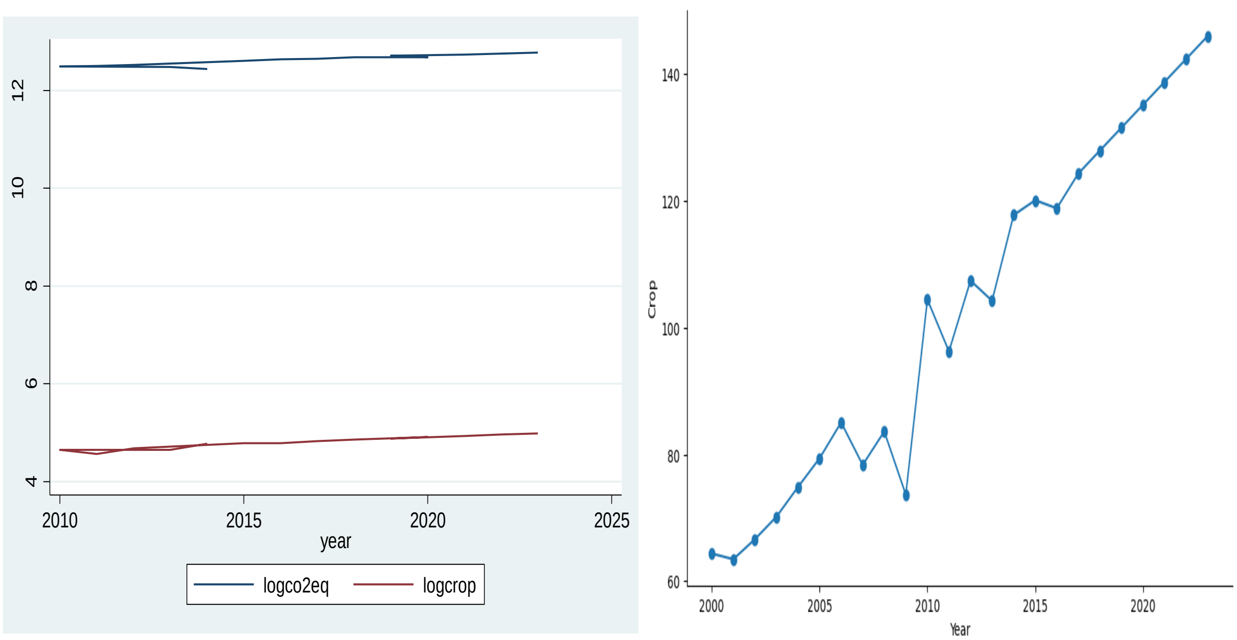

Figure 2.
Trend of CO_2e and crop production over the years.

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4.3. CO_2e Emissions and Livestock Production

As presented in Figure 3, CO_2e emissions have been increasing, while livestock production has been steadily increasing at a rate of 2% per annum. The trend shows a positive correlation between CO_2e emissions and livestock production, indicating a potential increase in GHG emissions from livestock. Similarly, the trend of livestock production shows substantial growth, reflecting expanding animal husbandry and increasing demand for animal products, contributing to agricultural diversification. This study is in line with Herrero et al. [14], who found that livestock production is projected to increase by 70% by 2050, leading to increased CO_2e emissions.

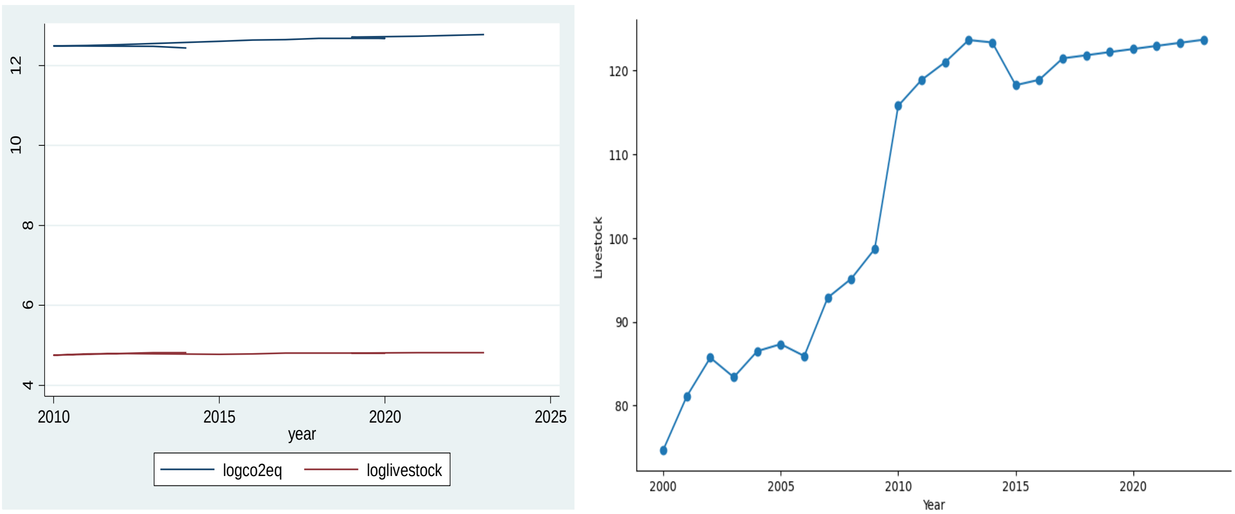

Figure 3.
Trend of CO_2e emission and livestock production over the years.

4.4. CO_2e Emissions and Cereal Production

As presented in Figure 4, CO_2e> emissions have been increasing, while cereal production has been fluctuating due to factors like climate change and pests. The trend shows a slight increase in cereal production, but at a slower rate than CO_2e> emissions. Cereal production is more susceptible to environmental factors (climate change), leading to pronounced fluctuations, highlighting the need for climate-resilient agricultural practices. This study is similar to Lesk et al. [15], who, in their separate studies, found that climate change has led to increased variability in cereal yields, especially wheat and maize, making food security more vulnerable.

Figure 4: Trend relationship between CO_2e and cereal production over the years

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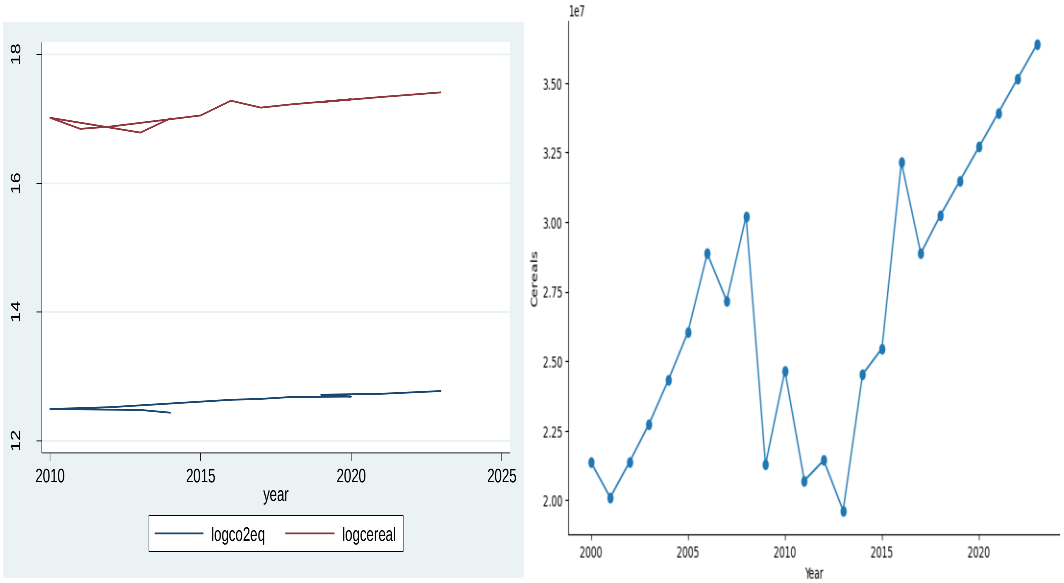

Figure 4.
Trend of CO_2e and cereal production over the years.

4.5. Food, Livestock, Crop, and Cereal Production

As presented in Figure 5, all four parameters have been increasing but at different rates. Food production has been increasing at a slower rate than livestock production, which has been steadily growing, with fluctuations in crop and cereal production. This result is in line with the Intergovernmental Panel on Climate Change [9], which reported that climate dynamics are impacting agricultural production, including crop, livestock, and cereal production.

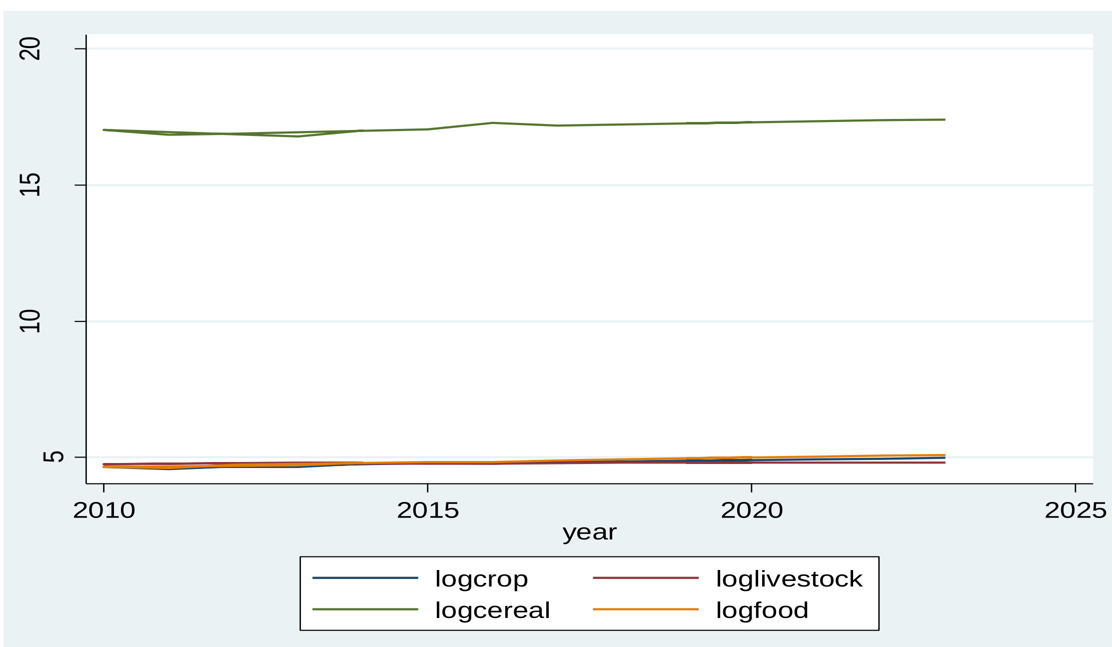

Figure 5.
Trend relationship between the variables.

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4.6. Effect of CO_2e Emissions on the Variables

As presented in Table 1, the results indicate a significant relationship between CO_2e emissions and agricultural production. Food, crop, livestock, and cereal production have a highly significant positive effect at a 5% level (Sig.=0.000, Beta coefficients = 0.937, 0.944, 0.957, and 0.519, respectively).

Table 1.
Effect of CO_2 equivalent emissions on livestock, cereals, food, and crop production.

	Unstandardized Coefficients		Standardized Coefficients		
	B	Std. Error	Beta	T	Sig.
Food production (Constant)	67.843	3.996		16.979	0.000
CO_2 eq emission	0.000	0.000	0.937	12.561	0.000
R	0.937				
R^2	0.878				
Adjusted R^2	0.872				
F (Statistics)	157.780 (0.001)				
Crop (constant)	68.649	3.156		21.749	0.000
CO_2 eq emission	0.000	0.000	0.944	13.363	0.000
R	0.944				
R^2	0.89				
Adjusted R^2	0.885				
F (Statistics)	178.579 (0.000)				
Cereals (constant)	23206980	1533863.9		15.13	0
CO_2 eq emission	18.7 06	6.561	0.519	2.851	0
R	0.519				
R^2	0.270				
Adjusted R^2	0.237				
F (Statistics)	8.128(0.000)				
Livestock (constant)	84.917	1.792		47.383	0.000
CO_2 eq emission	0.000	0.000	0.957	15.476	0.000
R	0.957				
R^2	0.916				
Adjusted R^2	0.912				
F (Statistics)	239.494(0.000)				

These results suggest that CO_2e emissions are a significant predictor of agricultural production in Nigeria. The findings indicate that increased CO_2e emissions are positively and significantly associated with increased agricultural production in Nigeria, which contradicts the general expectation that emissions would negatively impact agricultural productivity due to climate change. The coefficient of determination (R^2) values of 0.878, 0.890, and 0.916 for food, crop, and livestock production suggest that CO_2e emissions account for 91.6% of the variability in livestock production, which is the highest compared to other variables, and this variability is explained by CO_2e emissions. The remaining 8.4% is attributed to other factors such as climate, policy, and technology. The models effectively explain the variance in agricultural production, indicating a good fit. According to Kimball [16], emissions can stimulate plant growth, leading to increased crop yields (fertilization effect). Similarly, Burney et al. [17] in a separate study, it was revealed that increased emissions may serve as a proxy for intensified agricultural activities, leading to higher production.

5. Long-Run Dynamics Results

The Vector Error Correction Model (VECM) estimates the long-run relationships between CO_2e emissions and agricultural (food, livestock, cereals, and crop) production. The results are as presented:

Table 2.
Vector Error Correction Model estimates of long-run relationship between the variables.

Variables	Coefficient	Standard error	t-statistics
CO_2 equivalent emission	0.2482	0.697	0.356***
Food production	6.7865	2.836	2.393***
Livestock	0.1121	0.353	0.318(NS)
Cereals	1.6454	0.384	4.284***
Crop	-7.7549	3.145	-2.466***

Note: *** indicates 5% significance level, NS=Not significant

The Augmented Dickey-Fuller (ADF) test, as presented in Table 2, indicates that food and cereals production have a significant positive relationship with CO_2e emissions at a 5% level (Coefficient = 6.7865, 1.6454; t-statistic = 2.393, 4.284; Significance = 0.018, 0.000). This suggests a CO_2e fertilization effect due to its positive relationship with these variables. Conversely, the negative relationship between CO_2e emissions and crop production at a 5% level indicates potential climate change-related stresses. The non-significant relationship with livestock production suggests that CO_2e emissions do not significantly influence livestock production in Nigeria. This study emphasizes the need for sustainable agricultural practices to mitigate the impacts of climate change, supported by previous research Acheampong et al. [18] and Oke et al. [19].

6. Short-Run Dynamics

Table 3: Vector Autoregression Estimates of the Short-Run Relationship Between CO_2e Emissions and Agricultural Production.

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Table 3.
Vector Autoregression Estimates.

Carbon Dioxide Equivalent Emission (CEE)				
Variable	**Coefficient**	**Standard Error**	**t-stat.**	**p-value**
CEE (Lag 1)	0.11	0.32	0.35	0.726 (NS)
CEE (Lag 2)	1.84	0.50	3.71	0.000***
FP (Lag 1)	-0.000	0.000	-0.36	0.720
FP (Lag 2)	0.000	0.000	1.475	0.140
LS (Lag 1)	0.000	0.000	2.145	0.032
LS (Lag 2)	0.000	0.000	2.396	0.017
Cereals (Lag 1)	-25.181	21.125	-1.192	0.233 (NS)
Cereals (Lag 2)	-77.993	33.325	-2.340	0.019***
Crop (Lag 1)	-0.000	0.000	-0.749	0.454
Crop (Lag 2)	0.000	0.000	1.109	0.267
Constant	52444.858	22938.403	2.286	0.022
Food Production (FP)				
Variable	Coefficient	Standard Error	t-stat.	p-value
CEE (Lag 1)	-103789.33	27409.15	-3.79	0.000
CEE (Lag 2)	84262.50	29582.80	2.85	0.004
FP (Lag 1)	-5.27	5.15	-1.02	0.308 (NS)
FP (Lag 2)	4.422	5.553	0.796	0.426(NS)
LS (Lag 1)	-3.569	2.296	-1.554	0.120
LS (Lag 2)	1.350	2.479	0.545	0.586
Cereals (Lag 1)	1942833.908	1837739.084	1.057	0.290
Cereals (Lag 2)	-2176781.613	1983478.641	-1.097	0.272
Crop (Lag 1)	-5.623	5.401	-1.041	0.298
Crop (Lag 2)	4.218	5.829	0.724	0.469
Constant	9.069	4.306	2.106	0.035
Livestock Production (LS)				
Variable	Coefficient	Standard Error	t-stat.	p-value
CEE (Lag 1)	8431.77	5904.79	1.43	0.153
CEE (Lag 2)	-13819.95	3876.10	-3.57	0.000
FP (Lag 1)	0.53	1.10	0.48	0.630
FP (Lag 2)	-1.534	0.728	-2.108	0.035
LS (Lag 1)	-0.425	0.494	-0.856	0.390 (NS)
LS (Lag 2)	-0.668	0.324	-2.058	0.040***
Cereals (Lag 1)	-0.283	0.345	-0.821	0.411
Cereals (Lag 2)	-0.966	0.901	-1.073	0.283
Crop (Lag 1)	5.468	5.491	0.996	0.454
Crop (Lag 2)	-4.225	6.036	-0.700	0.267
Constant	8.413	1.922	4.377	0.000

Note: CEE= carbon dioxide equivalent emission, LS=livestock production; FP= food production

As presented in Table 5, for carbon dioxide equivalent emission (CEE), a 1% increase in CEE in the previous period (Lag 2) leads to a 1.84% increase in CEE in the current period and is significant at a 5% level. In food and crop production (FP), the p-values at lag 1 and 2 were not significant, indicating that there is no significant relationship between food and crop production and carbon dioxide equivalent emission. Similarly, a 1% increase in livestock and cereal production in the previous two periods (Lag 2) leads to a 0.668% and 77.99% decrease in CO_2e, with p-values (0.040 and 0.019, respectively) significant at a 5% level. However, it can be deduced that carbon dioxide equivalent emission (CEE) is highly persistent, with past values significantly affecting current values. Thus, CEE has significant short-term effects on agricultural production, particularly food, livestock, and cereals production, while livestock and cereals production have a significant negative impact on CEE in the long run. There is no significant relationship between food production, crop production, and CEE.

This study is similar to studies carried out by Kumar et al. [20] and Burney et al. [21], who, in their separate studies, discovered that livestock production contributes significantly to greenhouse gas emissions and that there exists a significant positive relationship between CO_2 emissions and agricultural production.

7. Conclusion

From the study results, it can be demonstrated that a relationship exists between CO_2e, crop, food, livestock, and cereal production in Nigeria. The trends indicate a potential threat to food security due to the increasing gap between CO_2e emissions and food production. Climate change is impacting crop and cereal yields, while livestock production is increasing, contributing to GHG emissions. Similarly, the results of VECM proved that the variables are cointegrated, which implies that they share a common long-run equilibrium relationship and the error term is stationary. The results of the VAR model, on the other hand, proved the dynamic responses of agricultural production parameters to shocks in CO_2e emissions. In essence, emissions resulting from changing rainfall and temperature patterns could have debilitating effects on agricultural production through soil degradation, water scarcity, and pest and disease outbreaks. However, sustainable farming practices and climate-resilient crop and animal varieties are necessary to mitigate these impacts. Additionally, livestock production, as a significant source of CH_4 emissions, can be mitigated through practices like feed optimization, manure management, and enteric fermentation reduction. The findings have important implications for policymakers, farmers, and consumers. Results emphasize the need for sustainable agricultural practices, considering CO_2e and climate change impacts.

8. Recommendations

The following policy recommendations were proffered:

- Promote sustainable agricultural practices to mitigate climate change impacts.
- Implement policies to reduce greenhouse gas emissions from livestock production.
- Encourage climate-resilient crop varieties and farming methods.
- Support agricultural diversification to reduce dependence on emission-intensive crops.
- Develop strategies to enhance carbon sequestration in agriculture.
- Provide incentives for farmers to adopt environmentally friendly practices.
- Invest in climate change research and development to improve agricultural productivity.

Transparency:

The authors confirm that the manuscript is an honest, accurate, and transparent account of the study; that no vital features of the study have been omitted; and that any discrepancies from the study as planned have been explained. This study followed all ethical practices during writing.

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