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The Impact of Carbon Emission on Food Insecurity in Sub-Saharan Africa

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ABSTRACT

The study examines the impact of carbon emissions on food insecurity in sub-Saharan Africa. A panel data of selected sub-Saharan countries was used. The span is from 2000-2021. To achieve the objective of the study, carbon emissions index was created and PARDL model was employed. The results show that an increase carbon emission index has a positive impact of food insecurity. The emissions at farmgate also showed a positive impact on the rate of food insecurity in sub-Saharan Africa. For emissions from agrifood systems, the results showed that an increase in emissions from agrifood systems lead to a rise in the rate of malnutrition. The study brings to light the effect of carbon emissions on food insecurity by creating an index. This approach offers policy makers opportunity to understand the cumulative impact of emissions on food insecurity.

Keywords: Carbon Emissions, Sub-Saharan Africa, Agrifood Systems, Farmgate Emissions
JEL Classifications: C33; O13; Q43

1. INTRODUCTION

Agriculture is highly dependent on the climate and natural resources; hence, climate change does significantly impact agricultural production. According to the (Bennetzen et al,, 2016), climate change has a long-term effect on agriculture and food security. Due to rapid population growth and changes in food patterns, food consumption or demand is projected to increase by 60% by 2050. Unfortunately, however, climate change continues to hurt global food systems. Climate change may affect the system in several ways, ranging from direct effect on crop production (such as changes in rainfall leading to drought or flooding or warmer temperatures). One of the worrying findings by the Intergovernmental Panel on Climate Change (Iturbide, et al, 2020) contends that climate change crises will worsen food and nutrition in the world. Most ominously, the IPCC predicts that climate extremes would raise the probability of simultaneous crop losses in major food-producing countries, potentially causing food costs and prices to skyrocket.

Despite agriculture's enormous capacity to absorb carbon dioxide (CO_2), agriculture, forestry, and other land-use practices accounted for around 24% of global greenhouse gas (GHG) emissions in 2010 (Tubiello et al., 2014). Climate change is inextricably linked to food security because agriculture is directly dependent on the climate and natural resources (Kyalo, M. S. (2018). This is especially worrying given the critical role of smallholder farmers in global food production (Samberg 2016). Climate change is widely acknowledged to be threatening food security.

However, most of the literature has focused on the complex and many pathways connected with climatic stressors (Lobel et al., 2011, Wheeler and von Braun, 2013) and the links to food production rather than food security. In contrast, this study looks at how recent changes in food insecurity can partly be attributed to climate change.

Food security has become a buzzword in development discourse and agriculture because of the intersectionality of climate change and agriculture production (Firdaus et al., 2018; Tan et al., 2021; Yadav et al.,2019). Hunger and malnutrition hurt most people who rely on agriculture for their livelihood (Luan et al.,2018; Yadav et al., 2019).

Despite, the multi-dimensional nature of food security, boosting food production has been the primary focus. Hence, food accessibility and utilization have received less attention (Capone et al., 2014; Stringer, 2016; Firdaus et al., 2020). Most researchers and industry practitioners acknowledge the existential impact of climate change on food security. However, literature thus far focuses on the complex mechanism of climate change stressors and vulnerability rather than food security; and studies concentrate on future effects. In contrast, we investigate how much present trends in food insecurity can be attributed to climate change and other factors in Africa.

What is more, most researchers and industry practitioners acknowledge the existential impact of climate change on food security. However, literature thus far focuses on the complex mechanism climate stressors, vulnerability rather than food security; and studies concentrate on future effects. In contrast, we investigate how much present trends in food insecurity can be attributed to climate change and other factors in Africa. The rest of the study is organized as follows. Section 2 presents the literature review. Section 3 outlines the methodology, while section 4 concludes the study.

2. LITERATURE REVIEW

Food insecurity has been linked to factors such as biofuel production, environmental degradation, arable land and population growth. Some shreds of evidence seem to suggest that the food insecurity situation would be worsened through climate change (Wheeler and Von Braun, 2013, Jones and Thornton, 2003). It is estimated that about 1.7 million people globally are at risk of undernourishment by 2050 attributable to climate change (Dawson et al., 2016). Climate change is expected to have an impact on future food production. Attempts to deal with issues of undernourishment have resulted in agricultural intensification leading to environmental issues such as deforestation, habitat and biodiversity loss, and greenhouse gas emissions (Sengupta and Mukhopadhyay, 2016, Green et al., 2005, Laurance et al., 2014).

Sengupta and Mukhopadhyay (2016) noted that measures often adopted to reduce food insecurity many times generate additional GHG emissions as recorded in the case of India’s National Food Security Act (NFSA) program.

The Sustainable Development Goals (SDGs) placed much emphasis on issues of food insecurity. The first goal of SDGs is to end hunger and achieve food security, improved nutrition and promote sustainable agriculture. According to (Bennetzen et al,, 2016) food security is defined as “at the individual, household, national, regional and global levels are achieved, when all people, at all times, have physical and economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life.” Food security has to do with the availability, accessibility, utilization and stability of food. This means to tackle food insecurity; food must be available to an individual throughout his/her lifetime. In 2010, it was estimated that about 795 million people globally lacked access to adequate food for a healthy living. Most of the food insecure population are from developing countries with Sub-Saharan Africa having a greater number (Laborde et al., 2016). Food deprivation, climate change, and low income are leading causes of hunger and poverty (Ghanem (2010). Issues relating to malnutrition, hunger and chronic food insecurity have received attention in the past two decades (8). Food insecurity at the global and national levels is mostly attributed to a lack of access and redistribution at the household level. The unavailability of food for consumption often attributed to inadequate resources is the most commonly reported form of food insecurity Clark (2009).

The causes of food insecurity are multifaceted and include social factors, income and environmental factors. These factors are reported to have caused food insecurity among households in sub-Saharan Africa as it increases the level of uncertainty about nutritional adequacy and limit household’s ability to in more socially acceptable manner (Maskooni et al., 2013). Household social economic status is often reported as a major cause of food insecurity in sub-Saharan Africa. It is estimated that investments in nutrition programmes to order to save about 3.7 million people from starvation by 2025 (Laborde et al., 2016, Abbasi et al., 2016).

Food insecurity is a public health issue and is common in developing countries where millions of people are suffering from food insecurity, which often results in deaths (Kotir, 2011).

Even though the provision of a varied and balanced diet is essential in reducing malnutrition, food insecurity negatively affected dietary intake (Nnakwe and Onyemaobi, 2013). Children are mostly the most affected toed due to their high demand for nutrients for growth (Rah et al., 2010). Food insecurity often results in absenteeism, early dropout and low academic achievement among students, and reduced productivity among adults (Aguayo et al., 2016). Food insecurity at the household level can lead to psychological dysfunction and poor health among household members (Aguayo et al., 2016).

Malnutrition is one of the glaring consequences of food insecurity. It is estimated that the number of malnourished children in the past decade has increased from 5.5 million to 30 million in sub-Saharan Africa. Malnutrition has led to the death of over 3.5 million children under five ages due to inadequate consumption of food (Mohajan, 2022). Globally, children under 5 years stood at 8.8 million of which 93% came from developing countries in Asia and Africa (Dukhi, 2020). Shortfalls in agricultural output is partly attributable to environmental issues.

Carbon emission (CEM) has impact of agricultural practices with extreme conditions negatively affecting crop and productions (Fadina and Barjolle, 2018). CEM has caused fluctuation in annual rainfall resulting in poor harvest leading to reduction in per capita food production (Zidouemba et al., 2020). Reduction in per capita food production often results in food shortages leading to malnutrition. The disparity in the world's cereals production is greatly attributed to carbon emissions (Mansoor et al., 2022).

It is estimated that food production could fall by 8 % by 2050 attributable to CEM factors, which could eventually limit food supply (Abegunde et al., 2019; Benke and Tomkins, 2017). There has been a rise of new pathogens in cereal crops, like wheat explosions the development, which is attributed CEM. These pose a risk to agriculturalists and endangers their food production, possibly affecting food supply (Upadhyaya et al., 2021; Rodriguez-Algaba et al., 2022).

Rise in carbon emission is expected to cause food shortage, which will disrupt the distribution of foodstuffs, culminating in price hikes and a decline in poor people's survival, particularly in low-income nations (Chilunjika and Gumede, 2021). High food price means families, especially the poor will not be able to meet food needs of their households. This situation will further result in global deprivation and food insecurity, which high food prices would exacerbate weather extremes, variation, and relatively small accessibility to food (Surahman and Shivakoti, 2018; Chilunjika and Gumede, 2021).

In this study, carbon emissions index is created to measured their impact on food insecurity. Principal Component Analysis is used to get the emissions components that actually impact of food insecurity. This approach is a complete departure from previous studies, which relied solely on only one component of carbon emissions.

Table 1 provides a list of some researches that looked at food insecurity. The impact of environmental factors on food insecurity has not received attention. The studies mainly concentrated on the impact of socio-economic factors on food insecurity. To contribute to the debate on food insecurity, we seek to look at the impact of carbon emission on food insecurity in Africa.

3. METHODOLOGY

3.1. Data

This study employs panel data for the period from 2000 to 2022 of selected Sub-Saharan countries which include, Angola, Benin, Botswana, Burkina Faso, Cabo Verde, Cameroon, Central African Republic, Chad, Congo, Côte d'Ivoire, Democratic Republic of the Congo, Djibouti, Eswatini, Ethiopia, Gabon, Gambia, Ghana, Guinea, Guinea-Bissau, Kenya, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Namibia, Niger, Nigeria, Rwanda, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Togo, Uganda, United Republic of Tanzania, Zambia, and Zimbabwe. This study uses as the independent variable of interest CO_2 index captured by a composite index of CO_2 indicators (constructed from Emissions from crops, Emissions from livestock, Emissions on agricultural land, Land Use change, Farm gate and Agrifood systems) as a proxy for environmental degradation. Food insecurity is our dependent variable and proxied by prevalence of undernourishment (percent, 3-year average). We measure economic growth by GDP per capita growth (annual %) and inflation captured by the consumer price index (annual %). Lastly, total population is derived from the definition of population, which includes all residents regardless of legal status or citizenship. All the variables used in this study were obtained from the World Bank Development Indicators (WDI).

3.2. Model Specification and Estimation Technique

To accomplish the objective, the study builds from the Gamso (2024) model presented as follows:

$$FIS = f(CO_2, GDPpc, POP, INF) \tag{1}$$

Where *FIS* denotes food security, CO_2 index of the carbon dioxide, *GDPpc* (gross domestic product per capita), *INF* is inflation rate. Employing the natural logarithm transformation to improve the interpretability of the results, we assemble the linear model as follows:

$$LFIS_{it} = \beta_0 + \beta_1 LCO2_{it} + \beta_2 LGDPpc_{it} + \beta_3 LPOP_{it} + \beta_4 LINF_{it} + \alpha_i + e_{it} \tag{2}$$

Where β_1,β_2,β_3,β_4 are the coefficient of the independent variables that shall be estimated, β_0 is the intercept, and e_{it} is the error term. In order to investigate the long-run and short-run relationship between these variables we used the Panel Autoregressive Distributed Lag (Panel ARDL) methodology. This method was chosen for its appropriateness regardless of whether the order of integration of the variables is I(0), I(1), or a combination of both. Additionally, it provides the short and long-term effects simultaneously. The empirical model of PARDL is expressed in the equation below:

$$\begin{aligned}\Delta LFIS_{it} = {} & \alpha_0 + \sum_{i=1}^{n} \vartheta_1 \Delta FS_{it-j} + \sum_{i=1}^{n} \vartheta_2 \Delta LCO2_{it-j} + \\ & \sum_{i=1}^{n} \vartheta_3 \Delta LGDPpc_{it-j} + \sum_{i=1}^{n} \vartheta_4 \Delta LPOP_{it-j} + \\ & \sum_{i=1}^{n} \vartheta_5 \Delta LINF_{it-j} + \varphi_1 LFIS_{2it-1} + \varphi_2 LIECO2_{it-1} + \\ & \varphi_3 LGDPpc_{it-1} + \varphi_4 LPOP_{it-1} + \varphi_5 LINF_{it-1} + u_{it}\end{aligned} \tag{3}$$

Where α_0 signifies the intercept, Δ is the first difference operator, ϑ_1, ϑ_2, ϑ_3, ϑ_4, and ϑ_5 shows the short-run estimated coefficients of the variables. The long-run estimated coefficient is then deduced from φ_1, φ_2, φ_3, φ_4, φ_5. Once we ascertain the presence of the

Table 1: Summary of the literature

Author and Year	Study location	Participants	Topic	Findings
Walton and Allen (2011)	Developing countries	Review of literature	Malnutrition in developing countries	"Severe acute malnutrition was a problem in developing countries"
Akombi et al. (2017)	Sub-Saharan Africa	2,810 articles were reviewed	Stunting, Wasting and Underweight in Sub-Saharan Africa	"Low education of mother-father, child's age, sex of child (male) and poverty were associated with all forms of malnutrition."
Quisumbing and Smith (2007)	Developing countries	Women	Intrahousehold Allocation, Gender Relations, and Food Security	"The programme improved the condition of the poor households."
Psaki et al. (2012)	Eight country study	800 households and with children aged 24-60 months	Household Food Access and Child Malnutrition	"Food insecurity was associated with wasting, underweight stunting."
Ijarotimi (2013)	Developing countries	Countries	Determinants of childhood malnutrition and Consequences in Developing Countries	"Poverty, lack of nutrition knowledge, poor child-feeding practices and lack of care by caregivers all-cause malnutrition."
De Graaff et al. (2011)	Sub-Saharan Africa	Eight countries	Agriculture and food security	"Some countries were not able to achieve national food security while others were."
Mbwana et al. (2016)	Tanzania	120 households	Determinants of Household Dietary Practices in Rural Tanzania	"The literacy status of the mother and the distance to a water source impact household dietary diversity."
Abo and Kuma (2015)	Ghana	Households	Determinants of the Food Security Status of Female-Headed Households	"Age of household head, educational level of household head and the size of the family were predictors of household food insecurity."
Ihab et al. (2015)	Malaysia	223 households of mothers aged18–55 years old	Assessment of Food Insecurity and Nutritional Status of Children	"The prevalence of underweight, stunting and wasting was high among food-insecure households. Income, household size and the number of children were associated with"
Bremner (2012)	Africa	African countries	Population and Food Security	"30 million children in sub-Saharan Africa are underweight."
Tembo and Simtowe (2009)	Malawi	Households	The Effects of Market Accessibility on Household Food Security	"Households without access to the market were more food insecure, as compared to those with access."
Black et al. (2013)	Low- and middle income countries	Households	Maternal and Child Undernutrition and Overweight	"Maternal and child undernutrition was prevalent in Sub-Saharan Africa and Asia."
Kandala et al. (2011)	DR Congo	8.992 children under 5 years old	Prevalence of Malnutrition in Rural and Urban Areas	"Malnutrition was prevalent in rural areas, as compared to urban areas."
Frelat et al. (2016)	Sub-Saharan Africa	13,000 households	Drivers of Households Food Insecurity	"Lack of market access and food price were associated with household food insecurity."

Drammeh and Hamind (2019)

long-run association between variables, then we estimate the error correction model (ECM) as shown below:

$$\Delta LFS_{it} = \alpha_0 + \sum_{i=1}^{n} \vartheta_1 \Delta FS_{it-j} + \sum_{i=1}^{n} \vartheta_2 \Delta LCO2_{it-j} + \sum_{i=1}^{n} \vartheta_3 \Delta LGDPpc_{it-j} + \sum_{i=1}^{n} \vartheta_4 \Delta LPOP_{it-j} + \sum_{i=1}^{n} \vartheta_5 \Delta LINF_{it-j} + \rho_1 ECM_{t-1} \quad (4)$$

Equation (4) is similar to equation (3) except for the ρ_1 which represent the coefficient for the speed of adjustment to equilibrium. Due to the fact that different specification estimator can somehow be sensitive, we further use the Full Modified Ordinary Least Square for robustness check.

4. RESULTS AND DISCUSSIONS

The results section commences with the panel unit root tests estimates based on four approaches: Levin, Lin & Chu t*, Im, Pesaran and Shin W-stat, ADF-Fisher Chi-square, and PP-Fisher Chi-square (Table 2). The results shows that the CO_2-index, Lpop (log of population), and inflation are stationary at their levels. Contrastingly, GDP per capita (GDP-pc) variable is non-stationary at level, but becomes stationary after first differencing, suggesting it contains a unit root. The mixture of stationary and non-stationary variables supports the use of the Panel Autoregressive Distributed Lag (PARDL) model, which accommodates variables of different integration orders effectively.

Table 3 presents the results on descriptive statistics. The descriptive statistics results specified that all the variables were distributed normally, and this was endorsed with the values of standard deviation, probability and Jarque-Bera statistics.

Table 4 shows the results on principal component analysis. Being a dimensional reduction tool, the results show that component 1 and principal component 2 jointly explain about 82.54% of the model. The component 1 and component 2 have eigenvalues of 3.799013 and 1.153158, respectively. They are all >1 satisfying their inclusion in the analysis. In terms of proportion, component 1 and component 2 explain 63.3% and 19.2% of variance of the data.

Table 5 presents the results on the correlation among the variables. The results show a perfect positive correlation between emissions from agri-food systems and emissions on agricultural land. A rise in emissions from agri-food systems leads to an increase in emissions from agricultural land and vice versa. The results show a strong positive correlation between emissions at farmgate and emissions on agricultural land. Also, there is a strong positive correlation between emissions at farmgate and emissions from agri-food systems. A rise in emissions at farmgate results in an increase in emissions from agri-food systems and vice versa. The results further establish a perfect correlation between emissions from land use change and emissions on agricultural land. There is also a perfect positive correlation between land use change and emissions on agricultural land. A rise in emissions from one lead to a rise in emissions from the other. The emissions from land use change and emissions from farmgate also shows a positive strong correlation. The results show a strong positive correlation between emissions from the livestock and emissions from the farmgate.

Table 2: Panel unit root results

Variable	At level method		At first difference		
		Statistic	Prob.**	Statistic	Prob.**
CO_2-index	Levin, Lin and Chu t*	−4.77369	0.0000		
	Im, Pesaran and Shin W-stat	−4.33701	0.0000		
	ADF - Fisher Chi-square	150.153	0.0000		
	PP - Fisher Chi-square	167.516	0.0000		
Lpop	Levin, Lin and Chu t*	−13.2197	0.0000		
	Im, Pesaran and Shin W-stat	−3.63696	0.0001		
	ADF - Fisher Chi-square	999.970	0.0000		
	PP - Fisher Chi-square	509.376	0.0000		
inflation	Levin, Lin and Chu t*	−45.3267	0.0000		
	Im, Pesaran and Shin W-stat	−20.5542	0.0000		
	ADF - Fisher Chi-square	338.372	0.0000		
	PP - Fisher Chi-square	358.559	0.0000		
GDP-pc	Levin, Lin and Chu t*	115.528	1.0000	−4.6737	0.0000
	ADF - Fisher Chi-square	0.00853	1.0000	165.221	0.0000
	PP - Fisher Chi-square	0.00940	1.0000	155.024	0.0000

Table 3: Descriptive statistics

ITEMS	LFOODINSEC	CO_2-INDEX	LPOP	INFLATION	GDP-pc
Mean	2.817988	−0.002599	16.00705	7.799176	1.675683
Median	2.931190	−0.189357	16.35691	4.941301	2.081978
Maximum	4.210645	3.988765	19.17869	557.2018	27.83109
Minimum	0.916291	−2.821034	11.32025	−8.974740	−36.77770
Standard deviation	0.657245	1.088945	1.529152	23.62508	4.747624
Skewness	−0.691111	1.004004	−0.680750	18.42012	−1.467165
Kurtosis	2.987066	4.695253	3.569048	403.8425	14.69312
Jarque-Bera	60.34639	218.1138	68.77256	5117507.	4590.304
Probability	0.000000	0.000000	0.000000	0.000000	0.000000
Observations	758	758	758	758	758

Table 4: Principal component and correlation matrix results for CO_2 variables

Component number	Eigenvalue	Difference	Proportion	Cumulative value	Cumulative proportion
Component 1	3.799013	2.645855	0.6332	3.799013	0.6332
Component 2	1.153158	0.249845	0.1922	4.952172	0.8254
Component 3	0.903313	0.760507	0.1506	5.855484	0.9759
Component 4	0.142806	0.141096	0.0238	5.998290	0.9997
Component 5	0.001709	0.001708	0.0003	5.999999	1.0000
Component 6	8.15E−07	-	0.0000	6.000000	1.0000

Table 5: Ordinary correlation results

	EMAGLAPER	EMAGSYPER	EMCRPER	FARGATEMPER	LAUSECHEMPER
EMAGLAPER	1.000000				
EMAGSYPER	0.998732	1.000000			
EMCRPER	−0.140912	−0.140843	1.000000		
FARGATEMPER	0.754706	0.748058	−0.030383	1.000000	
LAUSECHEMPER	0.967864	0.968813	−0.165482	0.565472	1.000000
LISTOCEMPER	0.389875	0.380039	0.001802	0.757067	0.199956

A rise in emissions from the livestock leads to a rise in emissions from farmgate and vice versa.

Figure 1 presents result on scree plot of CO_2 index. In these results, the first two principal components have eigenvalues >1. These three components explain 82.54% of the variation in the data. The scree plot shows that the eigenvalues start to form a straight line after the second principal component. The of 82.54% is an adequate amount of variation explained in the data, so the first two principal components are used in the analysis.

Table 6 presents the results on the PARDL and Cointegration. CO_2-Index shows a positive relationship with prevalence of malnutrition. The result shows that in a long-run, a unit increase CO_2-index leads to about 6.71% increase in the rate of malnutrition. The result is statistically significant at 1% level. This finding corroborates study by Fadina et al. (2018); Zidouemba et al. (2020) who indicated that carbon emissions affect agricultural practices leading to poor crop yield and animals' health. Carbon emissions affect rainfall pattern leading to drought and flooding in some cases. These often results in poor yields resulting in famine and incidence of malnutrition. This also supports the study by Mansoor et al. (2022), which concluded that carbon emissions have led to a reduction in global food supply resulting in cereal disparity internationally. This finding further lends credence to the assertion that carbon emissions will cause about 8% reduction in food production in Africa and Asia by 2025 as it will limit food supply. Carbon emissions will result in a rise in new crop diseases that will pose a serious threat to agriculturalist there by affecting food production resulting a reduction in food supply (Upadhyaya et al., 2021; Rodriguez-Algaba et al., 2022). Finding further supports other studies, which found that an increase in carbon emissions will lead to malnutrition through a reduction in the food production, especially among resource poor households who depend solely on their farms (Ceesay and Ndiaye, 2022; Alvar-Beltrán et al., 2023). Carbon emissions does not only affect producers but also consumers through price hikes. Additionally, extreme CEM events can disrupt the distribution of foodstuffs, culminating in price hikes and a decline in poor people's survival, particularly in low-income nations (Chilunjika and Gumede 2021).

The results show a positive relationship between population growth and the rate of food insecurity (malnutrition). The findings corroborates the study by Bremner (2012), which concluded that population increase has a positive impact on the number of underweight children. The result show that a unit increase in the rate of inflation will result in about 3.05% rise in the rate of malnutrition in the long-run and it is statistically significant at 1% level. In the long-run, a unit change in the GDP per capita will lead to about 6.42% rise in the rate of malnutrition and statistically significant at 1% level.

The coefficient of the lagged ECM is negative and statistically significant at 5% level, indicating the existence of a long-run relationship between the variables. It also indicates that there is adjustment to equilibrium.

Figure 1: Scree plot of CO_2 index

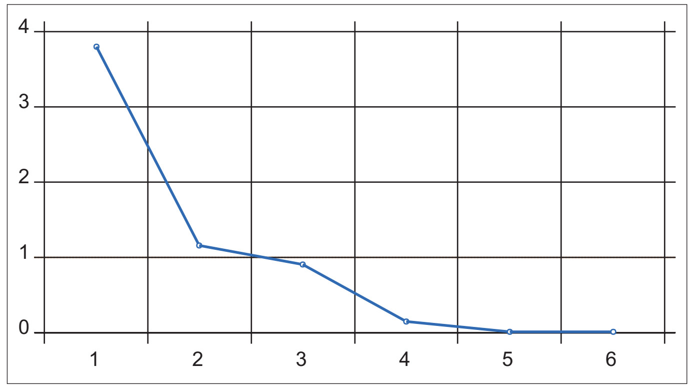

Table 6: PARDL and cointegration results

Variable	Coefficient	Standard error	t-Statistic	Prob.
Long-run (Pooled) Coefficients				
CO_2-INDEX	1.186624	0.176930	6.706752	0.0000
LPOP	0.218637	0.126564	1.727483	0.0845
INFLATION	0.006792	0.002230	3.045881	0.0024
GDP-pc	0.050300	0.007840	6.415540	0.0000
C	3.023188	1.915081	1.578621	0.1149
Short-run (Mean-Group) Coefficients				
ECM(-1)	−0.027276	0.013194	−2.067278	0.0391
D (CO_2-INDEX)	−0.105746	0.070886	−1.491771	0.1362
D (LPOP)	−5.198302	2.414854	−2.152636	0.0317
D (INFLATION)	0.000447	0.000613	0.729223	0.4661
D (GDP-pc)	−0.000303	0.001031	−0.293917	0.7689
Log-Likelihood	1236.725			
Cointegration test				
Kao Test	t-Statistic	Prob.		
ADF	−3.079288	0.0010		
Residual variance	0.005660	-		
HAC variance	0.011530	-		

4.1. Robustness Check

Table 7 presents the results on robustness check. Per capita emission at farm gate shows a positive relationship with malnutrition. The results show that unit increase in the rate of farmgate emissions results in about 6.34% rise in the rate of malnutrition and statistically significant at 1% level. For the population, the result show that a unit rise in the rate of the population results in about 26.25% rise in the rate of malnutrition and statistically significant at 1% level. Population growth may burden already poor agricultural infrastructure leading to imbalances in food supply. With poor yields per acre recorded in most countries, population growth means more people to depend on already inadequate food supplies. This development will lead to inequality in food access vulnerable people will be denied access to food, which will put many people at the risk of malnutrition. This supports the study by Okumu et al. (2021) which concluded that population growth may burden the infrastructure already in place, making it difficult to supply food efficiently to all locations, particularly distant ones.

The rate of inflation shows a positive relationship with the rate of malnutrition. The results show that a unit rise in the rate of malnutrition leads to about 2.54% rise in the rate of malnutrition and statistically significant at 5% level.

Table 7: PARDL results

Variable	Coefficient	Standard error	t-Statistic	Prob.
Long-run (Pooled) coefficients				
FARGATEMPER	1.423445	0.224549	6.339121	0.0000
LPOP	0.285699	0.010886	26.24515	0.0000
INFLATION	0.005553	0.002187	2.538626	0.0113
GDP-pc	0.012564	0.006548	1.918636	0.0554
Short-run (Mean-Group) Coefficients				
COINTEQ	−0.036198	0.012919	−2.802009	0.0052
D (FARGATEMPER)	−0.109844	0.139140	−0.789450	0.4301
D (LPOP)	−5.596210	1.988932	−2.813675	0.0050
D (INFLATION)	0.000164	0.000662	0.247562	0.8045
D (GDP-pc)	−3.30E-05	0.001161	−0.028397	0.9774
Log-Likelihood	1228.227			

Table 8: PARDL results

Variable	Coefficient	Standard error	t-Statistic	Prob.
Long-run (Pooled) coefficients				
EMAGSYPER	0.138570	0.040905	3.387608	0.0007
LPOP	0.171424	0.008607	19.91621	0.0000
INFLATION	−0.001602	0.002378	−0.673684	0.5007
GDP-pc	0.007391	0.003895	1.897857	0.0581
Short-run (mean-group) coefficients				
ECM(-1)	−0.080893	0.020277	−3.989358	0.0001
D (EMAGSYPER)	−0.020749	0.055206	−0.375846	0.7071
D (LPOP)	−0.704305	0.652241	−1.079823	0.2806
D (INFLATION)	0.000548	0.000623	0.878581	0.3799
D (GDP-pc)	0.000228	0.000986	0.231247	0.8172
Log-Likelihood	1191.074			

The rate of GDP per capita shows a positive relationship with malnutrition. The results show that a unit rise in the GDP per capita leads to about 1.93% rise in the rate malnutrition.

Table 8 presents results on PARDL. Emissions from agrifood systems per capita is include for robustness check. The results show that emission from agrifood systems per capita has a positive association with the rate of malnutrition. The results show that a unit increase in the rate of emissions from agrifood systems result in about 3.39% rise in the rate of malnutrition and is statistically significant at 1% level. The coefficient of the lagged ECM is negative and statistically significant at 1% level, indicating the existence of a long-run relationship between the variables. It also indicates that there is adjustment to equilibrium.

5. CONCLUSION

The study basically looked at the impact of carbon emissions on food insecurity in sub-Saharan Africa. An index of carbon emissions was created. The emissions from agrifood systems and emissions from farmgate were also included for robustness check. Population growth rate, inflation and GDP per capita were also included for analysis.

The result established a positive relationship between carbon emissions and food insecurity in sub-Saharan Africa. The carbon emissions index showed a positive relationship with food insecurity (malnutrition). Carbon emissions from agrifood systems also showed a positive relationship with food insecurity. The study further established a positive relationship between carbon emissions from farmgate and food insecurity.

Population growth, inflation and GDP per capita also showed a positive relationship with food insecurity.

The study showed that carbon emissions from agricultural sector pose a threat to food security in sub-Saharan Africa.

Based on these findings, we recommend the following for policy consideration:

- Farmers should be encouraged to embrace organic farming as it has the potential to reduce the rate of carbon emissions from the agriculture sector.
- Efficient use of energy in the agriculture sector should be encouraged and farmers should be encouraged to use non fossil fuel. There is the need to integrate low-carbon energy sources and efficiency programs into all development efforts and supplier relationships with farmers.
- Farmers should be encouraged to adopt emissions-reduction crop management practices and varieties.
- Countries in sub-Saharan African, should have a policy shift from subsidies on fertilizers to support for higher nitrogen use efficiency (NUE) where nitrogen use is excessive.

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