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Food Insecurity in West Africa: Is Global Warming the Driver?

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ABSTRACT

This research explores the causal correlation between food insecurity and global warming in West Africa, utilising secondary panel data from 2000 to 2020 and employing the Kao co-integration, FMOLS and GLM techniques. The variables studied include malnutrition prevalence, CO_2 emissions, inflation, foreign direct investment (FDI), GDP per capita, population growth, food imports, and arable land. The econometric analysis provides evidence of a positive long-term correlation between food insecurity and climate change. This finding underscores the region's agricultural sector's vulnerability to atmospheric changes, potentially worsening food insecurity. Based on the findings, the study proposes a comprehensive approach to addressing climate-induced food insecurity in West Africa. Recommendations include implementing climate-smart agricultural practices, reducing carbon emissions, increasing agricultural investment, improving incomes, adopting enhanced farming techniques, activating climate change mitigation programs, investing in agricultural research, and diversifying economic structures.

Keywords: Climate Change; Global Warming; Food Security; CO_2 Emission; Economic Growth; West Africa; Panel Data Models

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1. Introduction

A country's agricultural success depends on soil fertility, rainfall, and the tools adopted, influenced by temperature. Over the past two centuries, global warming has increased the earth's temperature, adversely affecting rainfall, soil fertility, CO_2 levels, and climatic patterns. The IPCC[1], attributes global warming primarily to human activities such as deforestation and burning fossil fuels, which release greenhouse gases that trap heat and disrupt natural climate patterns[2, 3]. In addition, ozone layer depletion due to chlorofluorocarbons (CFCs) exacerbates global warming[4]. Consequently, global warming is increasingly harming agricultural yields, threatening food production systems, and making affected regions food insecure and reliant on food importation[5]. Joshi et al.[6] and Amuji[7] project that by 2050, East and Southern Africa will experience air temperatures of 30 °C, making cropping in East and West Africa riskier due to shorter growing seasons. Burke, Lobell and Guarino[8] and Collinson et al.[9] predict that by 2025, areas where maize is planted in Africa will experience warmer temperatures, lowering crop outputs[10]. Field and Barros[11] and FAO[12] observed that mega-deltas, home to the world's major food production, face rising threats from saltwater intrusion, causing price fluctuations and jeopardising access to food and livelihoods. Sikiru et al.[13], note that climate change disrupts fisheries and aquaculture, reducing fish availability, a vital food source and income for coastal communities.

Moreover, changing precipitation patterns have affected water availability for irrigation, a critical factor for sustaining agricultural production[12, 14]. Climate change-induced events like floods, storms, frosts, heat waves and droughts further disrupt farming activities, lower livestock output, and increase crops' vulnerability to diseases and pests[15–17]. The rising temperature and extreme weather conditions pose a growing risk to rural households, potentially worsening food insecurity in vulnerable regions[11, 18]. Addressing food security in the context of climate change is one of the 21st century's most pressing challenges, with agriculture at the centre[5, 19–21]. Food insecurity, characterised by uncertain or limited access to adequate food due to poverty and unemployment, leads to hunger, malnutrition, and adverse health outcomes[22]. In contrast, food security ensures consistent access to sufficient, safe, and nutritious food[23, 24]. It requires addressing sociocultural and gender disparities and future challenges like population growth, health (HIV/ AIDS) and environmental degradation[25, 26]. Maity et al.[27] project that by 2080, based on various climate change scenarios, the number of people experiencing food insecurity may vary from around 200 to 600 million, underscoring the challenge for policymakers to ensure food for the vulnerable regions[28].

The global warming debate has prompted numerous studies explaining the factors driving the earth's rising temperature. Thornton et al.[29], Mamba and Ali[30], Nwozor and Olanrewaju[31], and Germer et al.[32] highlight the vulnerability of artisanal fishers, subsistence, pastoral and small-scale farmers to climate-related shocks, emphasising the risk of food insecurity in developing regions. Adeiza Bello et al.[33] demonstrated the adverse effect of climate change on African agricultural productivity. Rankoana[34] explored how grassroots small-scale farmers in South Africa use innovative practices to mitigate climate change effects. Meanwhile, FAO[22] accentuated that economic growth and responsible globalisation offer pathways to combat poverty, malnutrition, and hunger. Despite these insights, a significant gap remains in understanding how global warming affects African food security. Considering the geographical differences in food insecurity's environmental and socio-economic drivers and the uncertainty surrounding future global warming trajectories, focusing on vulnerable regions where the gap between potential and actual crop yields threatens food security is crucial. The choice of West African countries for this study is due to the agrarian nature of their economies. Despite a rich agricultural history, the region has become a major importer of agricultural and agro-industry products, surging over the last three decades[35]. The predicted negative impacts of climate change on agricultural production pose significant challenges for regional farmers and firms, making food security a critical issue[11].

West Africa faces a growing threat of food insecurity, exacerbated by population growth, rural-urban migration, inflation, climate change, and uneven development, despite being a major food-production region in Africa [36, 37]. **Figure 1** illustrates trends in food security in Africa, the world and West Africa from 2013 to 2022, revealing increasing undernourishment (million), worsening food insecurity among the total population (million), and declining per capita food production (US$) in West Africa.

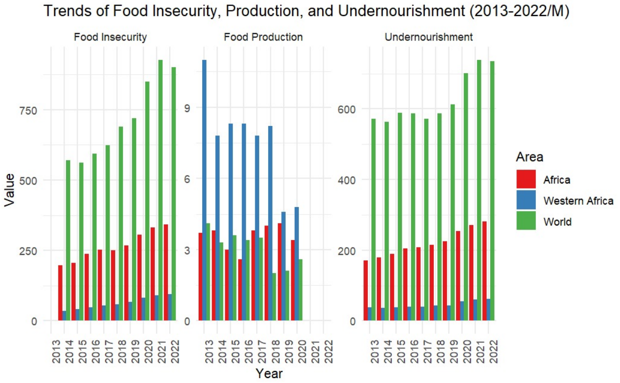


Figure 1. Food security trend in Africa and West Africa (2013–2022).

Source: Author's computation from FAOSTAT [38].

Specific country examples highlight the severity of the situation; for instance, Liberia relies heavily on food imports, with high child malnutrition rates [39]. Mali's infant mortality rate due to hunger was 104 deaths per 1,000 live births [40, 41]. In Nigeria, around 25 million people are projected to face food insecurity in 2024 due to violence, climate change, inflation, and soaring food prices [42–44]. Food insecurity in Togo, Benin, Sierra Leone, Côte d'Ivoire, Guinea, Ghana, and Guinea-Bissau has worsened, prompting ECOWAS (the economic community of West African States) to form the ECOWAP (the economic community of West Africa Agricultural Policy) initiative to ensure food security and fair compensation for agricultural workers [45, 46]. Nevertheless, agriculture is expected to help reverse the situation and provide food, revenue, employment, and environmental services by 2050 [36]. Building on this context, the study utilises secondary data from 2000 to 2020 and employs panel FMOLS and GLM econometric techniques to analyse food security in West Africa. It differs by examining per capita GDP, population growth, and level of food importation across member states, employing livelihood-based and scenario-based methodologies to identify location-specific adaptation methods. The research explores vulnerabilities caused by global warming and its long-term effects on household food poverty. Consequently, the following questions are asked to achieve its objectives: Is there a causative link between global warming and food insecurity in West African countries? Is there a long-term effect of global warming on food insecurity? The aim is to conduct empirical research to inform policies and interventions to help farmers in rural communities live with, understand, and adapt to these challenges. The paper is organised into sections covering the literature matrix, methodology, results, discussion, and concluding remarks.

2. Basic Definition and Review of Literature

The notion of "enough food" is described in various ways in Frankenberger's [47] literature review. Different authors summarise it as "minimal level of food consumed", "basic food (needed)", as the food "adequate to meet nutritional needs", "enough food for life, health and growth of the young and for productive efforts", "enough food for an active, healthy life", "enough food to supply the energy needed for family members to live healthy, active and productive lives". Food security includes four key concepts: food availability, dietary quality (accessibility), consistent supply (stability), and affordability [48]. Moreover, the WHO [49] defines food security as a state where all individuals have consistent access to sufficient, safe, nutritious food that meets their dietary diversity for a healthy life. However, in the case of West Africa, this concept has evolved in response to widespread hunger, undernourishment, famine, anaemia, and malnutrition, often leading to dietary instability and nutrient deficiencies that harm livelihood and well-being [50–52]. The challenging scenario is primarily attributed to the prevalence of lower-income families, making them particularly vulnerable to future food insecurity, and their susceptibility often reflects the broader system's vulnerabilities or those of its constituent parts [53]. Consequently, the literature matrix in **Table 1** includes articles selected systematically, targeting recent research at the intersection of climate change, food security, and developing countries/ African contexts, prioritising region-specific

Table 1. Empirical review matrix.

S/N	Author	Objective	Methodology	Findings
1	Adesete, Olanubi and Dauda[54]	To study climate change and food security linkage in 30 sub-Saharan African countries (2000–2019)	Generalised Method of Moments (GMM)	Increased population leads to undernourishment, which worsens food insecurity.
2	Abdi, Warsame and Sheik-Ali[55]	To analyse how changes in temperature and rainfall patterns impact East Africa's cereal crop yields (1990–2018).	Pooled mean group (PMG)	Temperature negatively impacts cereal production; while CO_2 emissions and rainfall positively influence yields in the long run. Rural population and land area positively correlate with agricultural output.
3	Fagbemi, Oke and Fajingbesi[56]	To study the effects of climate change on agricultural yields in 32 sub-Saharan African countries (2005–2019).	2-step GMM	Fossil fuel burning drives climate change and threatens agriculture. Rising temperatures and unpredictable rainfall disrupt crop production, particularly in rain-fed areas, jeopardising food security.
4	Tetteh, Baidoo and Takyi[57]	Understand how Ghana's temperature, precipitation, and carbon dioxide emissions impact specific food production (crops like maize, roots, and tubers) (1970 to 2019).	Dynamic ordinary least squares (DOLS) and fully modified ordinary least squares FMOLS	High temperatures negatively impact maize, root, and tuber crops. Rainfall benefits cereal and maize cultivation; while CO_2 emissions positively affect cereal production in Ghana.
5	Affoh et al.[58]	To evaluate climate variables and their relationship to food security in sub-African countries (1985–2018).	Panel autoregressive distributed lag (ARDL) and PMG	Rainfall and food security across all dimensions have positive impacts. Temperature negatively affects availability and accessibility. Increased CO_2 emissions positively affect food availability and accessibility but not food utilisation.
6	Pickson and Boateng[59]	To investigate climate change's role, trend and effects on food security in 15 African countries (1970–2016).	PMG	Unlike temperature, rainfall is positively significant to Africa's food security. The land area, population and per capita GDP positively enhance food security.
7	Ceesay and Ndiaye[60]	To evaluate the complex interplay between remittance inflows, agricultural productivity, climate change, and population dynamics on food security (1971–2020).	ARDL	Food production positively influences agriculture in The Gambia; while CO_2 emissions have a beneficial short and long-term impact on both. Populate increases are detrimental to food security.
8	Chandio et al.[61]	To examine how climate change affects Turkish cereal yields and agricultural productivity (1968–2014).	ARDL	CO_2 emissions significantly and negatively affect cereal yields in Turkey, labour, and land.
9	Alpízar et al.[62]	To examine the effectiveness of local climate adaptation strategies in reducing food insecurity.	Cross-Sectional Survey, Statistical Models.	Communities with effective climate adaptation strategies showed lower levels of food insecurity, even considering the evolving weather patterns.
10	Mahrous[63]	To analyse the East African Community (EAC) region's global climate change impact on cereal (2000–2014).	Pooled fixed effects	In the EAC region, food security is negatively impacted by temperature changes. Land areas available for planting cereal crops ensure better food security.

findings.

Despite the increasing body of study on global warming's influences on food security, there is a notable disparity in the focus of these studies, as presented in **Table 1**. Hence, this research addresses the imbalance by focusing on the vulnerable West African populations, considering their unique adaptation capacities. Doing so enriches the existing literature with region-specific insights and contributes to developing targeted strategies for enhancing food security in West Africa.

3. Research Methodology

3.1. Theoretical Framework

Climate change mitigation presents a complex global public good problem, characterised by greenhouse gas emissions as a global environmental externality. This challenge intertwines ecological science with economic theories, including game theory, the Coase theorem, and the theories of Malthus and Boserup. Morgenstern[64] and Von Neumann and Morgenstern[65] game theory offers a framework for modelling decision-making processes related to adaptation to global warming and food security in West Africa. The inherent uncertainty in global warming impacts creates a game without a clear saddle point[66] complicated by factors like asymmetric information and myopic self-interest[67, 68]. Recent studies demonstrate that the impacts have become more predictable and are subject to more targeted interventions[69, 70]. The Coase theorem, introduced by Coase[71], suggests that parties can negotiate to resolve conflicts over property rights efficiently without government intervention, given no transaction costs. This concept has been applied to environmental issues, including global warming mitigation strategies[72, 73]. The Malthusian theory[74], which predicts that population growth outpaces food production, remains relevant in West African nations[75]. Population growth has been accompanied by unstable output growth, increased poverty, conflicts, and epidemics[76]. Empirical studies support a proportionate link between these regions' food production capacity and population growth[77–80]. However, the Boserup theory[81] counters Malthusian pessimism, arguing that population growth drives agricultural intensification and innovation. Boserup posits that as population density increases, agricultural practices evolve to more intensive methods, spurring innovation to meet growing food demands[35]. This perspective is particularly relevant for West African countries facing both population growth and climate change impacts on agriculture. While Montesquieu's climate theory provides historical context, it has been superseded by modern understandings of climate-society interactions[82]. However, Owen[66] and Sivakumar et al.[35] state that these challenges can be addressed through science-based strategies, innovation, and appropriate policies. Therefore, addressing West Africa's food insecurity requires a comprehensive approach, taking cognisance of various economic and ecological theories and balancing population growth challenges with the potential for human ingenuity and technological advancement to develop effective solutions.

3.2. Model Specification and Method of Estimation

The empirical and theoretical framework provides the basis for examining the intricate linkage between food security, global warming, and relevant socioeconomic dynamics in West Africa while acknowledging the potential for human intervention in addressing food insecurity challenges. Following the adapted model of Adesete, Olanubi and Dauda[54], a Cobb-Douglas function is used to model food utility, with climate change as the input factor and food security as the output. Hence, the demand, supply, and utility theories were combined and modified as follows:

$$Uf = f(Z) \tag{1}$$

Z = Basket of food commodities $\mathrm{A}_1, \mathrm{A}_2, \mathrm{A}_3, \ldots \mathrm{A}_\mathrm{n}$

$$Z = (\mathrm{A}_1, \mathrm{A}_2, \mathrm{A}_3, \ldots, \mathrm{A}_\mathrm{n}) \tag{2}$$

$$Uf = f(\mathrm{A}_1, \mathrm{A}_2, \mathrm{A}_3, \ldots, \mathrm{A}_\mathrm{n}) \tag{3}$$

Z = f[(climate change, other factors (OF)]

Where: other factors (OF) are: Food price(FP); Food supply (FS); Real per capita income (Y); Population growth rate (PG); Climate Change (CLC); Food utility (Uf); Food insecurity (FISEC); Existence of malnourishment (ERM); Stochastic term (ϵ). Therefore, to evaluate the dependent variables and other factors' relationship, the utility, demand and supply equation is specified as follows:

$$Uf = f(\text{climate change, other factors}) \tag{4}$$

An increase in the maximum satisfaction derived from consuming a variety of food commodities $(\mathrm{A}_1, \mathrm{A}_2, \mathrm{A}_3, \ldots, \mathrm{A}_\mathrm{n})$ leads to a lower rate of malnourishment due to higher nutritional content. In other words, the higher the utility of food, the lesser the malnourishment. An increase in food utility signifies an expected improvement in food security, as higher utility indicates better food availability and nutritional quality.

Furthermore, Adesete, Olanubi and Dauda's[54] model is modified to derive a multi-linear equation model as shown below;

$$\begin{gathered} FISEC = Z = u(\mathrm{A}_1, \mathrm{A}_2, \mathrm{A}_3, \ldots, \mathrm{A}_\mathrm{n}) = \\ f(\text{climate change, other factors}) \end{gathered} \tag{5}$$

$$FISEC = Z = u(\mathrm{A}_1, \mathrm{A}_2, \mathrm{A}_3, \ldots, \mathrm{A}_\mathrm{n}) = f(\text{CLC, OF}) \tag{6}$$

$$FISEC = f(\text{CLC, OF}) \tag{7}$$

The Cobb-Douglas functional form is adapted into Equation (7).

$$FISEC = A(CLC)^{\alpha}(OF)^{\beta} \tag{8}$$

In Equation (8), A represents the constant technical know-how needed in food production. A logarithmic transformation, which enables the interpretation of regression coefficients as elasticities or percentage changes, is applied in Equation (9).

$$LNFISEC = LN\left[A(CLC)^{\alpha}\,(OF)^{\beta}\right. \tag{9}$$

$$LNFISEC = LN\,[A] + LN\,[(CLC)^{\alpha}] + LN\,(OF)^{\beta} \tag{10}$$

$$LNFISEC = LN\,[A] + \alpha LN\,[CLC] + \beta LN[OF] \tag{11}$$

Let

$$LN\,[A] = \text{constant}\,(\rho) \tag{12}$$

$$LNFISEC = \rho + \alpha LN\,[CLC] + \beta LN[OF \tag{13}$$

Recall: $OF = Y,$ POPGR, FDI, FP; therefore substitute into Equation (13).

$$\begin{aligned} LNFISEC &= \rho + \mathrm{A}_1 LN\,[CLC] + \mathrm{A}_2 LN\,[PG] \\ &+ \mathrm{A}_3 LN\,[INF] + \mathrm{A}_4 LN\,[GDPpcapita] + \\ &\mathrm{A}_5 LN\,[FDI] + \mathrm{A}_6 LN\,(FIMPORT) + \mathrm{A}_7 LN\,(AL) \end{aligned} \tag{14}$$

The error term (ϵ) is added to Equation (14) to derive the model in Equation (15).

$$\begin{aligned} LNFISEC &= \rho + \mathrm{A}_1 LN\,[CLC] + \mathrm{A}_2 LN\,[PG] \\ &+ \mathrm{A}_3 LN\,[INF] + \mathrm{A}_4 LN\,[GDPpcapita] + \\ &\mathrm{A}_5 LN\,[FDI] + \mathrm{A}_6 LN\,(FIMPORT) \\ &+ \mathrm{A}_7 LN\,(AL) + \epsilon \end{aligned} \tag{15}$$

Therefore, Equation (15) is rewritten as:

$$\begin{aligned} LNFISEC &= \alpha + \mathrm{A}_1 LN\,(CLC_{it}) + \mathrm{A}_2 LN\,(PG_{it}) \\ &+ \mathrm{A}_3 LN\,(INF_{it}) + \mathrm{A}_4 LN\,(GDPpcapita_{it}) + \\ &\mathrm{A}_5 LN\,(FDI_{it}) + \mathrm{A}_6 LN\,(FIMPORT_{it}) \\ &+ \mathrm{A}_7 LN\,(AL_{it}) + \epsilon_{it} \end{aligned} \tag{16}$$

Where: α = Intercept; A_1, A_2, A_3, A_4, A_5, A_6,A_7 = Parameters of the regression estimated; t = time; ϵ = stochastic. The a-prior expectation $A = \mathrm{A}_1 + \mathrm{A}_2 + \mathrm{A}_3 + \mathrm{A}_4 + \mathrm{A}_5 + \mathrm{A}_6 + \mathrm{A}_7; \alpha > 0; \mathrm{A}_1 > 0; \mathrm{A}_2 < 0; \mathrm{A}_3 < 0; \mathrm{A}_4 > 0; \mathrm{A}_5 > 0; \mathrm{A}_6 < 0; \mathrm{A}_7 < 0$. The following null and alternative hypothesis is tested to answer the study research question. H_0: A causative link exists between global warming and food insecurity; H_1: There is no causative link between global warming and food insecurity. Furthermore, fully modified ordinary least square (FMOLS) estimates the long-run relationship. FMOLS allow for varied country-specific fixed effects [83]. Also, the generalised linear model (GLM) econometric technique [84, 85] is used to forecast the behaviour of various economic variables. GLM effectively addresses the challenges of unbalanced panel data, including individual heterogeneity and autocorrelation. GLM controls for time-invariant factors influencing the dependent variable by incorporating fixed effects. These methods allow for a comprehensive analysis of both within- and between-individual variations, offering more profound insights into the relationships between variables.

3.3. Data, Sources and Description of the Variables

To establish the effect of global warming on food security, this research draws on secondary data sources from the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT), the World Bank's World Development Indicators (WDI), and the United Nations Conference on Trade and Development (UNCTAD). The data covers the period from 2000 to 2020. Also, the panel data analysis includes only 11 out of the 16 West African countries due to data accessibility constraints. The countries analysed are Cape Verde, Burkina Faso, Cote Di Vore, Ghana, Gambia, Niger, Mali, Nigeria, Liberia, Sierra Leone, and Mauritania. The dependent variable is food insecurity (FISEC), and the independent variables are global warming and foreign direct investment. The control variables are food prices, per capita GDP, population growth rate, food import and arable land. All things being equal, each country's agricultural sector is expected to have the potential to boost economic performance and improve living standards. Hence, the study posits that higher levels of adaptation, developing new farming strategies and pesticides, and identifying areas more prone to challenges can increase domestic and regional agricultural productivity. Adesete, Olanubi and Dauda [54] explained that food insecurity, the dependent variable, can serve as a proxy for the prevalence of malnutrition in the economy and can be influenced positively or negatively by various independent variables.

The independent variable, global warming, is proxied by climate change (CLC), which measures the impact of CO_2 emissions levels. Climate unpredictability and inadequate technology in developing countries significantly affect food security. Population growth (PG), measured in millions, limits food availability for consumption, so a mixed correlation is expected[54]. The control variables follow the Affoh et al.'s[58] model and the a-priori expectation is positive, negative and positive. Food prices serve as a proxy for the inflation rate (INF) in each West African country, as an increase in food prices indicates worsening food insecurity due to reduced purchasing power. However, Yan and Alvi[86] opine that the increase in food prices is expected to affect the prevalence of malnutrition positively. Real per capita GDP is a proxy for income (Y). Economic growth, reflected in rising per capita, effectively reduces food insecurity and improves developing countries' quality of life. Thus, increased per capita indicates decreased food insecurity due to higher domestic earnings, which enhance citizens' purchasing power. Mahrous's[63] study explicitly demonstrates the positive interaction between the variables. As foreign direct investment (FDI) in the agricultural sector can reduce malnutrition and increase per capita income, improving food security. FDI inclusion is based on a negative correlation with food insecurity; the higher the FDI in the agricultural sector of an economy, the lower the food insecurity rate. Also, arable land (AL) measured in hectares is expected to affect food security significantly.

3.4. Descriptive Statistics of the Variables

The descriptive statistic in **Table 2** indicates no significant outliers in the dataset. Data dispersion was assessed using standard deviation, with GDP per capita showing the highest variability at 905.7437. The range between the minimum and maximum values for each variable was examined, revealing no notable outliers or data entry errors, which supports the integrity of the dataset. All variables show positive skewness, suggesting right-skewed distributions with longer tails on the right side. This indicates a tendency towards higher values in each variable. Kurtosis analysis further revealed that the prevalence of malnutrition, food imports, and arable land exhibit platykurtic distributions, suggesting fewer extreme values. In contrast, population growth, FDI, CO_2 emissions, and GDP per capita show leptokurtic distributions, indicating more frequent extreme values or outliers[87]. The Jarque-Bera test used to assess the normality of distributions yielded probability values greater than 0.05 for all variables. Despite the observed skewness and kurtosis, this supports accepting the Ho of normally distributed data[88]. The probability of all tests is statistically significant for all variables, and the observed number of samples used differs due to the unbalanced nature of the data.

3.5. Graphical Distribution Trend

The graphical distribution trend in **Figure 2** revealed varied distribution patterns among the countries. Some exhibited right-skewness; while others appeared more normally distributed. These disparities indicate varying degrees of dispersion and potential interrelationships within the dataset.

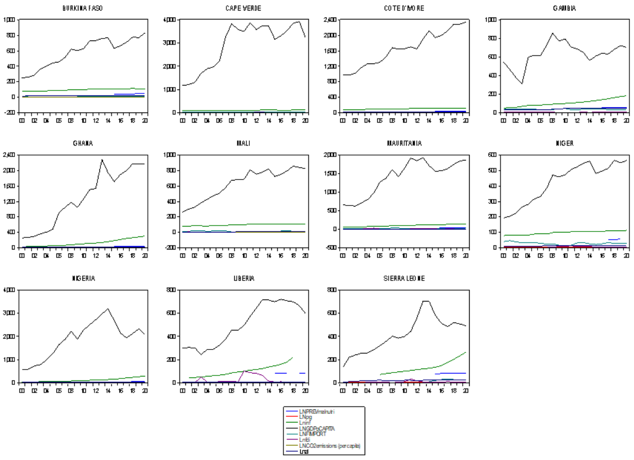


Figure 2. Graphical representation using individual cross-sectional trend.

4. Results Presentation and Discussions

4.1. Correlation Analysis

In this section, the results in **Table 3** show the relationships between the prevalence of malnutrition (LNPREVMALNUTRI) and other key variables: LNPREVMALNUTRI and LNPG (population growth) have a weak

Table 2. Summary of statistics.

Variables	Prevalence of Malnutrition (%)	Population Growth Rate (Millions)	Food Imports (%)	FDI (US$)	CO_2 Emissions (Metric Tons per Capita)	Arable Land (Hectares)	GDP per Capita (US$)
Mean	50.89057	2.705655	22.11630	6.293638	0.349745	15.72527	1122.562
Median	43.00000	2.692873	19.61286	3.944345	0.251684	12.40695	722.1312
Maximum	86.70000	5.785413	45.45473	103.3374	1.074460	44.46640	3928.309
Minimum	26.30000	0.799709	9.778790	−10.95398	0.051341	0.378384	138.7139
Std. Dev.	17.49870	0.771556	8.573703	11.77177	0.272094	12.26510	905.7437
Skewness	0.892136	0.400675	0.644504	5.798659	1.054700	0.943432	1.382080
Kurtosis	2.447403	5.473528	2.436521	40.94045	3.107370	2.909464	4.230588
Jarque-Bera	7.704849	65.06986	15.42008	15149.52	42.93804	34.34635	88.11614
Probability	0.021228	0.000000	0.000448	0.000000	0.000000	0.000000	0.000000
Sum	2697.200	625.0064	4135.747	1453.830	80.79115	3632.537	259311.8
Sum Sq. Dev.	15922.63	136.9188	13672.56	31872.12	17.02811	34599.50	1.89E+08
Obs.	53	231	187	231	231	231	231

positive correlation value of 0.1941; LNPREVMALNUTRI and LNINF (inflation) have a weak positive correlation value of 0.2222. The LNPREVMALNUTRI and LNGDPPERCAPITA have a negative correlation value of −0.5893; and LNPREVMALNUTRI and CO_2_EMISSIONS_PERCAP have a negative correlation of −0.6099. Lastly, LNPREVMALNUTRI and LNFIMPORT (food imports) have a positive correlation value of 0.4053. To ensure the validity of the regression, avoid spurious regression, and address potential multicollinearity issues, a variance inflation factor (VIF) test was performed. The results show a mean VIF of 2.91, as presented in the **Table A1**. Hence, the H_0 could not be rejected as there is no multicollinearity. According to Gold and Rasiah[89] and Neter et al.[90], the acceptable threshold for VIF should be less than 10 (< 10).

4.2. Panel Unit Root Test

Table 4 indicates that the prevalence of malnutrition is non-stationary at its original level based on Levin-Lin-Chu (LLC)[91], Im-Pesaran-Shin (IPS)[92], Fisher-ADF, and PP-Fisher tests[93, 94]. According to the decision criterion, the H_0 is rejected only if the *p*-value (in parenthesis) is below the 5% significance threshold. However, the explanatory variables in the model show mixed stationary levels, except for LNFIMORT, LNFDI, and LNAL, which are stationary at the same level.

Therefore, stationarity tests were conducted at the first difference for non-stationary variables to achieve stationarity and follow an I(1) process across all West African countries studied. The results in **Table 5** indicate the stationarity of all variables except for LNAL–LLC and IPS at the first difference as indicated by the *p*-values from various tests. The consistent I(1) nature of these variables raises the possibility of co-integration. Hence, the Kao co-integration test is done.

4.3. Panel Co-Integration Test

The Kao's[95] co-integration test in **Table 6** reveals a t-statistic of −4.7260 with an associated probability of 0.0000. This *p*-value falls below the conventional 0.05 significance level. Hence, the H_0 is rejected, concluding that a long-run equilibrium exists between the prevalence of malnutrition and the set of predictor variables under examination[96].

4.4. Panel FMOLS

The panel FMOLS estimation in **Table 7** reveals that the coefficients of $LNCO_2$_EMISSIONS, LNPG, LNAL, and LNFIMPORT are statistically significant at 10%, 5% and 1%. Given the logarithmic transformation of variables, these coefficients can be interpreted as elasticities. Specifically, a 1% change in $LNCO_2$_EMISSIONS will lead to an 18.3% change in the prevalence of malnutrition (LNPREVMALNUTRI). The other variables show a positive relationship with the LNPREVMALNUTRI, meaning that increase in these variables lead to higher malnutrition rates. Conversely, LNAL shows a negative coefficient, indicating that a 1% change will decrease the LNPREVMALNUTRI, aligning with *a*-priori expectation. The LNFIMPORT variable shows that as imports increase, malnutrition also increases, suggesting that higher import levels aggravate food insecurity. Furthermore, from **Table 6**, all variables conform to the *a*-priori expectation. Based on these criteria, the FMOLS model can be judged to be statistically fit.

Table 3. Correlation analysis.

Variables	LNprev Malnutri	LNPG	LNINF	LNGDP PCAPITA	LNF IMPORT	LNFDI	LNCO2 EMISSIONS PERCAP	LNAL
LNprev malnutri	1.0000	0.1941	0.2222	−0.5893	0.4053	0.0873	−0.6099	0.4207
LNPG	0.1941	1.0000	−0.1322	−0.7560	−0.0567	−0.1032	−0.7159	0.1008
LNINF	0.2222	−0.1322	1.0000	0.0898	−0.1826	−0.0628	0.0318	0.3763
LNGDPP CAPITA	−0.5893	−0.7560	0.0898	1.0000	−0.1349	−0.0157	0.8535	−0.2808
LNFIMPORT	0.4053	−0.0567	−0.1826	−0.1349	1.0000	0.3643	−0.1401	0.1519
LNFDI	0.0873	−0.1032	−0.0628	−0.0157	0.3643	1.0000	−0.0001	−0.2242
LNCO2 EMISSIONS PERCAP	−0.6099	−0.7159	0.0318	0.8535	−0.1401	−0.0001	1.0000	−0.3983
LNAL	0.4207	0.1008	0.3763	−0.2808	0.1519	−0.2242	−0.3983	1.0000

Table 4. Panel unit root test (level).

Variables	LLC	IPS	FISHER-ADF	PP-FISHER
LNPREVMALNUTRI	2.6787 (0.9963)	2.5334 (0.9944)	10.7849 (0.9033)	15.5121 (0.6266)
LNPG	−0.6444 (0.2596)	0.9739 (0.8379)	31.5047 (0.0862)	32.2718 (0.0729)
LNINF	10.2010 (1.0000)	13.0741 (1.0000)	9.2898 (0.9917)	17.9383 (0.7096)
LNGDPPCAPITA	−2.5645 (0.0052)	0.4467 (0.6725)	14.6229 (0.8779)	23.5363 (0.3720)
LNFIMPORT	−5.4968 (0.0000)	−4.0576 (0.0000)	49.1829 (0.0003)	49.3261 (0.0003)
LNFDI	−1.8751 (0.0304)	−3.0122 (0.0013)	44.2883 (0.0033)	45.4077 (0.0024)
LNCO2_EMISSIONS_	−0.2295 (0.4092)	1.3244 (0.9073)	15.9981 (0.8160)	16.2090 (0.8054)
LNAL	−1.8623 (0.0313)	−2.2077 (0.0136)	44.7881 (0.0028)	98.9613 (0.0000)

4.5. Generalised Linear Model

The generalised linear model is used when the residuals are not normally distributed and the variables are non-linear. GLMs measure continuous data effectively and can handle data that follows normal, gamma, or exponential distributions suitable to model various numeric outcomes. GLMs are a powerful tool in statistics and data analysis that is used to model a wide variety of data types while accommodating the characteristics and distributional properties of the data. It possesses the systematic component($A_1, A_2 \ldots, A_n$), log and random component. As shown in **Table 8**, all variables' probability values are below 0.05 except LNAL and LNFDI. Still, the majority of predictors were found to be statistically significant. This rejection of Equation (15) H_0 implies a strong relationship between independent and dependent variables.

4.6. Panel Granger Causality Test

The Granger[97] causality test states that if $p < 0.05$, the H_0 of no causality is rejected, indicating the existence of causality. Conversely, if $p > 0.05$, heterogeneous causality exists, and the H_0 cannot be rejected. **Table 9** reports that LNPG does not Granger-cause LNPREVMALNUTRI, as the Ho is rejected at $p = 0.0071$, indicating a causal relationship. However, LNPREVMALNUTRI does not Granger-cause LNPG with $p < 0.5734$, meaning the H_0 cannot be rejected, and no causality exists in the direction. LNGDPPCAPITA results show that it does not Granger-cause LNPREVMALNUTRI, and LNPREVMALNUTRI does not Granger-cause LNGDPPCAPITA, as the $p > 0.05$ for both tests. Therefore, the H_0 cannot be rejected, indicating no causal relationship between these variables. Thus, there is no plausible reason for Equation (16) H_0's rejection, indicating heterogeneity within the panel.

4.7. Discussion of Results

To ensure robust results, several tests were conducted to assess data stationarity, including VIF, correlation analysis and multiple unit root tests: LLC, Fisher-type, ADF, PP[93, 94] and the IPS. Subsequently, the Kao's[95] co-integration test determined potential long-term relationships among the variables, and the panel diagnostic test was carried out to examine the robustness of the results. Also, Granger's[97] causality tests were conducted to explore causal linkages. The economic interpretation of this study's findings was based on the magnitude, signs, t-statistics and a-priori expectations of the results from the model specified in Equation (16). The normalised co-integration equation results were given particular attention, with specific interpreta-

Table 5. Panel unit root test (first difference).

Variables	LLC	IPS	FISHER-ADF	PP-FISHER
LNPREVMALNUTRI	−10.3401 (0.0000)	−1.9109 (0.0280)	17.9290 (0.2100)	25.1230 (0.0250)
LNPG	−6.3815 (0.0000)	−5.9241 (0.0000)	78.1362 (0.0000)	90.8625 (0.0000)
LNINF	−1.5786 (0.0572)	−2.0817 (0.0187)	63.8809 (0.0000)	70.4970 (0.0000)
LNGDPPCAPITA	−9.6649 (0.0000)	−8.0983 (0.0000)	100.877 (0.0000)	122.650 (0.0000)
LNFIMPORT	−3.9000 (0.0000)	−8.8368 (0.0000)	108.369 (0.0000)	181.793 (0.0000)
LNFDI	−14.5112 (0.0000)	−14.2202 (0.0000)	180.206 (0.0000)	192.283 (0.0000)
LNCO2_EMISSIONS_	−11.5946 (0.0000)	−10.8590 (0.0000)	134.986 (0.0000)	188.763 (0.0000)
LNAL	4.4987 (1.0000)	13.1399 (1.0000)	114.850 (0.0000)	123.158 (0.0000)

Table 6. Kao co-integration test.

H0 : No Cointegration				**t-Statistic**	**Prob.**
ADF				−4.7260	0.0000
Residual variance				4.1749	
HAC variance				3.9171	
Augmented Dickey-Fuller Test Equation					
Variable	**Coefficient**	**Std. Error**		**t-Statistic**	**Prob.**
RESID (−1)	−1.564280	0.2643		−5.9183	0.0000
D(RESID (−1))	0.766034	0.1809		4.2341	0.0003
R-squared	0.8854		Mean dependent var		0.2398
Adjusted R-squared	0.7888		S.D. dependent var		2.8003
Log-likelihood	−53.7194		Akaike info criterion		4.1274
Durbin-Watson stat	1.7479		Obs.		27

tions and explanations for each significant finding. The Kao co-integration test shows a significant long-term linkage between CO_2 emissions and food insecurity in West Africa. Surprisingly, this positive correlation indicates that increased CO_2 emissions correlate with higher per capita GDP and substantially raise the incidence of malnutrition, thereby worsening food insecurity. The finding confirms Affoh et al.[58] and Abdi, Warsame and Sheik-Ali[55] on East and sub-Saharan Africa but contradicts Mahrous[63] on EAC. This aligns with the first hypothesis, suggesting a causative food insecurity and global warming link, with t-statistic > 2 indicating the significance of global warming as a driver of food security challenges in West Africa.

The analysis shows a negative long-run relationship between food insecurity and FDI inflows in GLM estimates. Theoretically, increased FDI should lead to decreased food insecurity[81]. However, its impact on West African economies is complex. While FDI can stimulate economic growth and agricultural modernisation, it may also prioritise large-scale commercial agriculture over smallholder farmers, exacerbating food insecurity. FDI often focuses on export-oriented crops and monoculture farming, which may not meet the dietary needs of the local population, increasing demand for land and water resources and displacing smallholder farmers. Another plausible reason Fagbemi, Oke and Fajingbesi[56] suggested is the misappropriation of FDI due to the characterised weak institutions of many African countries. Furthermore, the negative correlation between GDP per capita and food insecurity aligns with Ceesay and Ndiaye's[59] findings on The Gambia but negates Pickson and Boateng's[60] findings in Africa. It suggests that increased income will reduce malnutrition rates. This is consistent with the absolute income hypothesis, which posits that consumption rises with income, though not proportionally. However, income inequality exacerbates food insecurity in West Africa; many of the populace are impoverished. As global warming disrupts agriculture and reduces economic opportunities, low-income individuals face heightened vulnerability, spending a substantial portion of their earnings on food and being exposed to price fluctuations due to climate-related supply shortages.

Table 7. Grouped mean panel FMOLS results.

Variables	Coefficient	Std. Error	t-Stat.	Prob.
LNCO2_EMISSIONS	183.938	34.1105	5.3933	0.0167**
LNPG	286.3820	45.2127	6.3341	0.0597*
LNAL	−66.0037	10.9594	−6.0227	0.0047***
LNFIMPORT	4.3814	0.5852	7.4874	0.0445**
R-Squared	0.918504	**Mean Dependent Var**		40.12000
Adjusted R-Squared	0.674014	**Long-Run Variance**		0.339290

Note: * denotes a 10%, ** denotes a 5% and *** denotes a 1% significance level.

Table 8. GLM regression results.

Variables	Coefficient	Std. Error	z-Statistics	Prob.
C	82.0785	14.7035	5.5822	0.0000
LNPG	−12.6336	3.5395	−3.5694	0.0004
LNINF	0.0732	0.0258	2.8362	0.0046
LNGDPPCAPITA	−0.0083	0.0027	−3.0713	0.0021
LNFIMPORT	0.5355	0.1754	3.0541	0.0023
LNFDI	−0.3238	0.3669	−0.8846	0.3764
LNCO2_EMISSIONS	−23.0428	9.0038	−2.5592	0.0105
LNAL	−0.0644	0.1190	−0.5412	0.5884
Mean Dependent Var.	46.3556	**Prob (LR Statistic)**		0.0000
LR Statistic	86.3577	**Log-Likelihood**		−153.5443
Akaike info Criterion	7.179	**Schwarz Criterion**		7.5009
Obs.	45			

Furthermore, the Kao co-integration, FMOLS and GLM results indicate that food imports and insecurity share a positive relationship. This reiterates Adesete, Olanubi and Dauda's[54] findings. It implies that increased food imports correlate with higher food insecurity, underscoring the region's dependency on external markets. While imports can alleviate immediate shortages, they expose countries to global price fluctuations and supply chain disruptions, making them vulnerable to external shocks. Population growth positively correlates with food insecurity in the FMOLS results, which aligns with Abdi, Warsame and Sheik-Ali[55] and Pickson and Boateng's[59] findings on Africa. While this study established a negative effect in reported GLM results, which conforms with Malthus's[74] theory and reinstates Fagbemi, Oke and Fajingbesi's[56] and Adesete, Olanubi and Dauda's[54] findings on sub-Saharan Africa. Therefore, West Africa's high population growth rate intensifies the demand for food resources, increases pressure on arable land, and exacerbates climate change vulnerabilities as Mahrous[63] and Ceesay and Ndiaye[60] confirmed. Inflation (CPI), exacerbated by climate change-induced agricultural disruptions, compounds food insecurity issues, as established in this study and Adesete, Olanubi and Dauda's[54] on sub-Saharan Africa and Tetteh, Baidoo and Takyi[57] on Ghana. Global warming impacts crop yields and agricultural productivity, reducing the supply of staple foods and raising prices. This disproportionately affects vulnerable households with limited financial resources, forcing them to spend much of their income on food. Addressing this requires climate-resilient agricultural strategies and policies that consider regional income disparities.

Lastly, the FMOLS result shows a negative relationship between arable land availability and food insecurity. This finding contradicts Abdi, Warsame and Sheik-Ali[55] but is in consonance with Chandio et al.'s[61] findings where available land correlates negatively with cereal production in Turkey and Pickson and Boateng's[59] in Africa. Increased access to arable land correlates with reduced food insecurity rates. However, arable land in West Africa is diminishing due to urbanisation, deforestation, and soil degradation, posing additional challenges to food security. Importantly, these findings underscore the region's complex global warming, economic factors, and food security interplay, highlighting the necessity for all-encompassing, climate-resilient plans that address environmental and socioeconomic challenges.

Table 9. Panel granger causality results.

Null Hypothesis	Obs.	F-Statistics	Prob.	Decision	Causality
LNPG does not Granger Cause LNPREVMALNUTRI	42	8.08795	0.0071	Reject	Unidirection
LNPREVMALNUTRI does not Granger Cause LNPG		0.32251	0.5734	Accept	Unidirection
LNINF does not Granger Cause LNPREVMALNUTRI	41	0.21103	0.6486	Accept	Unidirection
LNPREVMALNUTRI does not Granger Cause LNINF		12.7566	0.0010	Reject	Unidirection
LNGDPPCAPITA does not Granger Cause LNPREVMALNUTRI	42	2.02579	0.1626	Accept	Independent
LNPREVMALNUTRI does not Granger Cause LNGDPPCAPITA		2.08133	0.1571	Accept	Independent
LNFIMPORT does not Granger Cause LNPREVMALNUTRI	36	9.71156	0.0038	Reject	Independent
LNPREVMALNUTRI does not Granger Cause LNFIMPORT		4.73872	0.0367	Reject	Independent
LNFDI does not Granger Cause LNPREVMALNUTRI	42	3.08807	0.0867	Accept	Independent
LNPREVMALNUTRI does not Granger Cause LNFDI		2.76678	0.1043	Accept	Independent
LNCO2_EMISSIONS__PER_CAP does not Granger Cause LNPREVMALNUTRI	42	0.25760	0.6146	Accept	Independent
LNPREVMALNUTRI does not Granger Cause LNCO2_EMISSIONS__PER_CAP		0.90549	0.3472	Accept	Independent
LNAL does not Granger Cause LNPREVMALNUTRI	42	1.79150	0.1885	Accept	Independent
LNPREVMALNUTRI does not Granger Cause LNAL		1.14137	0.2919	Accept	Independent
LNINF does not Granger Cause LNPG	211	1.51437	0.2199	Accept	Independent
LNPG does not Granger Cause LNINF		0.30967	0.5785	Accept	Independent
LNGDPPCAPITA does not Granger Cause LNPG	220	11.2095	0.0010	Reject	Independent
LNPG does not Granger Cause LNGDPPCAPITA		4.13500	0.0432	Reject	Independent
LNFIMPORT does not Granger Cause LNPG	171	0.02320	0.8791	Accept	Independent
LNPG does not Granger Cause LNFIMPORT		0.07666	0.7822	Accept	Independent
LNFDI does not Granger Cause LNPG	220	0.03803	0.8456	Accept	Independent
LNPG does not Granger Cause LNFDI		1.71088	0.1923	Accept	Independent
LNCO2_EMISSIONS__PER_CAP does not Granger Cause LNPG	220	12.9152	0.0004	Reject	Independent
LNPG does not Granger Cause LNCO2_EMISSIONS__PER_CAP		5.21883	0.0233	Reject	Independent
LNAL does not Granger Cause LNPG	220	0.07096	0.7902	Accept	Unidirection
LNPG does not Granger Cause LNAL		9.29638	0.0026	Reject	Unidirection
LNGDPPCAPITA does not Granger Cause LNINF	211	5.83153	0.0166	Reject	Independent
LNINF does not Granger Cause LNGDPPCAPITA		4.63012	0.0326	Reject	Independent
LNFIMPORT does not Granger Cause LNINF	171	2.19766	0.1401	Accept	Independent
LNINF does not Granger Cause LNFIMPORT		0.01813	0.8931	Accept	Independent
LNFDI does not Granger Cause LNINF	211	0.83794	0.3610	Accept	Independent
LNINF does not Granger Cause LNFDI		0.61262	0.4347	Accept	Independent
LNCO2_EMISSIONS__PER_CAP does not Granger Cause LNINF	211	0.07791	0.7804	Accept	Independent
LNINF does not Granger Cause LNCO2_EMISSIONS__PER_CAP		0.01669	0.8973	Accept	Independent
LNAL does not Granger Cause LNINF	211	11.5126	0.0008	Reject	Unidirection
LNINF does not Granger Cause LNAL		0.65664	0.4187	Accept	Unidirection
LNFIMPORT does not Granger Cause LNGDPPCAPITA	171	0.08384	0.7725	Accept	Independent
LNGDPPCAPITA does not Granger Cause LNFIMPORT		0.10303	0.7486	Accept	Independent
LNFDI does not Granger Cause LNGDPPCAPITA	220	0.35071	0.5543	Accept	Independent
LNGDPPCAPITA does not Granger Cause LNFDI		0.46192	0.4975	Accept	Independent
LNCO2_EMISSIONS__PER_CAP does not Granger Cause LNGDPPCAPITA	220	24.9563	1.E−06	Reject	Unidirection
LNGDPPCAPITA does not Granger Cause LNCO2_EMISSIONS__PER_CAP		0.44744	0.5043	Accept	Unidirection
LNAL does not Granger Cause LNGDPPCAPITA	220	0.17589	0.6753	Accept	Independent
LNGDPPCAPITA does not Granger Cause LNAL		3.61180	0.0587	Accept	Independent
LNFDI does not Granger Cause LNFIMPORT	171	3.96813	0.0480	Reject	Unidirection
LNFIMPORT does not Granger Cause LNFDI		0.23372	0.6294	Accept	Unidirection
LNCO2_EMISSIONS__PER_CAP does not Granger Cause LNFIMPORT	171	0.00824	0.9278	Accept	Independent
LNFIMPORT does not Granger Cause LNCO2_EMISSIONS__PER_CAP		0.02301	0.8796	Accept	Independent
LNAL does not Granger Cause LNFIMPORT	171	0.33375	0.5642	Accept	Independent
LNFIMPORT does not Granger Cause LNAL		1.46606	0.2277	Accept	Independent
LNCO2_EMISSIONS__PER_CAP does not Granger Cause LNFDI	220	0.25224	0.6160	Accept	Independent
LNFDI does not Granger Cause LNCO2_EMISSIONS__PER_CAP		0.84619	0.3587	Accept	Independent
LNAL does not Granger Cause LNFDI	220	1.66378	0.1985	Accept	Independent
LNFDI does not Granger Cause LNAL		0.34449	0.5579	Accept	Independent
LNAL does not Granger Cause LNCO2_EMISSIONS__PER_CAP	220	6.40505	0.0121	Reject	Unidirection
LNCO2_EMISSIONS__PER_CAP does not Granger Cause LNAL		3.56105	0.0605	Accept	Unidirection

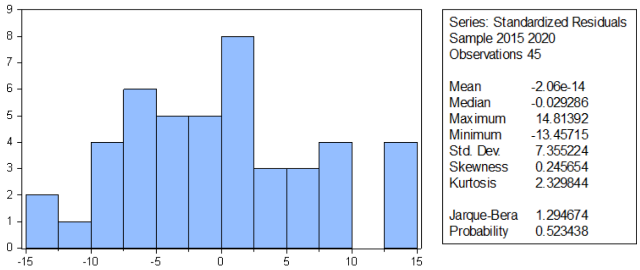
4.8. Panel Diagnostic Test

In **Table 10**, the Wald test[98] results show that each variable in the model is significant at 0.05. Then, H_0 is rejected; it states that each variable equals zero, and the alternative is accepted. Then, the coefficient diagnostic indicates that each variable contributes meaningfully to the model. The Bai, Baltagi and Pesaran's[99] heteroskedasticity Pesaran CD test indicates no cross-sectional dependence among the residuals. Based on the test result, the *p*-value of 0.7002 exceeds the 0.05% level, indicating a lack of evidence to reject the H_0. This suggests that the observations in the panel are independent of each other, enhancing the credibility of the analysis.

Table 10. Panel diagnostic test.

Wald Test:	
F-statistic	198.6759
Chi-square	1589.407
Probability	0.0000
Heteroscedasticity Test: Pesaran CD	
F-statistic	−0.3851
Probability	0.7002

The H_0 in Jarque-Bera states that the residual or discrepancy is normally distributed. The H_1 suggests that the residual or discrepancy is not normally distributed. As shown in **Figure 3**, the residual is more than 0.05 significance level, the probability of the model being beyond the threshold of 0.05. Therefore, the model's residuals are normally distributed. Hence, there is no plausible reason to reject the H_0, affirming the normal distribution of the error term.



```
Series: Standardized Residuals
Sample 2015 2020
Observations 45

Mean          -2.06e-14
Median        -0.029286
Maximum        14.81392
Minimum       -13.45715
Std. Dev.      7.355224
Skewness       0.245654
Kurtosis       2.329844

Jarque-Bera    1.294674
Probability    0.523438
```

Figure 3. Histogram normality test (Jarque-Bera test).

5. Conclusions and Policy Recommendations

The research examined the causal relationship between food insecurity (FISEC) and climate change, determined its long-term impact and assessed its effect on the food basket of nations in West Africa. An empirical panel data study from 2000 to 2020 employed the Kao co-integration, FMOLS, GLM, and panel granger causality techniques to achieve these objectives. The study tested two hypotheses: (1) A causative link exists between food insecurity and global warming; (2) No causative link exists between food insecurity and global warming. The findings from the econometric investigation add scientific value by offering evidence-based insights into the relationship and challenges of food insecurity and global warming in West Africa, aligning with existing literature and integrating ecological and economic theories.

Therefore, to tackle the challenges of the prevalence of malnutrition induced by climate change (CO_2 emissions) in West Africa, this study recommends the following strategies: First, West African nations should establish a Climate-Smart Agriculture Program drawing from Boserup's theory of agricultural intensification. This initiative should prioritise improved water management, soil conservation, and the cultivation of drought-resistant crop varieties, such as maize, millet, sorghum, and cassava. Also, developed nations could offer incentives to protect tropical rainforests, such as the Upper Guinea rainforest, including sections of Nigeria, Guinea, Sierra Leone, Ghana, Togo, Liberia, and Côte d'Ivoire. This approach will help reduce carbon emissions and advance food security, as Coase has theorised. Secondly, a climate-resilience agricultural fund should be established to provide microloans and grants for smallholder farmers to adopt climate-resilient practices and access essential farm inputs. This will expand capital accessibility for farmers and agricultural investors, increase food production, lower sensitivity to external shocks induced by global commodity price shifts, and improve regional food security. Thirdly, West African Nations should focus on policies of improved income consistent with game theory. This would enhance households' purchasing power and capacity, increased food accessibility and lower malnutrition rates. Fourthly, a Climate-Resilient Infrastructure Initiative is crucial. This involves investing in flood-resistant storage facilities, climate-adaptive irrigation systems, and resilient farm-to-market roads in vulnerable areas. Also, a cross-border food reserve system centred on staple crops identified in the literature is essential for managing climate-induced food shortages.

Furthermore, agricultural research should be prioritised to develop techniques for mitigating the impacts of global warming by integrating advanced climate modelling and real-time crop monitoring into the ECOWAS early warning system and focusing on critical indicators like rainfall variability and temperature extremes. This research should focus on educating farmers and agricultural stakeholders about modern farming practices. The region can enhance agricultural productivity and resilience against climate-related challenges by adopting these advanced techniques. The possibility of adopting technology-based farming is presently slim. However, it could become feasible in the near future if West African countries put in place a strong institutional structure that promotes FDI in the agricultural sector. This approach, as Boserup recommended, would improve food security and support the overall economic stability of West African countries in the face of changing environmental conditions. Lastly, the study's limitations include data unavailability in certain West African countries, the potential constraints on generalising region-specific findings, and the exclusion of some socioeconomic factors. Based on these limitations, future research should focus on long-term impact, detailed regional analyses, technological interventions, socioeconomic factors, policy measure assessments, intersectoral linkages, climate adaptation strategies, economic diversification, behavioural studies, cross-disciplinary approaches, and robust monitoring and evaluation frameworks. These efforts will enhance insight into the region's complex global warming and food security interplay.

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Data Availability Statement

All the generated data is available from the sources stated in the manuscript.

Conflicts of Interest

The author declares no conflict of interest.

Appendix A

Table A1. Multicollinearity test with Variance Inflation Factor (VIF).

Variable	VIF	1/VIF
GDPPERCAPITA	5.56	0.179795
CO2_EMISSIONS_PERCAP	5.50	0.181686
PG	3.12	0.320753
ARABLE LAND	1.81	0.554001
INF	1.53	0.655433
FDI	1.45	0.688172
FIMPORT	1.41	0.710515
Mean VIF	**2.91**	

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