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EFFECTS OF GLOBAL WARMING ON FOOD INSECURITY IN SELECTED WEST AFRICAN COUNTRIES: EMPIRICAL ANALYSIS (2001- 2021)

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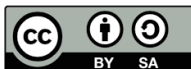
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There is growing evidence that global warming will have an essential negative impact on agricultural yields, succinctly in developing nations. With the greatest levels of poverty and hunger, the continent most at risk from climate change is Africa, as it is seen has a home to low-income earning families. Therefore, this study reflects how global warming affects West Africa's food insecurity between 2001 to 2021. Food insecurity is measured using the prevalence of undernourishment, while global warming is measured with temperature changes. Population growth, food price, income, FDI, and arable land are all included in the econometric model as control variables, and panel ARDL pool mean group (PMG) was employed as the appropriate estimation technique to achieve the study's aim. The PMG regression results show that global warming increases food insecurity in the region during the short and long periods. It is therefore imperative for West African policymakers to show more concern regarding global warming, by establishing initiatives that encourage innovative research or investment in sustainable climate activities and discouragement of activities that contribute to climate warming. Other policy options were further discussed in the study.

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1. INTRODUCTION

The agricultural success of a country depends on its soil fertility, rainfall, and tools adopted. In the listed requirements, soil fertility and rainfall depend on temperature. However, global warming has been increasing the temperature of regions, which has a multiplier effect on rainfall and soil fertility, creating a vacuum that needs to be filled through importation, thereby leading to dependent and food insecure nations. The Intergovernmental Panel on Climate Change (IPCC) announced that the impacted agricultural yields of major crops was caused by global warming, with projected future impacts likely to exacerbate food insecurity in vulnerable regions.¹ The term "global warming" describes the steady rise in temperatures close to the surface of the earth over time. For some earliest centuries backward, this issue has been noted for bringing disruption and alteration in the earth's weather system. Yet, global warming is still regarded as a contentious notion, as science researchers have released numerous facts and assertions to support the motive that the earth temperature is on the peak. East and Southern Africa are predicted to regularly encounter air temperatures of 30° by 2050, and agriculture in East and West Africa may become a riskier endeavour as a result of shorter growing seasons.² On average, the planting season temperature in the majority of Africa's maize-producing regions would be higher than it has ever been by 2025.³

There is growing fact regarding agricultural production to be adversely affected by global warming in developing countries. This poses a danger to rural households, and they will be more susceptible to food insecurity

¹ IPCC, *Climate Change 2014: Impacts, Adaptation, and Vulnerability* (2020) <https://www.ipcc.ch/report/ar5/wg2/> accessed 20 November 2024.

² P Ericksen and others, *Mapping Hotspots of Climate Change and Food Insecurity in the Global Tropics* (CCAFS Report No 5, CGIAR Research Program on Climate Change, Agriculture, and Food Security (CCAFS), 2011).

³ MB Burke and others, 'Shifts in African crop climates by 2050 and the Implications for Crop Improvement and Genetic Resources Conservation' (2009) 19 *Global Environmental Change* 317–325.

if they are unable to manage this risk.⁴ Given that many of the nations experiencing high level of poverty along with hunger are equally very susceptible to the impacts of climate change and the changes that come with it, particularly in Africa, where low-income families predominate, the significance of a climate-resilient food system cannot be overstated.⁵

It has been stated that a country's wealth and economic viability are directly related to its food security status. This idea is concerned with people being in a position to get as many foods as they want at any time. The type of food available, its quality, its supply consistency, and who can obtain it are the key factors to be taken into account in food security challenges.⁶ The WHO states that an individual is expected to consume between 2500-3400 calories and 65 to 86 grams of protein on a daily basis, of which 40 percent of the protein should be sourced from animal products. Hunger and starvation pose severe issues where they interfere with people's livelihood and development in most impoverished countries. In the same vein, eradicating starvation along with guaranteeing every individual's access to quality nutrients still pose a challenge to leaders in many developing countries. The problem is even bigger in Africa as it is home to a large number of hungry people, housing 38% of the overall proportion of people who face hunger globally.⁷

1.1 Statement of the Problem

Nigeria and its selected West African counterpart are agrarian based with agriculture contributing a substantial amount to each country's GDP. Despite each of the selected countries boasting of a huge history in agriculture these countries remain food insecure, with global warming

⁴ FO Aminu, 'Agrarian Households Vulnerability to Food Insecurity in Ogun State Nigeria' (2023) 4(2) *Journal of Agriculture, Food, Environment and Animal Sciences* 214-229.

⁵ HA Owasa and AF Fall, 'Food Security in Developing Countries: Factors and Mitigation' (2024) 13(3) *American Journal of Climate Change* 391-405 <https://doi.org/10.4236/ajcc.2024.133018>.

⁶ World Food Summit, *Rome Declaration on World Food Security* (1996).

⁷ FAO, *Regional overview of food security and nutrition* (2021) <https://openknowledge.fao.org/server/api/core/bitstreams/dca947e8-08ca-47df-a686-48499811a2e5/content/sofi-statistics-africa-2023/prevalence-undernourishment.html>.

being a significant cause. A study by ⁸ revealed that smallholder farmers are vulnerable to climate-related shocks, with an emphasis on food crises in developing countries. These shocks often result in low income, which reduces the level of farmers' ability to apply essential preventive measures in areas that are more likely to become less fertile and dry, or where there is not enough water, as well as in places where this is occurring at high levels. The weather and temperature records are no longer reliable, forcing farmers to make educated guesses about when and method of planting crops due to the continuous change in planting dates and conditions. Thus, as climate change aggravates food security issues by enhancing adverse impacts on the environment and economy at large, policy makers must correctly identify which areas, how, and when to formulate and implement transformative policy.

Based on the body of literature, this paper specifically aimed to investigate how food insecurity is influenced by change in climate from 2001 to 2021, with the West African region being our targeted area, as many research in Africa bordering on how food security and climate variability are related did mostly focus on Sub-Saharan Africa.^(9, 10, 11, 12, 13, 14, and 15) The motive of this research is to account for the differences in the magnitude of atmospheric carbondioxide discharge along with increase in temperature in several Sahel regions, enhancing the insights on abundance of food along with climate change in the region. Also, the few recent research on food security and climate change in Western Africa have focused on

⁸ PK Thornton and others, 'Is agricultural adaptation to global change in lower-income countries on track to meet the future food production challenge?' (2018) 52 *Global Environmental Change* 37-48 <https://doi.org/10.1016/j.gloenvcha.2018.06.003>.

specific countries (⁹ for Benin; ¹⁰ for Cameroon; ¹¹ for Mali; ¹² for Ghana; and ¹³ for Nigeria), while a study by ¹⁴ used production level of specific crops as a food security indicator in the region. Instead, this study will focus on all the countries in the region as a whole using panel data analysis and will measure food insecurity using the prevalence of undernourishment, as it strongly reflects how severe it is to secure food in the region. This study's distinctiveness stems from its endeavour to mainly focus on the Western African region, using the prevalence of undernourishment as a proxy for food insecurity, and finally comparing the results to previous studies in Sub-Saharan Africa. Apart from being more accurate than CO₂ and precipitation, temperature directly reflects the combined effects of CO₂ together with other warming gases on ecosystems and economies. The most prevalent determinant factor in defining climate change harmony and its economic impact is the annual

⁹ ELR Gninkplékpo and others, 'Small ruminant farmers' feeding strategies to cope with Climate Change Across Five Agroecological Zones of Benin, West Africa' (2024) *Heliyon* <https://doi.org/10.1016/j.heliyon.2024.e39834>.

¹⁰ CT Kum and others, 'Soil Greenhouse Gas Fluxes and Net Global Warming Potential from Two Maize Farming Practices in the Bamenda Highlands, Cameroon' (2024) 10 *Heliyon* 15 <https://doi.org/10.1016/j.heliyon.2024.e34855>.

¹¹ A Coulibaly and others, 'Impact of climate change on the distribution of *Bombax costatum* Pellegr. & Vuillet in Mali, West Africa' (2023) 11 *Trees, Forests and People* 100359 <https://doi.org/10.1016/j.tfp.2022.100359>.

¹² P Antwi-Agyei and others, 'Understanding climate services for enhancing resilient agricultural systems in Anglophone West Africa: The Case of Ghana' (2021) 22 *Climate Services* 100218 <https://doi.org/10.1016/j.cliser.2021.100218>.

¹³ KJ Ani, 'The impact of climate change on food and human security in Nigeria' (2021) 14(2) *International Journal of Climate Change Strategies and Management* 148-167 <https://doi.org/10.1108/IJCCSM-11-2020-0119>.

¹⁴ LS Cedric and others, 'Crop Yield Prediction Based on Machine Learning Models: Case of West African Countries' (2022) 2 *Smart Agricultural Technology* 100049 <https://doi.org/10.1016/j.atech.2022.100049>.

change in temperature ^(15,16, and17). Temperature change was thus used in this study as the climate change's stand-in metric.

In addition, the Pool Mean Group (PMG) estimation technique is employed for the study's data analysis. This method addresses the bias caused by heterogeneity in panel estimates while maintaining flexibility by permitting short-term variations in coefficients, even as it enforces long-term coefficient uniformity, thereby ensuring the estimator remains consistent. The remainder of this research work will go as follows: The second section provides an explanation of prominent concepts and a review of relevant literature. Section three gives the categorization of methodology; method and estimation tools used to achieve the research purpose. Section four emphasized on the outcomes of the research empirically, while conclusion along with policy recommendations with regard to the study's observations are made in part five.

2. CONCEPTUAL FRAMEWORK

2.1 Global Warming

The term global warming refers to the natural or, as recent theories have suggested, anthropogenic rise in global mean temperature of the globe. The temperature of the Earth has constantly grown over some time due to actions arising from combustion along with cutting trees, that results in more gases referred to as greenhouses being present within the atmosphere.¹⁸ In contemporary discourse of global warming, heightened atmospheric carbon dioxide levels, methylhydride, laughing gas, along with freons are often linked with increasing global temperatures. As

¹⁵ M Letta and RS Tol, 'Weather, Climate, and Total Factor Productivity' (2019) 73(1) *Environmental and Resource Economics* 283-305 <https://doi.org/10.1007/s10640-018-0262-8>.

¹⁶ M Dell and others, 'Temperature shocks and economic growth: Evidence from the last half century' (2012) 4(3) *American Economic Journal: Macroeconomics* 66-95 <https://doi.org/10.1257/mac.4.3.66>.

¹⁷ M New and others, 'Evidence of trends in daily climate extremes over southern and west Africa' (2006) 111(D14) *Journal of Geophysical Research: Atmospheres* <https://doi.org/10.1029/2005JD006289>.

¹⁸ IPCC, *IPCC Sixth Assessment Report* (2021) <https://www.ipcc.ch/report/ar6/wg1/> accessed 12 March 2025.

people continue in carrying out these actions, there exists more of these gasses which makes the Earth warmer¹⁹, thus posing a risk to the people's lives and home.

A high ozone gas concentration in the earth's uppermost atmosphere, known as the ozone layer, filters potentially dangerous UV light.²⁰ Scientists contend that the depletion of the ozone layer is due to CFCs, which were not discovered until the 20th century. Many scientists think that our planet becomes warmer because of the actions done by people, whereas others think that it is possible but there is no certainty that increased levels of greenhouse gases are the cause of this warming. Warmer temperatures are frequently viewed by many as a typical variation that happens over extended periods of time. They also mention how volcanic eruptions that happen naturally might alter the atmosphere's gas concentrations and weather patterns temporarily.

Many governmental policies that impact people, businesses, and industry have been developed as a result of the volume of study on global warming conducted over the twentieth century. Environmental regulations and their impact on entities are the main sources of contention concerning global warming.

Food Insecurity

Food insecurity is a complex socio-economic condition characterized by uncertain or limited access to adequate food due to poverty, unemployment, or other factors. It often leads to hunger, malnutrition, and negative health outcomes.²¹ A person is deemed food insecure when they do not consistently have food security necessary for healthy advancement, evolution, along with maintaining energetic, fulfilling

¹⁹ UCS, *UCS global warming* (2021) <https://www.ucsusa.org/resources/global-warming> accessed 12 March 2025.

²⁰ United Nations Environment Programme (UNEP), *All about ozone and the ozone layer* (United Nations) <https://ozone.unep.org/ozone-and-you>.

²¹ A Coleman-Jensen and others, *Household food security in the United States in 2021* (United States Department of Agriculture, Economic Research Service, 2022).

human existence within a country. This may be due to lack of food or their inability to acquire the needed food anywhere they go.

Achieving guarantee of food, climate resilience along with its mitigation are three of the biggest issues of the twenty-first century, and agriculture is at the centre of these challenges as vital resources like water, energy, and land become more and more limited.²² In Nigeria, one of the consequences of changing climate due to global warming is flooding. National Emergency Management Agency, a government body, stated in 2022 that due to heavy rains that occurred during the growing season of that year, over 676000 hectares of the agricultural land in Nigeria was ravaged and therefore food production declined drastically thus posing high risk of hunger throughout the nation.²³

Undernourishment is pervasive throughout West Africa and children are vulnerable, particularly in Liberia with 15% of children underweight and 34% of children younger than 5 years old suffering from stunting.²⁴ Generally speaking, stunting affects 30.9% of children under 5 in West Africa, whereas wasting affects 6.9% of the population.²⁵ The Central Intelligence Agency (CIA) estimated Sierra Leone's infant mortality rate at (71.2/1,000) live births in 2024, the highest in West African.²⁶ The average life expectancy in the region is 71.58 years for both sexes, with Cape Verde having the highest life expectancy at birth (76.22 years).²⁷

²² J Beddington and others, 'Achieving food security in the face of climate change: Final report from the Commission on Sustainable Agriculture and Climate Change' (CGIAR Research Program on Climate Change, Agriculture, and Food Security (CCAFS), 2012) <www.ccafs.cgiar.org/commission>.

²³ OCHA, *Nigeria - Floods Response: Flash update 4* (ReliefWeb, 2022) <https://reliefweb.int/report/nigeria/nigeria-floods-response-flash-update-4-last-updated-14-december-2022>.

²⁴ USAID, *Feed the Future Liberia 2015: Zone of Influence Interim Assessment Report* (2016).

²⁵ Global Nutrition Report, *The burden of malnutrition at a glance* (2022) <https://globalnutritionreport.org/resources/nutrition-profiles/africa/western-africa/>.

²⁶ CIA, *Country comparisons – Infant mortality rate* (2024) <https://www.cia.gov/the-world-factbook/field/infant-mortality-rate/country-comparison/>.

²⁷ Worldometer, *Life expectancy of the world population* (2024) <https://www.worldometers.info/demographics/life-expectancy/>.

Agriculture is expected to be crucial in reversing the trend and providing food for the 9.6 billion people who is projected to live on the earth by 2050. It will also generate income, jobs, and environmental benefits.

Table 1 shows the food insecurity trend in West Africa between 2014 and 2022. The nine-year span shows the increasing rate of the level of undernourishment and as well as the food insecurity intensity which is in correspondence with the drop in the production of food standard value. The drop brought about by a number of varying factors with climate (global) warming being a major player, which therefore requires the employment of various ways and policies to reduce the externality created.

Table 1: Trend of food insecurity in West African region.

Years	2014	2015	2016	2017	2018	2019	2020	2021	2022
Prevalence of undernourishment (million)	37.0	37.9	39.2	40.1	42.9	43.8	55.8	60.8	62.8
Severe food insecurity among total population (million)	35.3	39.5	45.7	50.1	53.8	57.9	66.9	71.7	74.3

Source: FAO food security indicators

2.2 Empirical Review

This section of the article seeks to establish how climate change influences food insecurity by drawing from the literature. The extent on how climate change affects food insecurity can therefore be assessed by analyzing four domains of guarantee of food which are; reachability, ease of access, consistency along with utilization.

Aside from detrimental consequences of climate disasters in Nigeria's six geographical zones' guarantee of food, it has also exacerbated the violent clashes over natural resources, threatening human security.²⁰Global Warming will alter the regularity along with harshness of a number of health problems, including zoonotic infections, vector-borne disease, and heat stress, which are particularly dangerous for farmers, agricultural

laborers, and their families.²⁸ Considering this, ²⁹ studied the factors that led to food insecurity within agricultural households in Oyo State's rural areas. Data from 211 respondents in each home were collected for the study using a multi-stage sampling strategy and estimated an ordered logit model. A method used to assess guarantee of food condition of the families was Household Food Insecurity Scale (HFIAS). The study concluded that 12.8 percent of the families achieved food security, whereas the remaining households' levels of food insecurity varied according to factors such as age, education level, gender, farming scale, practical exposure, food expenditure, non-farming revenue, and accessibility to farm advisory programs. In order to make ends meet, the majority of small landowners and peasants farmers now extend their non-farm work.^(30,31 and 32) They also reduce their food consumption and other expenses like education and medical care.^(33and34) Nutritional knowledge can improve farming households' food security through an educational intervention program.²⁹

Increasing temperature was discovered to have negatively impacted maize, wheat, and barley yields in various African regions, leading to potential food shortages.³⁵ Furthermore, research suggests that wealthy households

²⁸ WHO, *Quantitative risk assessment of the effects of climate change on selected causes of death, 2030s and 2050s* (2014).

²⁹ OA Otegunrin, 'Assessing Food Insecurity and its Drivers Among Smallholder farming households in rural Oyo State, Nigeria: The HFIAS Approach' (2022) 11(12) *Agriculture* 1189 <https://doi.org/10.3390/agriculture11121189>.

³⁰ M Fafchamps, 'Vulnerability, Risk Management, and Agricultural development' (Working Paper Series No AfD-0904, *Agriculture for Development*, Center for Effective Global Action, University of California, 2019) 1–29.

³¹ H Kazianga and C Udry, 'Consumption smoothing? Livestock, Insurance, and Drought in rural Burkina Faso' (2016) 79 *Journal of Development Economics* 413–466.

³² J McPeak, 'Contrasting Income Shocks with Asset Shocks: Livestock Sales in Northern Kenya' (2014) 56(2) *Oxford Economic Papers* 263–284.

³³ TR Frankenberger and others, 'Operationalizing Household Livelihood Security: A Holistic Approach for Addressing' (USAID 2000).

³⁴ E Skoufias and A Quisumbing, 'Consumption Insurance and Vulnerability to Poverty: A Synthesis of the Evidence from Bangladesh, Ethiopia, Mali, Mexico, and Russia' (2015) 17 *European Journal of Development Research* 24–58.

³⁵ DB Lobell and others, 'Nonlinear Heat Effects on African Maize as Evidenced by Historical Yield Trials' (2011) 1(1) *Nature Climate Change* 42–45.

can sell off assets to fund current deficits, whereas households with lower incomes are more inclined to reduce their spending.^(36, 38, 39, and 37)

The 2007 IPCC Fourth Assessment estimates that, depending on global warming situations, two hundred to six hundred million individuals may face an acute food shortage by 2080 as a result of climatic variability. Consequently,³⁸ created a total of 15 climate change situations resulting from the comparison of three growth prospects for economy and five potential climate situations. The report highlights that economic development, rather than climate change, will play greater part in shaping global guarantee of food by 2050. However, the study agreed that climate change does aggravate the negative impact of the natural phenomenon. They predict that differences in the quantity of calories accessible to individuals due to varying economic development and weather assumptions scenarios will result in an increase in the number of hungry children. Over the baseline situation, they discovered it rises within the range of 8.5% -10.3%. Additionally, their analyses suggest that altering international food exchange trends could lessen the climate change' impact up to the year 2050.

Anglophone West African countries' policymakers are yet to integrate climate services for informed national and regional policymaking, despite the serious risks posed by global warming on agricultural efficiency and socio-economic advancement in the region.¹⁹ They further concluded that the primary obstacles to publicizing of global warming information services in Ghana are policymakers' lack of climate change awareness, including institutional and workforce capacity limitations.³⁹ Utilizing the multivariable binary and multinomial logistic regression to assess the

³⁶ M Carter and T Lybbert, 'Consumption versus asset smoothing: Testing the Implications of Poverty Trap Theory in Burkina Faso' (2012) 99 *Journal of Development Economics* 255–264.

³⁷ T Kurosaki and M Fafchamps, 'Insurance market efficiency and crop choices in Pakistan' (2012) 67(2) *Journal of Development Economics* 419–453.

³⁸ GC Nelson and others, 'Climate Change: Impact on Agriculture and Costs of Adaptation' (Intl Food Policy Res Inst 2009) 21.

³⁹ V Tarasuk, 'Geographic and Socio-Demographic Predictors of Household Food Insecurity in Canada, 2011–12' (2019) 19(1) *BMC Public Health* 1–12.

geographical and social factors influencing food insecurity within Canadian households from 2011 to 2012. The study measured food accessibility through the 18-item Household Food Security Survey Module and established a variation in the level of food insecurity across the country's region, with the severity depending on the region, income source, educational level and household structure.

A hotter temperature incorporated with intricate precipitation variabilities in 2050 was forecasted by ¹⁵ using 17 Global Circulation Models (GCMs), chosen for their comparative accuracy in modeling Sub-Saharan Africa. The research predicted a rise in childhood malnutrition and reduced food availability due to high food prices resulting from the potential unfavourable agricultural yield caused by adverse climate change.⁴⁰ Adopting FEEDME (Food Estimation and Export for Diet and Malnutrition Evaluation) modeling framework in evaluating how climate change could be responsible for food security crises till 2050. Employing population and land use as control variables, the study established that while climate change might potentially affects food security, positive population growth tends to be the major driver of food insecurity, with an emphasis on the worst impact on countries with projected rapid population growth.

In advising the Sub-Saharan African Region to hasten up in meeting its 13th sustainable development goals (SDGs) of lowering carbon pollution to zero after their research on how the region's food security is affected by climate change between 2000 and 2019 demonstrated a harmful effect of greenhouse gas emission on prevalence of malnourishment. Their research incorporated income and food supply as control variables into their employed generalized method of moments (GMM) model, and both variables appeared to favourably influence food security.

¹⁴ measured climate change with three different proxies – amount of rainfall, carbon dioxide (CO₂), and temperature – and analysed how they are related to three levels of food security (accessibility, utilization, and availability). Employing the pool mean group (PMG) estimation techniques, the study estimated panel data regression on 25 SSA's countries

⁴⁰ A Molotoks and others, 'Impacts of land use, population, and climate change on global food Security' (2021) 10(1) Food and Energy Security 261 <https://doi.org/10.1002/fes3.261>.

between 1985 and 2018 and revealed that food accessibility and availability is positively influenced by rainfall and CO₂ emission, while temperature negatively impacted both. In addition, rainfall demonstrated a significant positive with food utilization, while temperature and CO₂ are insignificantly related to food utilization in the long run, but the impact of CO₂ emission on food utilization was insignificant. To validate the earlier estimation technique's findings, they subsequently utilized dynamic ordinary least squares (DOLS) and fully modified ordinary least squares (FMOLS) regression. Latest research from ¹⁰ and ¹¹ confirm these findings. ¹⁰, Instead of PMG, employed the Panel Corrected Standard Error (PCSE) technique, extended the number of Sub-Saharan African countries to 40, and examined the how food security is connected to climate variability from 2000 to 2021, while ¹¹ employed Cross Sectional – Autoregressive Distributed Lag (CS-ARDL) and Ordinary Least Square regression (OLS) models to estimate data obtained from 26 SSA's countries between 1996 and 2020. Still in Sub-Saharan Africa, ¹² advocate for a good adaptation approach in agricultural food production after establishing an adverse impact of CO₂ emissions on agricultural yield in 32 SSA's countries from 2005-2019, using Two-Step System-GMM estimation and Fixed Effects (FE).⁴¹ considered the growth of the economy, population growth and globalization as the potential factors that affect food production in Nigeria. Data from 1980 to 2022 were estimated using Quantile Autoregressive Distributed Lag (QARDL) and Wavelet Coherence (WTC), demonstrating a detrimental effect of globalization and population growth on food security in the short and long period. Conversely, GDP increases food security in both periods due to improvements in level of income distribution.

⁴¹ JC Onwe and others, 'Food Security in Nigeria Amidst Globalization, Economic Expansion, and Populations Growth: A Wavelet Coherence and QARDL analysis' (2024) 18 *Journal of Agriculture and Food Research* 101413 <https://doi.org/10.1016/j.jafr.2024.101413>.

3. METHODOLOGY

3.1 Model Specification

This research employs ¹³ model to examine the effect of global warming through climate change on the absence of food security in West Africa region. The model was modified by including foreign direct investment (FDI), and availability of arable land, while food supply was excluded as an independent variable from the model since many studies ^(10, 12,14, and 40) often considered it as other measures of food insecurity. The inclusion of arable land was justified with ⁴⁰, who research on how global food security is affected by land use, climate change, and population, while FDI was justified with ⁴¹, who's study considered FDI, the growth of the economy, population growth, and globalization as the potential factors that affect food production in Nigeria and as well as the study conducted by ¹². A negative relationship is expected between arable land availability and food insecurity as the availability of more agricultural land tends to increase food availability for consumption, thereby reducing food insecurity. A quality FDI truly not only increase local productivity but also reduce unemployment in the process, providing stable income for the citizens to access quality food. Hence, FDI is expected to adversely affects food insecurity. This model, which is a replication of the study's broad and explicit objectives, captures the role played by the regressor on food insecurity as shown below;

$$FSEC = \alpha + \beta_1 TEMP_{it} + \beta_2 PG_{it} + \beta_3 FP_{it} + \beta_4 Y_{it} + \beta_5 FDI_{it} + \beta_6 AL_{it} + \xi_{it} \quad (1)$$

Where:

α = Intercept

$\beta_1, \beta_2, \beta_3, \beta_4, \beta_5, \beta_6$ = The regressors' coefficients

ξ =stochastic error term

FISEC = Food insecurity

TEMP = Climate change

PG = Population growth rate

FP = Food price

Y = Income
FDI = Foreign direct investment
AL = Arable land
i = cross-sectional unit (country)
t = time period

3.2 Data Sources

Using panel data analysis, the study analyses annual secondary data on 15 West African countries, ranging between 2001 and 2021. Food insecurity (prevalence of undernourishment) is the dependent variable, while climate change measured by annual change in temperature is the independent variable. The control variables included population growth, income, food price, FDI and availability of arable land. All data were sourced from FAOSTAT and the World Bank World Development Indicators Database. All variables are utilized in their original form, and an overview of their descriptions is provided in Table 2.

Table 2: Variables Description, Expected Signs and Sources

Variable	Symbol	Metric	Expected Sign	Source
Dependent variable				
Food Insecurity	FISEC	Prevalence of undernourishment (% of population)		Food and Agriculture Organization Corporate Statistical Database (FAOSTAT)
Independent variable				
Global Warming	TEMP	Temperature change with respect to a baseline climatology.	Positive	Food and Agriculture Organization of the United Nations (FAO). 2022. FAOSTAT Climate Change, Climate Indicators, Temperature change. License: CC BY-NC-SA 3.0 IGO. Extracted from: https://www.fao.org/faostat/en/#data/ET . Accessed on 2023-03-28.
Population Growth	PG	Population growth (annual %)	Positive	

Food Price	FP	Inflation, consumer prices (annual %).	Positive	World Bank World Development Indicators Database
Income	Y	GDP per capita (constant 2015 US\$)	Negative	
Foreign Direct Investment	FDI	Foreign direct investment, net inflows (% of GDP)	Positive/Negative	
Arable land	AL	Arable land (% of land area)	Negative	

Sources: Authors' Computation

3.3 Estimation Technique

The results of testing panel data indicate that the series under consideration are of different order – some being I(0) and some I(1). Based on this, it became apparent that the Panel Autoregressive Distributed Lag (Panel-ARDL) method, which was created by Pesaran, Shin, and Smith in 1999 and 2001, should be used to analyze the data. Pool mean group (PMG) was specifically used since it provides a balance between Dynamic Fixed Effect (DFE) and MG (mean group) estimators, combining pooling and averaging.⁴² For both stationary and non-stationary regressors, the PMG model's coefficients are asymptotically normal and consistent under certain regularity criteria.⁴³

By permitting short-term coefficient heterogeneity, the PMG model is flexible enough to permit long-term coefficient homogeneity while also consistently correcting the panel estimation's heterogeneity.¹⁴ Under the general panel ARDL model framework, the expression for equation (1) is as follows:

$$FISEC_{it} = \alpha_i + \sum_{l=1}^m \lambda_{ij} FISEC_{i,t-l} + \sum_{l=0}^n \gamma_{ij} X_{i,t-l} + E_{it} \quad \dots\dots\dots(2)$$

⁴² MN Pesaran and others, 'Pooled Mean Group Estimation of Dynamics Heterogeneous Panels' (1999) 94(446) Journal of the American Statistical Association 621-634.

⁴³ P Pedroni, 'Panel Cointegration: Asymptotic and Finite Sample Properties of Pooled Time Series Tests with an Application to the PPP Hypothesis' (2004) 20(3) Econometric Theory 597-625.

Reparametrizing the model as a Panel Error Correction Model (PECM) system, we have:

$$\text{FISEC}_{it} = \theta_i(\text{FISEC}_{i,t-1} - \varphi_i X_{i,t-1}) \sum_{l=1}^{m-1} \lambda^*_{ij} \Delta \text{FISEC}_{i,t-j} + \sum_{j=0}^{n-1} \gamma^*_{il} \Delta X_{i,t-l} + E_{it} \dots\dots\dots(3)$$

Where;

FISEC_{it} = The dependent variable for country i at time t

$X_{i,t-1}$ = The $(k \times 1)$ vector of independent and control variables for country i at time t

λ = The dependent variable's coefficient in the short run

γ = The independent and control variables' coefficient in the short run

m = The dependent variable lag

n = The independent variables lag

φ_i = The long-run coefficients

α_i = The country-specific intercept

E_{it} = combined time /country/cross-sectional error term

θ_i = The error correction term (ECT)

The optimal lag lengths for the n and m in the model are determined using the Schwarz Information Criterion (SC), with lower SC values indicating a better fit. SC and Akaike Information Criterion (AIC) deal with issues of overfitting in the models by adding a term that penalizes the use of more model parameters, however, due to SC's greater sensitivity to sample size, SC has higher relative weights of the penalty term, especially when the sample sizes exceed seven.⁴⁴ The sustained equilibrium connection between the variables is established as the error correction term (θ_{it}) coefficient is significantly negative.

⁴⁴ P Stoica and Y Selen, 'Model-order Selection: A Review of Information Criterion Rules' (July 2004) IEEE Signal Processing Magazine 36–47 <https://doi.org/10.1109/MSP.2004.1311138>.

4. RESULTS AND DISCUSSIONS

4.1 Descriptive Statistics and Correlation Analysis

Table 3 and 4 show the summary statistics of the study, where the prevalence of undernourishment for the 15 West African countries is 17.44% on average, within a wide range of 50.4% at maximum and 3.8% at minimum. This significant gap is consistent with a high standard deviation of 9.43%, suggesting substantial variations in food insecurity's intensity across the countries. Probably, this is explainable through the notable disparity in the arable land and GDP per capita among the countries, as the GDP per capita and arable land range between \$354.01 to \$3,667.06 and 3.7% to 48.7%, respectively, with a high standard deviation of \$734.6 and 12.47%. \$1,089.8 is the region's GDP per capita on average, which is 112.5% and 97% lower than Africa's GDP per capita recorded in 2014 and 2022, respectively, indicating a low level of individual income that may limit access to a diet sufficient for good health. Within the region, there is also variation in GDP per capita, with only Cape Verde, followed by Nigeria, Côte d'Ivoire, Ghana, and Senegal, respectively, exceeding the regional average GDP per capita among the 15 countries during the study period. Conversely, Liberia and Sierra Leone have extremely low GDP per capita at \$643.4 and \$553.9, respectively, and the highest percentages of undernourished populations, at 35.1% and 33.3%.

The average temperature change for the region is 1.14°C, which is nearly equal to the 1.1°C average global temperature rise since 1880. The standard deviation of 0.33°C indicates an extremely low variation in their temperature, probably due to the similarities in their weather pattern or greenhouse activities. Similarly, there is low variation in population growth, although the regional population growth rate increases by an average of 2.66% per year.

The overall average consumer price inflation is 5.58%, with an extremely high standard deviation of 6.35%, indicating considerable fluctuations in food prices across the region. With a maximum net FDI inflow of 103% and a minimum net FDI outflow of -2.57%, this extreme variation results in an average FDI of 4.7% of GDP, which may not effectively contribute

to the region's food security. The PMG estimation's results will provide further clarification and validation of this analysis.

The variables' association is displayed in Table 5, where temperature, GDP per capita, population growth, and arable land showed an inverse connectivity with food insecurity, while consumer price inflation and FDI are positively correlated with food insecurity. However, temperature, population growth, and consumer price inflation were statistically insignificantly related to food insecurity. Furthermore, the coefficients of the variables are in the moderate range, indicating no multicollinearity problem between the variables.

Table 3: Summary Statistics

	FISEC	Temperat ure	Populatio n Growth	Food Prices	Income	FDI	Arable Land
Mean	17.43714	1.137723	2.662888	5.581066	1089.814	4.661789	19.29511
Median	15.40000	1.145000	2.647942	3.563515	723.5042	2.511457	16.09619
Maximum	50.40000	2.083000	5.785413	41.50950	3667.057	103.3374	48.72219
Minimum	3.800000	0.283000	0.799709	-3.502586	354.0894	-2.574579	3.712537
Std. Dev.	9.429061	0.330021	0.685649	6.346164	734.6262	10.20923	12.47330
Observati ons	315	314	315	301	315	315	315

Sources: Authors' Computation

Table 4: Within Countries Averages

<i>I D</i>	<i>Country</i>	<i>FISEC</i>	<i>TEMP</i>	<i>Populatio n Growth</i>	<i>Food Prices</i>	<i>Income</i>	<i>FDI</i>	<i>Arable Land</i>
1	Benin	10.5	1.02938	2.94801	2.16904	1011.51	1.03389	23.4185
2	Burkina Faso	15.8143	1.02914	2.95481	2.07627	583.722	1.04872	18.7993
3	Cape Verde	16.7524	0.9372	1.18658	1.77126	2941.05	6.33922	12.1943
4	Cote D'Ivoire	14.0905	1.17067	2.34303	2.22238	1786.64	1.23819	9.85325
5	Gambia	17.2762	1.3689	2.89435	6.68417	649.294	5.19123	37.9447
6	G-Bissau	25.9429	1.3439	2.45406	1.94347	577.199	1.71942	10.3807
7	Ghana	8.49524	1.12076	2.44081	14.851	1497.23	4.95419	18.7803
8	Guinea	14.2714	1.20781	2.30643	14.8817	751.813	3.69358	11.9488

9	Liberia	35.0762	1.14295	2.78252	10.554	643.445	23.6555	4.78564
10	Mali	8.85714	1.1499	3.17769	1.94486	699.526	2.94262	5.35671
11	Niger	16.0286	1.04462	3.69513	1.98662	451.393	4.36456	12.4843
12	Nigeria	9.3619	1.0301	2.6295	12.6004	2266.19	1.45317	39.6543
13	Senegal	12.5476	1.37386	2.63508	1.68838	1212.15	2.71656	17.5179
14	Sierra Leone	33.3333	1.078	2.89571	10.0007	553.878	7.0467	20.125
15	Togo	23.2095	1.0291	2.59961	2.32323	722.16	2.52928	46.1832

Sources: Authors' Computation

Table 5: Correlation Matrix

Variable	Prevalence of Undernourishment (FISEC)	Climate Change (TEMP)	Population Growth (PG)	Consumer Price Inflation (FP)	GDP per capita (Y)	FDI	Arable Land (AL)
FISEC	1.0000						
TEMP	0.0031	1.0000					
PG	-0.0751	0.0151	1.0000				
FP	0.0276	-0.0439	-0.0869	1.0000			
Y	-0.3176***	-0.0999	-0.6211***	0.0258	1.0000		
FDI	0.3341***	-0.0181	0.0179	0.0982*	-0.0762	1.0000	
AL	-0.1806***	0.0131	0.0312	0.1173***	0.1419**	-0.1635***	1.0000

Sources: Authors' Computation ***, **, and * represents correlation coefficients significant at the 1%, 5%, and 10% level.

4.2 Panel Unit Root Test

Prior to using the PMG estimate approach, it is crucial to ascertain the variables' order of integration by looking at their stationary nature, as well as to avoid spurious regression results, which can lead to biased analysis. Thus, the study employed Lm-Pesaran-Shin and Levin-Lin-Chu to conduct the panel unit root tests. These tests operate under the assumption that the panels exhibit a unit root as the null hypothesis, while the alternative asserts their stationarity. A p-value below 0.05 at a 5% significance level leads to rejecting the null hypothesis in favor of stationarity.

Table 5 presents the two-unit root tests' results, indicating that temperature, and food price, are stationary at levels at 1% significance level, whereas at 1st difference, food insecurity, population growth, income, FDI and arable land are stationary. Since the variables combine both I(0) and I(1), this confirm the appropriate use of panel ARDL PMG estimation technique.

Table 6: Panel Unit Root Tests Results

Variables	Level/1st Difference	Levin-Lin-Chu		Im-Pesaran-Shin		Stationarity	Order Of Integration
		Statistic	P-value	Statistic	P-value		
FISEC	Level	2.02773	0.9787	2.63396	0.9958	NS	I(1)
	1st Difference	0.36154	0.6412	-3.11490	0.0009	S	
TEMP	Level	-7.77422	0.0000	-5.21577	0.0000	S	I(0)
PG	Level	1.86606	0.9690	0.21145	0.5837	NS	I(1)
	1st Difference	-12.2876	0.0000	-9.97875	0.0000	S	
FP	Level	-4.91613	0.0000	-4.64668	0.0000	S	I(0)
Y	Level	0.73859	0.7699	0.72386	0.7654	S	I(1)
	1st Difference	-9.54306	0.0000	-8.67573	0.0000	NS	
FDI	Level	0.47073	0.6811	-1.43704	0.0754	NS	I(1)
	1st Difference	-12.7728	0.0000	-12.2569	0.0000	S	
AL	Level	-1.39543	0.0814	-1.77983	0.0376	NS	I(1)
	1st Difference	-14.7357	0.0000	-14.3866	0.0000	S	

Source: Authors' computation

4.3 Optimal Lag Selection

Table 6 shows the results of different criteria (LogL, LR, FPE, AIC, SC, and HQ) for identifying the model's ideal lag length. The first-degree order has the lowest SC value, suggesting it is the model ideal lag length.

This choice minimizes the SC, suggesting that it provides the best fit while avoiding overfitting, thus offering a robust model for this research analysis.

Table 7: Lag Order Selection Criteria

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-6595.928	NA	3.69e+11	46.49949	46.58943	46.53555
1	-4096.263	4858.503*	11804.75*	29.24129*	29.96081*	29.52976*

Source: Authors' Computation

* indicates lag order selected by the criterion

4.4 Regression Results of the Panel ARDL

Table 8: Pool Mean Group (PMG) Estimated Results

Dependent variable: FISEC (Prevalence of Undernourishment)	
Variables	Long Run Results
Temperature (TEMP)	1.527***
Population Growth (PG)	-0.284***
CPI Inflation (FP)	0.177***
GDP per Capita (Y)	0.00506***
FDI	0.0493***
Arable Land (AL)	0.854***
Short Run Results	
Error correction term (ECT)	-0.178*
D. Temperature (TEMP)	0.325**
D. Population Growth (PG)	4.230
D.CPI Inflation (FP)	-0.0723
D. GDP per Capita (Y)	-0.00740*
D.FDI	-0.0364
D. Arable Land (AL)	2.387

Sources: Authors' Computation ***, **, and * represents correlation coefficients significant at the 1%, 5%, and 10% level.

PMG was used to estimate the panel ARDL model (1,1,1,1,1) selected based on Schwarz criterion (SC). Table 5 presents the panel ARDL long run and short run results. Conforming to our prior expectation, temperature changes positively influence undernourishment in both periods, indicating the nutritional deficiency caused by an increase in global warming. A long term temperature tends to affect the quality, safety, and shelf life of food, thereby reducing the nutritional quality of food. West African countries are highly susceptible to undernourishment, due to their lack of adequate food storage facilities to avoid a nutritional decline in their food consumption, thereby explaining the long run positive influence of temperature shift on the region's food insecurity. In addition, a sudden increase in temperature contributes to immediate food shortages and undernourishment as it negatively impacts crop growth and yield, justifying the short run positive relationship between temperature and food insecurity in the region. The report of ¹⁹ on the negligible attitude of West African policymakers toward climate variability and those by ¹⁰, ¹³, ¹⁴, ¹⁵, and ⁴² all agree that agricultural growth and productivity are negatively impacted by climate change.

All the control variables have long run significant positive relationship with undernourishment, except for population growth which surprisingly exhibits a significant negative influence on undernourishment. A United Nations (UN) report claims that, sub-Saharan Africa has 70% of its population under the age of 30.⁴⁵ Probably, a higher working-age youth arising from an increasing population can contribute to a decline in undernourishment through increases in economic productivity, which thereby raises individual income levels. However, the negative relationship between population growth contradicts our prior expectations, the studies of ¹³, ⁴⁰, ¹⁴ and the Malthusian population theory ⁴⁶, who posited the possibility of food shortages that accompanies

⁴⁵ United Nations Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries, and Small Island Developing States, 'Young people's potential is key to Africa's sustainable development' (United Nations) <https://www.un.org/ohrlls/content/young-peoples-potential-key-africas-sustainable-development>.

⁴⁶ TR Malthus, *An Essay on the Principles of Populations* (Project Gutenberg, 1798) <https://www.gutenberg.org/ebooks/4239>.

unchecked exponential growing population. Other surprising results that contradict our prior expectation are the long run significant positive in FDI, GDP per capita, and availability of arable land on food undernourishment. Although the results show that GDP per capita reduces undernourishment in a short period, probably due to the immediate impact of the increase in personal income, arising from positive economic growth. However, this consequentially raises the inflation rate, which positively affects food prices, thereby explaining how GDP per capita and food prices positively influence long-term food insecurity in the region. ¹⁰, ⁴¹, and ¹⁴ present findings that support the long-term positive effect of food prices on food insecurity, while the study by ⁴¹, ¹², and ¹³ support the short-term positive influence of GDP per capita on food insecurity. However, ⁴¹ and ¹⁴ argue against the long-term positive impact attributed to GDP per capita in reducing food insecurity. In addition, the results demonstrate that population growth, food prices, FDI, and arable land are unrelated to food insecurity in the short run.

Similarly, FDI inflow into West African countries is largely concentrated in the manufacturing, construction, and oil and gas industries, which has led predominantly agricultural economies into food import-dependent nations due to minimal investments in the sector. Development in other sectors without corresponding growth in the agricultural sector, will only cause an immediate increase in national income, which in turn causes inflation in the long period due to food shortage. Moreover, due to higher profits, farmers now prefer selling to processing industries or exporting their output rather than selling directly to the local food market, which further exacerbates food insecurity. Furthermore, the majority of arable land that is currently accessible has been purchased for the construction of buildings (such as factories, businesses, and residences) or retained for real estate speculation, with little regard for farming. These factors explain the positive effects of FDI and arable land availability on food insecurity in the region. Santangelo (2018) report that FDI in land decreases cropland in developing countries, which results in food

insecurity⁴⁷, further affirms this finding. However, the study by ⁷ indicates that land use does not significantly contribute to food insecurity.

Notably, temperature change appears to be the highest factor affecting food insecurity in this region, as a 1°C increase in temperature worsens food insecurity by 1.53% of the total population, indicating the severe impact of global warming on the region's food security. Lastly, the ECM coefficient, calculated as -0.178 and significant at the 10% level, signifies that the resolution rate of discrepancies from the long-term equilibrium is 17.8% per year. This provides compelling evidence that the variables are cointegrated.

5. CONCLUSION

This study assesses how global warming affects West Africa's food insecurity between 2001 to 2021. The prevalence of undernourishment was used to measure food insecurity, while temperature change was employed as a proxy for global warming. Population growth, food price, income, FDI, and arable land are all included in the econometric model as control variables, and panel ARDL was employed as the appropriate estimation technique to achieve the study aim. The PMG regression results show that global warming increases food insecurity in the region during the short and long periods, and this study regards it as the highest contributor to the region's food insecurity. Although income appears to reduce food insecurity in the short run, it is surprising that income, FDI, and arable land exacerbate food insecurity in the long run, while population growth reduces this impact.

Regarding these results, West African countries' policymakers should show more concern for global warming by raising awareness and warning the people about the consequential effects of climatic changing activities on food security. Moreover, initiatives that encourage innovative research or investment in sustainable climate activities should be established, while

⁴⁷ GD Santangelo, 'The impact of FDI in Land in Agriculture in Developing Countries on Host Country Food Security' (2018) 53(1) *Journal of World Business* 75-84 <https://doi.org/10.1016/j.jwb.2017.07.006>.

encouraging the people to disembark on activities that contribute to global warming. Despite that population growth has insignificant positive influence on food insecurity, its negative long run effects suggest that the region should continue to maintain a moderate population growth that breeds a higher percentage of the youth population. To curb FDI and economic growth which later suscept the region to food insecurity through inflation, heavy investments should be made on agricultural productivity to ensure balancing the region's economic development. The study only employed temperature as the climate change's stand-in metric, thus, further studies can adopt other proxies like rainfall and carbon dioxide (CO₂) to examine how global warming affects West Africa region's food insecurity.