

THE IMPACT OF CLIMATE CHANGE ON FOOD SECURITY: EVIDENCE FROM WEST AFRICAN COUNTRIES

A Thesis

**Submitted to the Master's Study Program of Economics at the Faculty
of Economics and Business in partial fulfillment of the requirements
for the degree of**

Master of Arts (M.A.)



by:

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UNIVERSITAS ISLAM INTERNASIONAL INDONESIA

DEPOK

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ABSTRACT

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The global efforts to eradicate hunger and food insecurity by 2030 which is goal number 2 of the United Nations sustainable development goals is being undermine by the adverse impact of climate change on food security. Developing countries especially in West Africa are among the most vulnerable countries to climate change mainly due to the sub-region's dependance on rainfed agriculture for livelihood. Based on this background, this study examines the impact of climate change on food security in West African climate vulnerable countries while controlling macroeconomic factors. To achieve our aim, we employ panel data model to analyze the study comprising 10 West African climate vulnerable countries over the period 2000 to 2020. Findings from model 1 of the study reveal that, rainfall, GDP, trade openness, and cereal production have positive significant impact on food availability; whereas, average temperature, drought, greenhouse gas emission, and population density have adverse effects on food availability. Additionally, results from model 2 indicate that, rainfall, greenhouse gas emission, GDP, political stability, and cereal production improve food accessibility. In contrast, average temperature, drought, and food prices are found to have negative impact on food accessibility. Our findings implies that while rainfall improve food security, other climatic factors such as average temperature and drought drastically reduce food security. Besides, the macroeconomic factors influence food security. These findings are relevant for policymakers and stakeholders to help in achieving food security and sustainable economic growth and development in the sub-region. Therefore, among the policies, we suggest governments in West African countries to reduce carbon emission, increase agricultural investment, provide farmers with drought resistance crops, promote free trade within the sub-region, and stabilize food prices. Finally, the study is limited by unavailability of complete data. Again, the study did not include other pillars of food security such as food utilization and stability in examining the impact of climate change on food security. Therefore, we recommend future research to incorporate these limitations.

Keywords: Climate change; food security; food availability; food accessibility; West African climate vulnerable countries; sustainable economic growth and development

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ABBREVIATION DIRECTORY

UNSDGs	: <i>United Nations Sustainable Development Goals</i>
IPCC	: <i>Intergovernmental panel on climate change</i>
UNFCCC	: <i>United Nations Framework Convention on Climate Change</i>
FAO	: <i>Food and Agricultural Organization</i>
AU	: <i>African Union</i>
ECOWAS	: <i>Economic Community of West States</i>
GHI	: <i>Global Hunger Index</i>
SSA	: <i>Sub-Sharan Africa</i>
UN	: <i>United Nations</i>
WB	: <i>World Bank</i>
WDI	: <i>World Development Indicators</i>
CRU	: <i>Climate Research Unit</i>
GDP	: <i>Gross Domestic Product</i>
GRDP	: <i>Gross Regional Domestic Product</i>
FED	: <i>Food Entitlement Decline</i>
FAD	: <i>Food Availability Decline</i>
FE	: <i>Fixed Effect</i>
RE	: <i>Random Effect</i>
OLS	: <i>Ordinary Least Square</i>
GHG	: <i>Greenhouse gas emissions</i>
CO2	: <i>Carbon emissions</i>
FPI	: <i>Food Production Index</i>
AGDPpc	: <i>Agricultural Gross Domestic Product</i>

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CHAPTER 1

INTRODUCTION

Agriculture plays an important role in driving economic growth and development in many countries, especially in developing countries of Asia and Africa. This is because the sector does not only contribute to food security through the production of crops, livestock rearing and other farming activities, but it also serves as a source of income for many people. In Africa, particularly Sub-Saharan Africa (SSA), agriculture is regarded as the backbone of the economies of those countries due to its significant contribution to economic growth and development. This sector accounts about 14% of Sub-Saharan's Gross Domestic Product (GDP) (Affoh et al., 2022). Besides, in 2019, about 52.9% of the labour force in SSA earned their living through agriculture (Affoh et al., 2022). According to Food and Agricultural Organization (FAO) (2008), agriculture serves as the main source of living for 36% of global labour force. In Asia and the Pacific, 40% to 50% of the workforce income depend on agriculture; whereas in Sub-Saharan Africa over 60% of the working-class source of livelihood is directly or indirectly from agriculture (FAO, 2008), which contributes to about third of Africa's GDP. However, of recent, agricultural production in the West African region is confronted with crises such as climate change, insurgences, and economic shocks. Thus, these pose a threat to food security in the region. Hence, improvement in agriculture will help in reducing hunger, poverty, and unemployment which will ultimately enhance economic growth and development.

1.1 Background of the study

1.1.1 Food Security

Food security is an essential element to human's life as it contributes immensely in eradicating hunger and malnutrition, hence, which will in turn improve the wellbeing of the people which could help to drive economic growth and development. In today's world, as global hunger is on the rise, food security stands to be a major concern for global leaders and international organizations. Due to the negative impact of climate change on food security, it has negatively affected economic growth and development in most developing countries, particularly those depending on rainfall for their crop and livestock production. For this reason, eradicating hunger has become a priority for governments and international organizations, as it is amongst the 2030 United Nations' sustainable development goals (UNSDGs). For this, scholars and institutions have tried to conceptualise food security. However, the most widely used definition is the one that was given during the world food

summit in Rome in November 1996. It states that “food security exist when all the people at all times have physical or economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life” (FAO, 2008). Going by this definition, it implies that food security is based on four pillars: food availability, accessibility, utilization, and stability (Mahrous, 2019). Yet, when any of these pillars is affected, it hinders food security.

Moreover, moderate rainfall and temperature positively enhance crop and livestock production hence, boosting agricultural production and food security. In contrast, climate change shocks such as drought, high temperature, sea level rise, flooding and so forth are major challenges to food security, as these shocks lead to low production. This could be confirmed in desert regions like Sub-Saharan Africa where long-dry spell of drought couple with an increase in temperature hinders food production, which in turn, leads to shortage of food supply in the market as a result causing a spike in food prices (Soumbara & El Ghini, 2023). Additionally, on the global front, despite the outbreak of covid-19 adversely affecting the global economy, as it disrupts the food supply chain which leads to a rise in food prices, for which, global leaders and international organization making serious efforts in restoring and recovering economies from the impact of covid-19, however. The challenges of climate change still remain as major concerns to global food security. For instance, in 2022, it was estimated that about 783 million people around the globe were exposed to hunger. Besides, it is projected that, 600 million would still face food insecurity in 2030, in which majority will come from developing countries particularly in Asia and Africa. This is because hunger is still on the increase in these continents, thus, causing a concern for the achievement of SDG number 2 (zero hunger by 2030) (FAO et al., 2023).

Yet, developed countries in Europe and America compared to countries in Asia and Africa, are less affected by the global food security crisis. Owing to the fact that, European countries have more favourable climatic conditions which makes it possible for them to produce large variety of agricultural products to feed their people and even export the surplus to other countries with low production. Basically, the climate in Europe is classified into two: the first is marine west coast covering countries such as Poland, Germany and Switzerland, and the second is the Mediterranean countries such as Italy, Spain, France, Greece and Portugal. Thus, each of these climatic conditions support the production of varieties of agricultural products (FAO et al., 2023).

Meanwhile, while significant efforts have been made in minimizing hunger in some parts of Asia, and Latin America, hunger is still increasing in Western Asia, the Caribbean, and the whole of Africa (FAO et al. 2023). The report further indicates that, the African continent is observing a rise in hunger by about 20% since 2021. Whereas in Asia and Latin America, the prevalence of undernourishment has significantly dropped from 8.8% and 8.5% as in 2021 to 7% and 6.5% as in 2022 respectively (FAO et al., 2023).

Moving forward, figure 1.1 below shows the global hunger index across regions in the world. From the Global Hunger Index (2023), it indicates that SSA and South Asia have high hunger level compare to Europe and central Asia. This shows that developing countries are facing higher food insecurity than developed countries. Likewise, in Figure 1.2 showing the global hunger index for West African countries in 2023, shows that Niger’s hunger level is at an alarming state as it has the highest hunger index (31.5) among West African countries; whereas the hunger index for Benin, Burkina Faso, Ivory Coast, Guinea Bissau, Guinea, Liberia, Mali, Mauritania, Nigeria, and Togo are consider to be at a serious level while the rest of the countries such as the Gambia, Senegal, Ghana, and Cabo Verde have moderate hunger index within the sub-region.

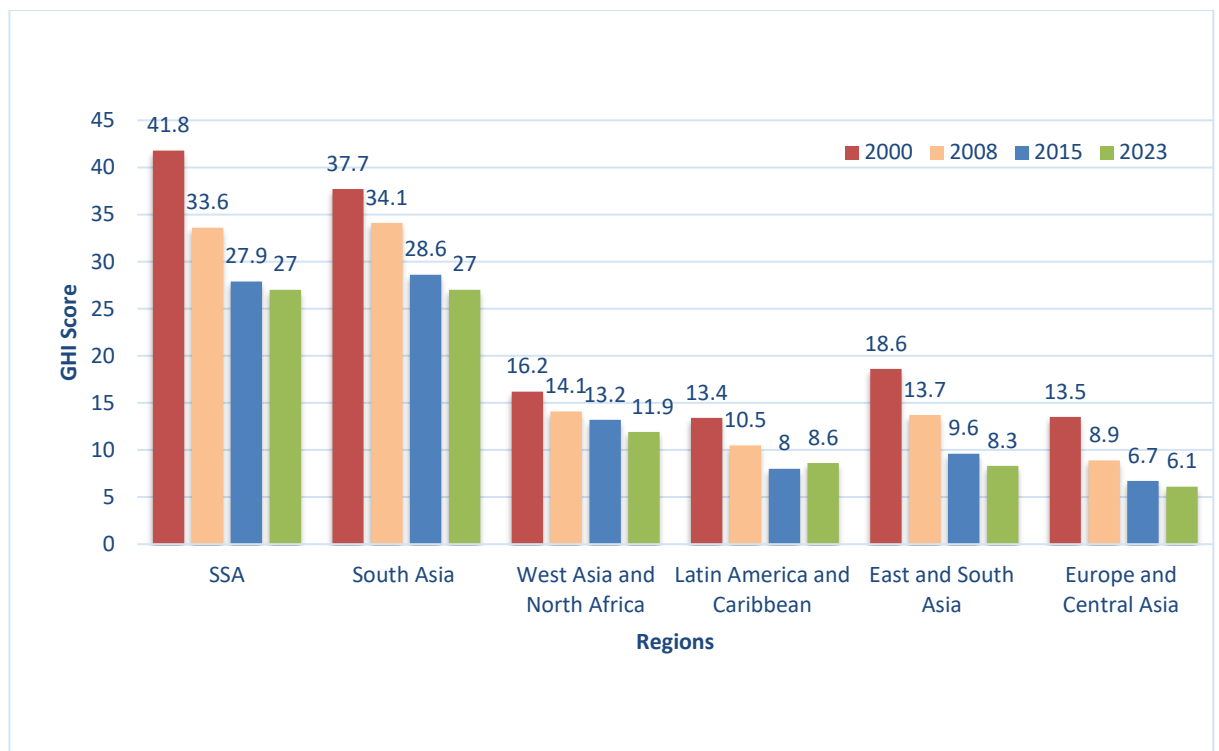


Figure 1.1: Regional global hunger index 2000 to 2023

Source: Graph by Author; data obtain from 2023 hunger index report

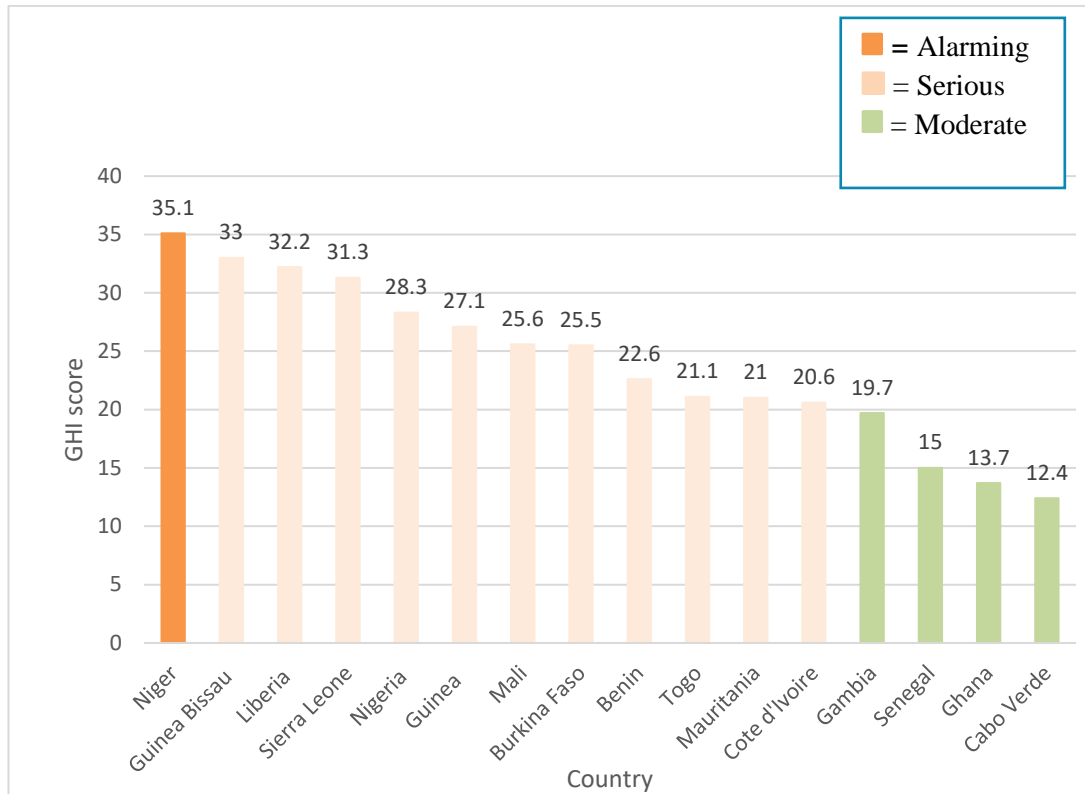


Figure 1.2: 2023 West Africa hunger index

Source: Graph by Author; data obtain from 2023 hunger index report

In addition, according to Wudil et al. (2022) , the prevalence of food insecurity has been rising inconsistently from moderate to severe since 2015 in Africa. For instance, in 2015, 52.3 million in the region were severely or moderately affected by food insecurity (Wudil et al., 2022). In Figure 1.3, it depicts the population percentage of SSA who experienced moderate or severe food insecurity. It shows that in 2014, 51% of the population were moderately or severely suffering from food insecurity. This situation is alarming as the number increases to 70.4% in 2021. According to the authors weak economic growth, climate change, rising of food prices, growing population, conflict, gender inequality, and low food production are the main drivers of food insecurity in SSA.

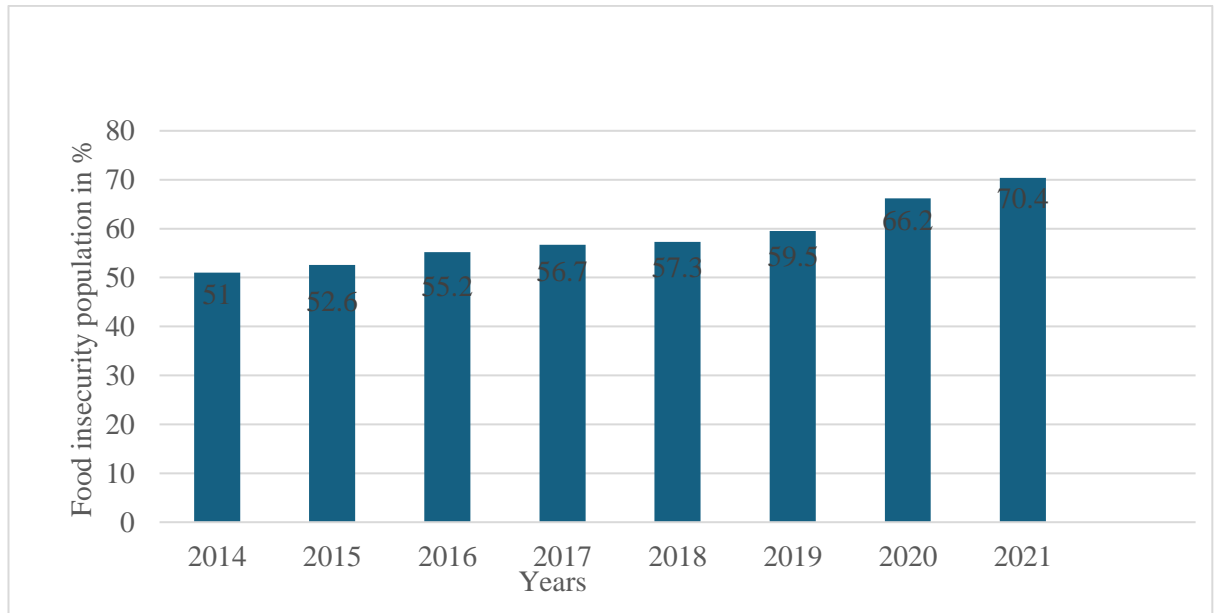


Figure 1.3: Prevalence of severe or moderate food insecurity in the population % of sub-Saharan Africa

Graph by author; data source: World Bank's World development indicators (accessed 10th May, 2024)

1.1.2 Climate Change

In today's world, climate change has become an important topic of discussion around the globe due to its influence on the environment and its habitat, and the threat it poses to the future world (Martins, 2020). The intergovernmental Panel on Climate Change (IPCC), and the United Nations Framework Convention on Climate Change (UNFCCC) define Climate change as variation of climate over a period of time either cause by natural or human activities which affect the state of the global atmosphere (Antwi, 2013). In the case of climate, it is regarded as the atmospheric condition of a specific place over a long period (Ani et al., 2021). While weather condition hinders human day to day activities, climate affect human conditions and decisions on what, where, and how to grow crops and rear animals as well as which place to live; as a result of this, it will have an influence on economic growth and development of a country (Antwi, 2013). Climate elements such as average rainfall, moderate temperature, and precipitation induce agriculture and food security; however, extreme weather events like drought, floods, high temperature, change in precipitation pattern, sea level rise, and terrestrial rainfall cause destruction to buildings, land degradation, and loss of crops and livestock which adversely affect agricultural production, food security, and livelihood income (Ayal et al., 2023).

The current increase in global warming is causing climate change and extreme weather events. For instance, from 1850 to 1950, global temperature has rose at the rate of 0.095 degree Celsius to 1.20 degree Celsius in every ten years (Ayal et al., 2023). Future global warming is expected to worsen and raise global mean surface air temperatures beyond pre-industrial levels as it is projected to rise by 2 degrees Celsius. Furthermore, according to Guodaar et al. (2021), global temperatures will likely rise over pre-industrial levels, at 3°C, even if all the signatories to the Paris Agreement meet their national emission objectives. Additionally, Mohammed (2021) postulates that, global warming is set to be higher in the African continent as temperatures are forecasted to rise between 3 and 6 degree Celsius which is above the global average.

Furthermore, Antwi (2013) indicates that, the effects of climate change are felt all over the world, however, the magnitude of the effects of climate change on food security varies from region to region with developing countries in Africa been the most affected. The African continent contributes only about 4% of the global carbon emission (Ayompe et al., 2020), yet becomes the most vulnerable region to the effects of climate change. The adverse effects of climate change will be worsened in SSA due to the region's location in the tropical and semi-arid zones where the lands are mostly dry and turning into desert. Again, large number of the people in the region, about 70%, mainly depend on rainfed agriculture for their livelihood, hence, making the region vulnerable to climate change (Antwi, 2013). Besides, weak environmental policies and insufficient capital to address climate change challenges are among the factors that makes the African continent vulnerable to climate change (Connolly-Boutin & Smit, 2015).

Climate change is mainly driven by natural and human activities. Human activities on the environment, have direct and indirect influence on climate change as they contribute to the increasing global warming. These activities involves the burning of fossil fuel (fuel, coal, oil, gas etc.) for electricity, cooking, transportation amongst others, which leads to carbon emission to the atmosphere (Beni et al., 2021). Again, deforestation which is a human activity, causes green house gas emission. Trees absorb carbon dioxide from the atmosphere which significantly help to reduce the negative impact of climate change. Thus, when deforestation occur, the carbon that was absorbed by the trees is now released to the atmosphere. Also, natural events like volcanic eruption leads to emission of gases which deplete the ocean layer and causes environmental degradation. Therefore, the concentration of carbon emission into the atmosphere will deplete the ocean layer which contributes to global warming and climate change (Antwi, 2013). Asides from rising temperature, climate

change in Sub-Saharan Africa is predicted to experience variations in rainfall intensity and rise in the frequency of extreme events as well as changes to some vector causing diseases resulting in modification to the temporal and spatial transmission of diseases. Therefore, impacts such as interrupted growing periods, a decrease in arable lands and reduction in agricultural production in several countries in sub-Saharan Africa are anticipated (Connolly-Boutin & Smit, 2015).

Figure 1.4 below presents the rainfall pattern in the West Africa. Rainfall plays a crucial role in crop and livestock production especially in African countries which mainly rely on rainfall to carry out their farming activities. Surprisingly, for the past two decades, between 2000 and 2022, most of the countries in West Africa have been experiencing low amount of rainfall, making rainfall below average. This pattern does not seem to improve as many countries are still experiencing further decline in rainfall far below the average. Specifically, Niger records the lowest and worst amount of rainfall compared to other countries within the sub-region. For over the past two decades it records closer to 1 mm compared to the average of about 75mm rainfall annually in the sub-region. Niger's low amount of rainfall could be attributed to country's being located in the Sahara Desert where rainfall is low in the area which negative affect food production and food security. On the other hand, Sierraleone rainfall is above average and records the highest amount of rainfall of about 250mm annually. However, despite Sierra Leone recording the highest amount of rainfall compared to other countries in the sub-region, the country is still facing serious hunger issues as seen in figure 1.2 above. That is to say, despite having high rainfall compared to other countries in the sub-region, food security is still low in Sierraleone.

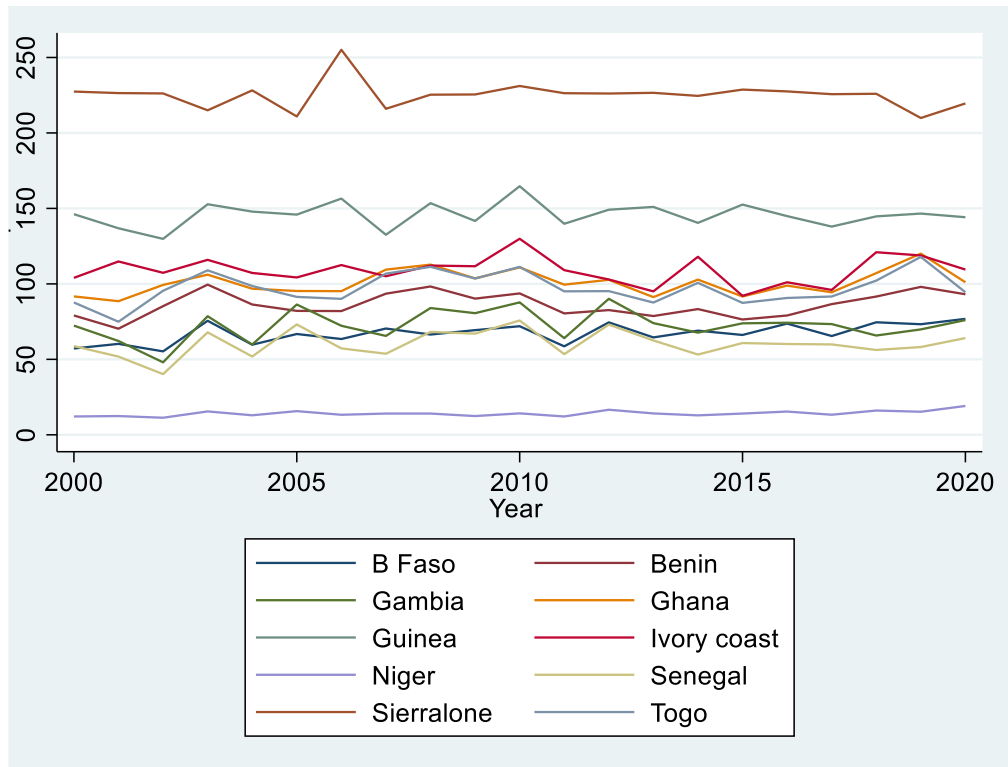


Figure 1.4: Rainfall pattern of for the selected West African countries in the study from 2000 to 2020

Source: Graph by Author; data source: World bank's climate knowledge data portal (accessed on the 10th of February 2024)

Additionally, Figure 1.5 below depicts the degree of average temperature of the selected countries in West African for the study. As seen below, over the period between 2000 and 2022, most of the countries have an average temperature of about 28°C, which is indeed high compared to other countries in the globe such as Europe and America. Besides on country specific, Guinea records lowest average temperature which is about 25°C whereas, Burkina Faso has the highest average temperature of about 30°C. The level of temperature in West Africa is showing no sign of declining as it is getting hotter which is evidence that climate change is happening and global warming is on the rise which is detrimental to the sub-region.

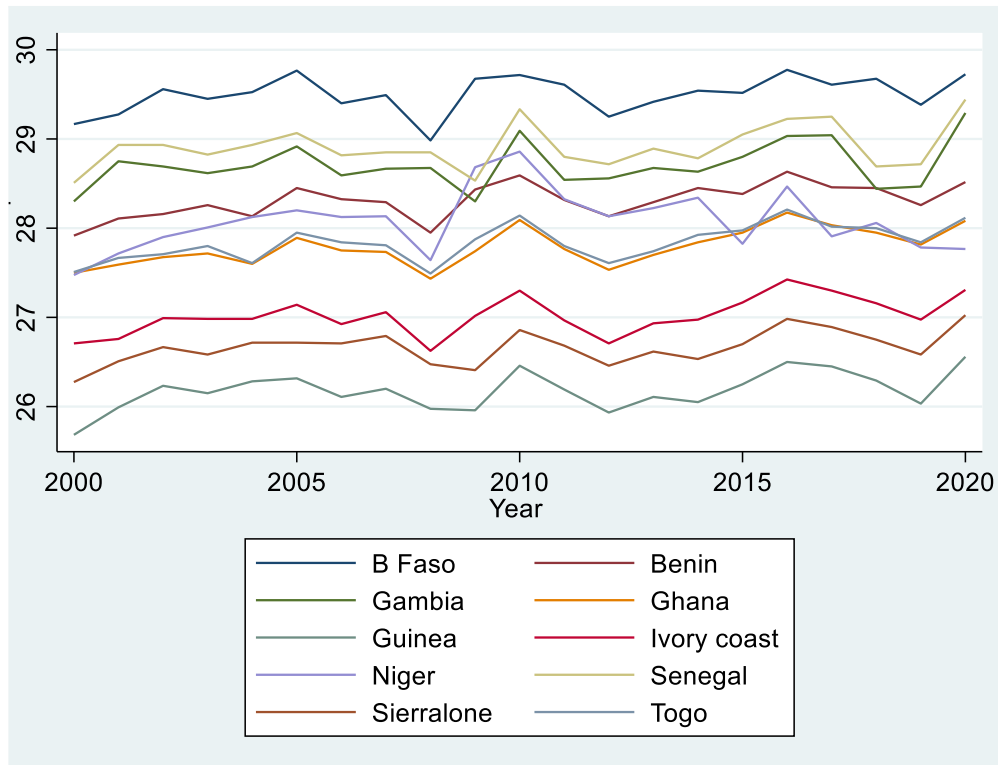


Figure 1.5: Degree of average temperature for the selected West African in the study countries from 2000 to 2020

Source: Graph by Author; data source: World bank's climate knowledge data portal (accessed on the 10th of February 2024)

1.2 Problem Statement

Food security is essential in ending hunger around the globe and ensuring sustainable economic growth and development. Many people in West Africa mainly depend on rainfed agriculture for their livelihood (Antwi, 2013). Agricultural activities such as fishing, crop and livestock productions do not only provide people with food to eat but also income through the sales of surplus farm production as well as agricultural workers who offer their services in return for wages or salaries. The agricultural sector which drive food security, is the largest contributor to the GDP of most West African countries, as it provides employment for about 60% (290 million people) of the labour force, and accounts 35% of the region's GDP (Jalloh et al., 2013). However, West African countries are increasingly facing food insecurity due to climate change shocks, thus, exposing the region to hunger and malnutrition.

According to Volz and Ahmed (2020), there are 68 climate vulnerable countries in the world, mainly from Asia and Africa. The West African region constitutes eleven (11) countries out of the 68 vulnerable countries. Interestingly, these 68 countries only

contribute 5% to the global emission, yet they are identified as climate vulnerable countries compared to countries with large emission. Therefore, since West African is identified as climate vulnerable region and is a rainfed dependent agriculture region thus, it makes this research important to examine the impact of climate change on food security in the region.

Moreover, it is essential to note that Sub-Saharan Africa, which includes West African countries, is in the semi-arid and sub-humid zones which expose them to risk of climate change (Antwi, 2013). Climate extreme events such as rising temperature and drought will have serious impact on food security (Soumbara & El Ghini, 2023). It was reported that from 1968 to 1997, West African countries experienced about 15-40% decline in rainfall compared to the years between 1931 and 1960. Again, there was 2.8 reduction in water availability in the whole of Africa with West Africa experiencing an average of 40-60% reduction in river discharge. This trend of water scarcity in West Africa is expected to worsen as it is projected that, by 2025 about 370 million people in Africa will be under water stress (Affoh et al., 2022). Crops yields and livestock need water for their growth and survival as well as ensuring food security through availability of food production. However, considering the fact that West Africa is a rainfed agricultural region, thus, the climate and extreme weather events will have an effect on food security through food availability and accessibility dimensions, thereby exposing the region to hunger and poverty crises.

Finally, climate change have direct and indirect impact on food security (Adesete et al., 2022). Changes in temperature and rainfall, level of carbon emission and rising in sea level have a direct impact on food security through the reduction in food production (Soumbara & El Ghini, 2023). Whereas, the indirect arises from the effects of climate on food accessibility. Climate extreme events such as drought and high temperature will affect crops yields and livestock production (Martins, 2020). As a result of this, a reduction in agricultural output will lower farmers income, disrupt markets food supply, and increase food prices which will reduce households' purchasing power (Antwi, 2013). Therefore, taking into consideration that, West African countries are low-income countries, depend heavily on agriculture for livelihood and are vulnerable to climate change, thus a direct and indirect effects of climate change on food availability and accessibility will have an influence on the food security status of the people in the region and their wellbeing.

In conclusion, the above literature indicated that, empirical research is needed to established the impact of climate change on food availability and accessibility in West African climate vulnerable countries, taking into consideration that, West Africa is a low-

income region, located in a tropical and semi-arid area, mainly relying on rainfed agriculture, and is identified as a climate vulnerable region.

1.3 Novelty of the study

After the empirical review of current studies related to climate change and food security in Africa, we found that, there are areas that need further research because there are inadequate studies that specifically examine the impact of climate change on food availability and accessibility in climate vulnerable countries in West Africa. Besides, the empirical review highlighted that, there are gaps in the current studies related to climate change and food security in Africa. Firstly, the study of Affoh et al. (2022) stated that, their study is confronted with limitations as they used 25 countries in sub-Saharan African region that have different climatic condition, and they do not also include external variables; hence, they suggested future researchers to address these gaps by using countries that have similar climatic condition, and also to include external factors when examining the impact of climate change on food security in order to produce robust results. Secondly, the study of Emediegwu et al. (2022) noted that, they did not include CO₂ in analysing the impact of climate change on agriculture in sub-Saharan Africa. Finally Pickson and Boateng (2021), suggested that to better understand the impact of climate change on food security, future researchers must consider including other dimension of food security such as food accessibility, utilization and stability.

Therefore, our study intends to fill these gaps by focusing on only West African countries because these countries have similar climatic conditions and are vulnerable to climate change. Additionally, the study will also consider the inclusion of macroeconomic factors as control variables as well as the interaction between policies, climate change, and food security in assessing the impact of climate change on food availability and accessibility in West African climate vulnerable countries, thereby making our study original.

1.4 Justification of the study

To begin with, the completion of this study will provide an invaluable contribution those in academia as it will add to the existing body of literature related to climate change and food security especially in West African climate vulnerable countries. In addition, the findings of this study will help policy makers to make informed decisions when addressing the impact of climate change on food security in the region. Finally, since the study will focus on climate vulnerable countries in West Africa, thus, the findings will help the affected countries to receive donor fundings and other support programmes from the regional blocs and international organizations such as the Economic Community of West

African States (ECOWAS) African Union (AU), World Bank (WB) and United Nations (UN) to help in addressing challenges pose by climate change on food security. Therefore, the above points serve as a clear indication that, this study is significant and should be given much consideration.

1.5 Research Questions

This study aims to answer the following questions:

1. What are the climate change elements that impact food availability in West African climate vulnerable countries?
2. What is the effect of climate change factors on food accessibility in West African climate vulnerable countries?

1.6 Research Objectives

The following are the objectives of the study:

- To examine the impact of climate change elements on food availability in West African climate vulnerable countries.
- To assess the effects of climate change elements on food accessibility in West African climate vulnerable countries.

1.7 Research Hypothesis

The research hypothesis for the impact of climate change on food availability in West African climate vulnerable countries are as follows:

- H₁: Climate change elements such as rainfall, temperature, and drought have statistically significant impact on food availability in West African climate vulnerable countries.
- H₂: Carbon emission has significant influence on food availability in West African climate vulnerable countries.

The research hypothesis for the impact of climate change on food accessibility in West African climate vulnerable countries is given below:

- H₁: Climate change indicators such as rainfall, temperature, and drought have statistically significant impact on food accessibility in West African climate vulnerable countries.
- H₂: Carbon emission has significant influence on food accessibility in West African climate vulnerable countries.

1.8 Thesis Structure

This thesis comprises five chapters, in which chapter one exclusively focuses on the introductory part of the study, where it provides an overview and background of the study, highlights the problem statement, states the justification of the study, and put forward the research questions and objectives of the study. Chapter two contains the literature review of the study, whereby current theoretical and empirical studies related to climate change and food security both at national, regional and global level are critically reviewed. It also provides the conceptual framework of the study. Chapter three describes the research methodology use in the study, state the source of the data, and explain the variables and the estimation process of the study. Chapter four focuses on the result and discussion of the study. Finally, chapter five provides the conclusion part of the study.

CHAPTER 2

LITERATURE REVIEW

This chapter presents the theoretical review and conceptual framework of the study as well as the review of current empirical studies related to climate change and food security. The literature review basically helps us to understand what have been studied and the research gap that exist in relation to our study. This will make us to fill the research gap identified from current studies thereby making our study new and original. Therefore, chapter will be structured in the following ways: firstly, it will present the theoretical review, followed by conceptual framework, and lastly the empirical literature review.

2.1 Theoretical Review

The theoretical review avail us the opportunity to understand existing theories regarding climate change and food security. This will enable us to build the theoretical framework of our study. Therefore, the following paragraphs will review the theories that are considered in this study.

2.1.1 Climatic Theory: Drought and Flood

Bezu (2018) stated that, food shortage can occur in areas that solely depend on rainfed agriculture due to damages cause by drought or flood. High amount of rainfall leads to flooding while shortage of rainfall causes drought both of which can lead to loss of crop and livestock production (Bezu, 2018). This can result to rise in food insecurity, hunger, and loss of income especially to farmers. He further highlighted that, the food scarcity that occurred in Ethiopia in 1958, 1973, 1984, and 2002-2003 was due to the drought event that happened in the country which led to the reduction in food production. Drought has both direct and indirect negative effects on food and agricultural production. Reduction in crop yields and livestock production due to drought, causes famine thereby influencing a rise in food prices and agricultural unemployment which increase food insecurity and poverty level (Harrison, 1988; Bezu, 2018). Additionally, Harrison (1988) suggested that, the food shortage that occurred in Africa from 1984 to 1985, was as a result of the drought event that happened in 21 countries within the region which adversely affected food security. Besides, in 1974, Bangladesh experienced food scarcity due to the flood event that occurred in the country which led to the destruction of rice production (Devereux, 1993; Bezu, 2018).

2.1.2 Malthusian population and food supply theory

Thomas Robert Malthus in his famous theory of population growth and food supply in 1798, stated that, population grows in geometric progression such as 2, 4, 8, 16, 32 etc while food production grows in arithmetic progression like 1, 2, 3, 4, 5 etc as a result, if the high rate of population growth is left unchecked, it will outpace food supply thereby causing food scarcity which leads to hunger and starvation (Ewugi & Yakubu, 2012). Malthus proposed that preventive and positive checks are ways to control population growth so as to avoid it growing more than food supply. The preventive checks include birth control, late marriage, contraceptive etc. and the positive checks include war, diseases, famine and disaster (Sakanko & David, 2018).

The Malthusian theory has been proven right in some parts of the world especially in third world countries particularly in Africa where the population is growing higher than food production. He further stated that high population growth leads to the use of more lands to build residential houses in order to accommodate the growing population. As a result of this, only a small area of land will be available to carry out farming activities thereby lowering food production which drastically affects food security (Sakanko & David, 2018). However, the Malthusian population and food supply theory suffers from some criticisms. Firstly, the theory failed to take into consideration the development and use of technology in food production activities and the advancement of transportation and communication to enhance global food trade (Bezu, 2018).

Moreover, in 1965 Ester Boserup developed a theory which established the relationship between population growth and transformation of the agricultural sector. This theory opposed Malthusian population and food supply theory. Boserup asserted that population growth has a beneficial impact because it influences investment in infrastructure such as water and irrigation, technology, transportation, and energy (Bezu, 2018). As a result of this, population growth promotes the adaptation of technological innovation which enables a large scale of food production thereby making food production to grow more than population (Bezu, 2018). Developed countries in Europe produce a large quantity of food and even export the surplus to countries with low food production like African countries due to the use of technology. Therefore, technology promotes food security which helps in improving households' wellbeing and economic growth and development (Bezu, 2018).

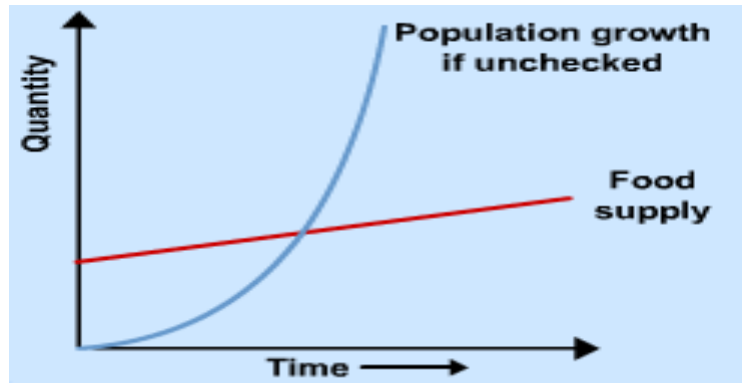


Figure 2.1: Malthusian population and food supply theory graph

Source: Adopted and modified by author; obtained from the geographer online



Figure 2.2: Ester Boserup population and food supply theory graph

Source: Adopted and modified by author; obtained from the geographer online

2.1.3 Economic theories on food insecurity

Amartya Sen (1981) proposed the food entitlement decline (FED) theory as a substitute approach to food availability decline (FAD). He argued that, the availability of food in a country or in the market does not warrant a person to consume food and food shortage can occur without a fall in the aggregate food availability or supply (Bezu, 2018). Sen stressed that, the ability to afford food contribute a significant role in ensuring food security which occurs through the source of entitlement to food like trade-base, production base, own labour, and inheritance and transfer (Bezu, 2018). This theory implies that, food availability

alone does not guarantee food security instead food accessibility dimension of food security also plays a crucial role in determining food security. However, this theory has some flaws among them are; not taking into account the distribution of food within households, failure to consider food aid which is used as a substitute in assisting food supply when other conventional means are inapplicable, the exclusion of transfer that are not legal binding thus, leading to conflict in the society, and the non-consideration of cultural food preferences and taste in influencing the food to eat under adequate food entitlement condition (Bezu, 2018).

Moreover, Deveraux (1993) proposed the market failure theory which seek to provide an economic understanding of food insecurity. He proposed that market failure occurs in two ways; demand side which is the pull failure and the supply side which accounts for the response failure. He argued that, demand failure can happen when individuals are unable to afford food (lack purchasing power) which is driven by poverty and this can be understood by the inability to demand and access food. Whereas, the supply failure can occur when markets are unable to adequately meet peoples demand which leads to imbalance between demand resulting to food insecurity (Bezu, 2018).

2.1.4 The Economics of Climate Change: The Stern Review

Climate change is set to affect most of the key sectors of an economy including agriculture, food security, and infrastructures (Stern, 2007). However, agricultural production, which is crucial in ensuring food security, will be the hardest hit sector from the adverse effect of climate change due to its dependence on climatic condition for food. Besides, the negative effect climate change will be higher in developing countries as they are more vulnerable compared to developed countries. Some of the factors that makes developing countries vulnerable to climate change are due to their geographical location, heavily depending on rainfed agriculture, and low-income level. As a result of this, if climate change is left unaddressed, it will undermine the ongoing global effort in reducing poverty (Stern, 2007). Additionally, heavy natural disasters could cost developing countries of about 5% of their GDP. For instance, climate change poses a threat to income earn from farming activities, leading to decreased in farmers' income and other agricultural employees. This will make households to dissave in order to meet their daily needs thereby limiting their ability to invest in good businesses, hence, leading to an increase in poverty (Stern, 2007). Millions of people will vulnerable to climate driven risk such as heat stress, flooding, malnutrition and water related and vector borne diseases. It is projected that by 2100, there would be a potential increase of 145-220 million people living on less than \$2 a day, and an additional

165 000 to 250000 child deaths per year in South Asia and sub-Saharan Africa due to income loss (Stern, 2007).

Furthermore, Stern (2007) stressed that in terms of food production, just a little warming in tropical areas, will significantly reduce yields but in higher latitude zones a little warming could moderately increase food production at the beginning, before eventually leading in declines as warming persist. Large number of people living in developing countries mainly depend on agriculture for sustenance, and most of whom live less than \$1 a day couple with rising population, therefore, the adverse effect of climate change on food production will hinder the achievement of food security as well as the sustainable economic growth and development. On the relationship between food insecurity and health, the author stated that malnutrition due to poor diet weakens the immune system which makes the body irresistible to infectious disease. In 2021, malnutrition accounted about 54% of child deaths in developing countries. The effects of climate change, will furthers worsen the situation, because mosquitos carrying malaria will migrate to new unaffected places potentially leading in more deaths among malnutrition people than those that are food secure (Stern, 2007).

Moreover, extreme weather events such as floods, storm, high temperature and so forth, cause destruction to infrastructure which hinders economic activities within affected areas. Currently, storm and flooding are the most destructive and costly natural disaster in the world. For instance, evidence indicates that in 2005 about 90% of the total losses from natural disasters, were caused by flooding and storm with developed countries bearing the largest part of the financial losses due to the risk and high value of their infrastructures (Stern, 2007).

2.2 Conceptual Framework

Figure 2.3 below presents the conceptual framework of the study which shows how the variables are connected. Since farming is weather dependent, thus, climate change can have an influence on crops and livestock production which affect food security. Climatic elements such as rainfall, temperature, drought, and greenhouse gas emission have direct impact on food availability dimension of food security (Chijioke et al., 2011). Again, economic factors such as population and trade also influence food availability. Moreover, adverse effect of climate change factors can lead to food shortage, hence, triggering a rise in food price which affect food accessibility thereby exposing households to the risk of food insecurity. Since food availability and accessibility are pillars of food security,

therefore an impact of climate change on these pillars, will have overall influence on food security.

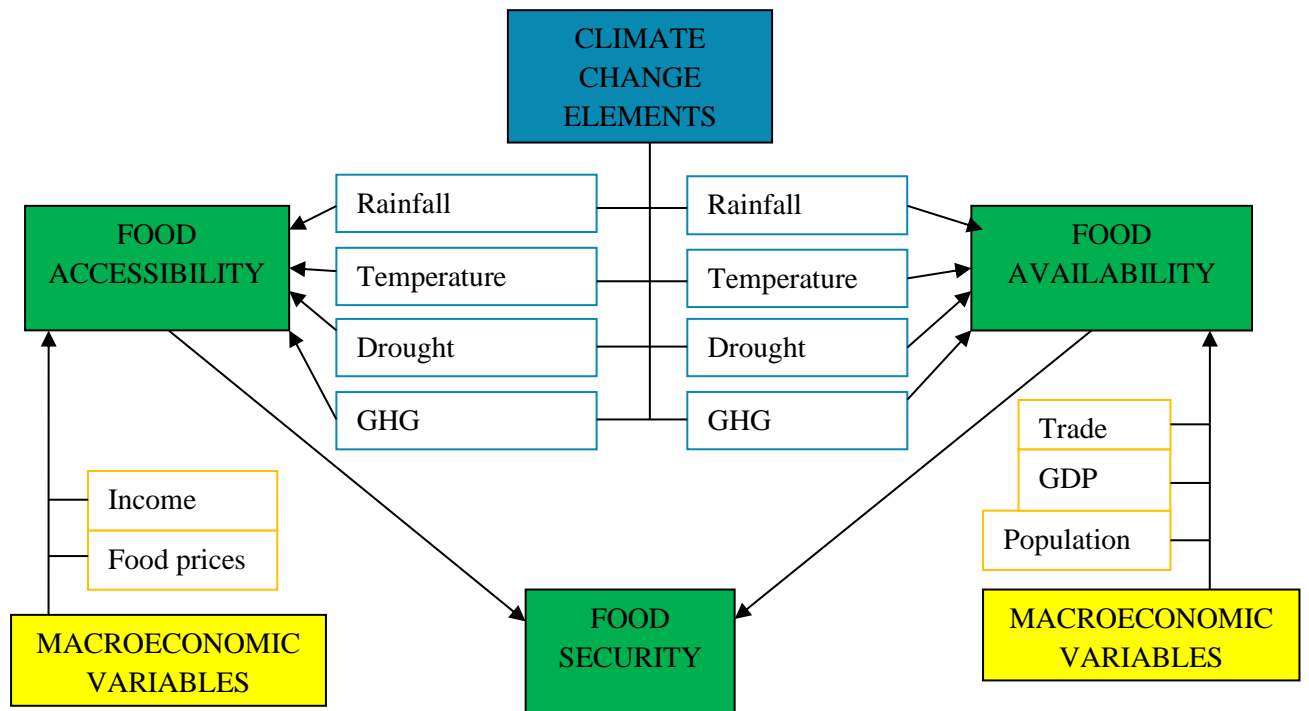


Figure 2.3: Conceptual Framework of the study

Source: Adopted and modified by author from Chijioko et al. (2011)

2.3 Empirical Literature Review

This part review current empirical literatures that are related to our study. This helps us to understand the findings of previous studies and the research gap that exist in relation to our study. Therefore, we will review current studies that examine the impact of climate change on food availability, the impact of climate change on food accessibility, climate vulnerability and food security, and the relationship between macroeconomic variables and food security.

2.3.1 The impact of climate change on food availability

Food availability as first pillar of food security is vital in enhancing food security. Food availability basically deals with the production, distribution and storage of food. Since agricultural production is weather dependent, thus, it is imperative to study this dimension of food security to help us understand the impact of climate factors and on food availability.

A study conducted by Affoh et al. (2022), examined the influence of climate variability and change on food security in 25 sub-Saharan Africa countries. Their pooled mean group (PMG) results indicated that rainfall and carbon emission have positive and significant impact on food availability in the long run whereas temperature has adverse effect on food availability. The study noted that, rising temperature causes reduction in agricultural output thereby leading to an increase in food insecurity, hunger, and poverty level in the region (Affoh et al., 2022). Similarly, a study conducted in the Sub-Saharan African found that, an increase in temperature and water vapour will lead to a decrease in millet yield. Whereas, increase in wet day frequency (WDF) enhance millet yield production. (Emediegwu et al., 2022). Again, Oyelami et al. (2023) found that, rainfall improves food availability whereas, temperature and inflation decrease food availability in Africa. The authors argued that, the negative effect of temperature and inflation on food security is a clear testimony that global warming combine with rising food prices is deepening food insecurity in the region as it reduces food production and purchasing power of the people especially low-income earners and net food buyers (Oyelami et al., 2023).

In addition, The study of Pickson and Boateng (2021) in 15 African countries, found that temperature has an adverse effect on food production both in the short run and long run but it is statistical insignificant in the long run. On the other hand, the authors revealed that rainfall has positive influence on food security both in short run and long run. The findings further revealed that, a bidirectional causal relationship exist between temperature and food security, arable land area and food security, population growth and food security, and GDP per capita and food security. Whereas, rainfall and food security were found to have unidirectional causality moving from rainfall to food security. (Pickson & Boateng, 2021). The authors suggested that, since African countries depend on rainfed agriculture, therefore, to improve agricultural production and food security, governments should provide rural farmers with irrigational facilities, increase access to finance, and promote land reform policies. (Pickson & Boateng, 2021). Likewise, a study by Pickson et al. (2023) investigated the effects of climatic condition on cereal production in Africa. The findings revealed that, rainfall has a positive influence on cereal production whereas average temperature has an inverse effect on cereal production. On country specific, the authors stated that, temperature and rainfall have different effect on cereal production across the 18 countries used in the study. The study further indicated that, trade openness, rural population, and land under cereal production help to improve cereal production. However, the country specific findings noted that, (Pickson et al., 2023).

Furthermore, Rosalia et al. (2020) analysed the spatial impact of flood and drought on food security in the Bengawan Solo, Indonesia. Their findings indicated that, both flooding and drought significantly decrease food security in the area. On the other hand, the results indicated that, human development index, size of farmlands, and gross regional domestic product per capita have positive influence on food security. The findings further highlighted that, Kidul, Paction, Gunung and Ngawi cities experience low food security because of the negative effect of flooding and drought. The authors argued that, reduction in food availability caused by flood and drought have the potential to increase food prices thereby making communities with low food security to be vulnerable to food insecurity and poverty. Therefore, to address the adverse effects of climate change on food security, the authors suggested that, adoption of climate change should be taken into consideration. They also suggested that region with high food production should supply food to region with low food production in order to improve security. Also, a study conducted in central Java, Indonesia found that, rainfall and population growth have inverse relationship with food security. Whereas, Gross regional domestic production (GRDP) as proxy for economic growth and rainy days have positive impact on food security (Suryanto et al., 2023). This implies that both rainfall and population reduce food availability while GRDP and rainy days increase food availability. The authors argued that, the increase in rainfall caused flooding which destroyed crop yield. Again, they argued that, rise in population means more farmland will be used to build residential homes thereby reducing lands available for the cultivation of crops and rearing of livestock which reduce food security (Suryanto et al., 2023). Besides, the authors stated that between 2018 and 20220, 254 flood events occurred destroying 3,465 hectares of rice fields (Suryanto et al., 2023).

Moreover, Mekonnen et al. (2021) stated that in Ethiopia, Agricultural activities are highly vulnerable to climate to change due to the fact Ethiopia is a low income country. Again, about 80% of the population mainly rely on rainfed agriculture and different regions experience different climatic condition thus, a variation in climate change will influence food availability and accessibility hence, affecting food security in the country. Their study revealed that, rainfall has positive relationship with food security despite the amount of rainfall decreasing on average over the past years. An increase in the rainfall by one millimetre will increase yield production per hectare by about 2.4kg. In contrast, temperature has an adverse impact on food security as an increase in temperature by one degree, is associated with a reduction in maize yield by 2.22kg (Mekonnen et al., 2021). Besides, increase in household family size and population have an adverse impact on food

security, while increase in cultivated land area significantly improve food security (Ayinu et al., 2022; Mekonnen et al., 2021).

Likewise, Alleyne and Jones (2021) examined the impact of climate change on agricultural production. The autoregressive distributed lag (ARDL) model results indicated that, rainfall has a positive impact on crop production in the short run, especially vegetable crops while an increase in temperature leads to a reduction in crop production but the negative effect of a rise in temperature only hinders shallow rooted crops like vegetables whereas, it supports deep rooted crops like cassava (Alleyne and Jones, 2021). In the same vein, from the nonlinear autoregressive distributed lag model (NARDL) results, the duo found that, rise in temperature couple with low seasonal rainfall have an adverse effect on cow milk production thereby causing food insecurity (Alleyne and Jones, 2021). The authors argued that, heat stress cause by high temperature, and small grazing areas caused by low amount of rainfall reduce fertility of cows which result to a decrease milk production. Again, low rainfall couple with high temperature cause drought thereby lowering crop and livestock production (Alleyne and Jones, 2021).

The study of Thompson et al. (2010) highlighted that, food availability will be the first pillar of food security that climate change will have effect on. Several communities and vulnerable groups in SSA exclusively depend on subsistence farming for sustenance. The study projected that average crop productivity would decline throughout Sub-Saharan Africa due to increase in temperatures, erratic rainfall, and the presence of drought (Thompson et al., 2010). These adverse effects are expected to affect susceptibility of subsistence farmers, who lack resources and capacity to withstand environmental pressures (Thompson et al., 2010). Anticipated climate warming and rainfall shortages are going to result in drought, while more frequent instances of heavy rainfall are likely to further exacerbate flood and soil degradation. Soil erosion poses challenges to the suitability of land for agriculture, as the depletion of nutrients restricts the ability of numerous crops to thrive. The absence of high-quality soil not only decreases its capacity to produce crops, but also restricts the types of crops that can be cultivated. Certain crops may exhibit more resilience in unfavourable conditions, although this leads to reduced agricultural diversification, resulting in a restricted range of food sources and subsequent health concerns (Thompson et al., 2010). Rain-fed farming methods prevail as the primary mode of agriculture among subsistence farmers in Africa. This technique is seen cost-effective compared to irrigation due to its minimal technological demands. However, it also

heightens vulnerability by heavily depending on rainfall for farming activities which affects food production (Thompson et al., 2010).

A recent study conducted in Morocco examined the asymmetric effects of climate variability on food security. The findings indicated that, temperature and rainfall have two side effects on food production. Increase in temperature and rainfall help to boost food production index vice versa (Soumbara & El Ghini, 2023). Besides, it revealed that GDP has directional impact on food production index while inflation has an inverse relationship with food security. However, the authors noted that GDP which measures the overall performance of the country's economic performance does not necessary guarantee a rise in food production in the country (Soumbara & El Ghini, 2023). For instance, if government does not give the support needed in the agricultural sector, it will still yield low agricultural production. Again, the negative impact of inflation on food production will not be felt much because of government subsidies on food production which prevent the increase in food price thereby protecting the Moroccan citizens from food insecurity crises (Soumbara & El Ghini, 2023). Mahrous (2019), investigated the influence of climate change on food security in the East African community region (EAC). The study highlighted that climate variables have more impact on food security than non-climatic variables. Specifically, the findings show that rainfall proxied by precipitation has a directional impact on food security, while temperature has negative effect on food security. This implies that, rainfall drive food production whereas, rising temperature decreases food security. (Mahrous, 2019).

Additionally, Ceesay and Ndiaye (2022) conducted a study in the Gambia and stated that, 100% increase in food production in the previous year does not influence an increase in food security in the current year, instead it reduces food security level in the country. Their argument was based on the system of farming that is practice in the country. Farmers use primitive tools to carrying out their farming activities which only yields small production mainly for home consumption, resulting to inadequate of food supply to the markets which increase food insecurity (Ceesay and Ndiaye, 2022). Their findings further revealed that, economic growth and population have adverse effects on food security. The duo stressed that the reduction of agricultural budget by the government combined with a growing population reduces food production and food security in the country as little resources are made available to the sector which hinder the overall performance of the economy (Ceesay and Ndiaye, 2022). On the other hand, the study indicated that, average rainfall has positive influence on food supply at lag 1, however, it is statistically insignificant (Ceesay and

Ndiaye, 2022). Therefore, to improve food security in the Gambia, the duo suggested that, farmers through the support from the government should move from traditional way of farming to a mechanized agricultural system. Doing this, will not only boost the availability of food in the country but also increase the income of farmers through exports of surplus output thereby enhancing food security and economic growth in the country (Ceesay & Ndiaye, 2022). On the contrary, study conducted by Pickson and Boateng (2021) found that, population growth has positive influence on food security in Africa. They attributed this due to governments effort in introducing policies that supports financial inclusion, growing of disease resistance crops, and reduction of environmental degradation. However, they noted that in some regions, high population growth coupled with poverty may have an adverse effect on food security (Pickson and Boateng, 2022).

2.3.2 The impact of climate change on food accessibility

The availability of food alone does not guarantee food security. As a result, to determine food security, it is also important to consider food accessibility pillar of food security. Food accessibility basically deals with the economic access to food in relation to households' ability to afford sufficient and nutritious food. It also includes political and social aspects in influencing food access. It is the pillar of food security that climatic factors can have an indirect impact which can hinder food security. In this case, the study of Affoh et al. (2022) study found that, rainfall has positive influence on food accessibility while, temperature has negative impact on food access. Besides, the study indicated that carbon emission has no effect on food accessibility. The authors stated that rising temperature influences drought in rainfed countries which adversely crop yields and livestock production. This will lead to scarcity of food production thereby resulting to loss of income and rise in food price which ultimately drive food insecurity. (Affoh et al., 2022).

Furthermore, a study conducted by Wossen et al. (2017) examined the effects of climate and price changes on households' income and food security in Ghana and Ethiopia. The authors found that climate change and price fluctuation have negative impact on households' income and food security in these countries. They noted that, climate change reduces food production which disrupts the supply of food to the markets, leading to a spike in food prices which decrease food security as buyers may not be able to afford food (Wossen et al., 2017). But for net food sellers, an increase in prices provide benefit for them because they will enjoy additional profit which increase their income (Wossen et al., 2017). Climate change has effects on both food output and cost of production which negatively affect food access (Wossen et al., 2017; Wheeler & Braun, 2013; Hertel et al., 2010).

Likewise, a study conducted in Africa suggested that GDP per capita has significant and positive long-term impact on food security. This means that, from the demand perspective, when income of households increase, it enhances food buying which helps to improve food access and food security level in the region. From the supply side, increasing per capita helps to promote large scale food production which also improve food security (Pickson & Boateng, 2021). Again, Adesete et al. (2022) found that, there is a directional relationship between income and food supply. On other hand, the study indicated that food price has an inverse relationship with food security which implies that an increase in food prices negatively affect food affordability which reduces food security (Adesete et al., 2022).

Brenton et al. (2022) investigated the effects of climate change on agricultural trade. The authors stated that, the effects of climate change on global trade are a double edge sword in the sense that countries especially in Africa that are vulnerable to climate change experience low food supply hence hindering global food trade which affect food security. On the other side, countries with favourable climate conditions especially those in higher latitude regions like European countries experience large food production as result, farmers export their surplus and earn income which contribute in driving economic growth and development in those countries (Brenton et al., 2022). Food importation is important in achieving food security because for many countries, local food production is adequate to meet the demand due to the unfavourable climatic conditions thus, necessitating them to import food from countries with surplus food production (Brenton et al., 2022). Therefore, the authors suggested that, to improve global food security, countries with excess food production should lift their trade barriers and export restriction policies so that, food insecure countries can have access to food imports through the global markets. Likewise, The study of Barau and Valenzuela (2018) indicated that, 1°C rise in temperature leads to fall in food export for Africa and Asia by about 4.8% and 14.4% respectively. However, in the case of Austria New Zealand, the results show that a 1-degree Celsius increase in temperature will lead to 8.3% increase in their food export (Barau and Valenzuela, 2022).

In addition, the global food commerce is predicted to grow, with wheat trade estimated to rise from 253 million metric tonne in 2000 to 646 million metric tonne by 2050. In addition, trade in meat products is forecasted to increase from 11 million metric tonne to 57 million metric tonne (Ringler et al., 2010). The growth of commerce will be propelled due to the rising food imports from developing regions. Sub-Saharan Africa which is expected to have the second-highest rise in food import bills due to the negative effects of climate change on food production coupled with a rising population (Ringler et al., 2010). Besides, Horn et

al. (2022) examined the interaction between climate change, food trade, and food security. They found that, grains and animal products which forms the most food import in Sweden, are vulnerable to climate change from the countries where they import these foods from, as a result exposing Sweden and their trading partner countries to food insecurity risk. The authors highlighted that food import plays a crucial role in achieving global food security however, food production is challenged by the effect of climate change, hence, disrupting global food supply chain which poses a threat to food security.

Moreover, according to Ringler et al. (2010), climate change will affect the demand and supply food equations throughout the world. They argued that, increase in dry period during growing season combine with rising temperature will cause shortage of food supply thereby fuelling food prices which reduces the farmers income and purchasing power of households, thus, decreasing food security (Ringler et al., 2010). The study projected that, food prices of rice, wheat, and maize are expected to rise by 41%, 28%, and 36% respectively by 2030. Additionally, from 2000 to 2050, these prices are projected to rise by 48%, 36%, and 34% respectively (Ringler et al., 2010). The authors stated that, if the adverse effect of climate change on food security is left unaddressed it will continue to hinders the global efforts of achieving a world free from hunger. As a result, leading to a setback in achieving goal number 2 of UNSDGs by 2030. ((Ringler et al., 2010; Wheeler & Braun, 2013). Likewise, Gregory et al., (2005) revealed that climate change causes an interaction effect on the economic situation of vulnerable countries. Drought and high temperature lower food output thereby reducing income and increasing food prices which reduce food accessibility hence, exposing people to hunger and food insecurity (Gregory et al., 2005). The authors suggested that government should give incentives to food producers to help them increase food supply to the markets and lower food prices which will help to enhance food security. To improve food security, they also suggested that countries should specialize in producing food which they have less cost comparative advantage in order to reduce production cost and food prices.

Similarly, a study conducted in South Asia examined the effects of climate change on food production, food prices, and food security. The results of the study revealed that, climate change causes an increase in food prices (Bandara & Cai, 2014). The authors suggested that extreme weather events like flooding causes lost of soil nutrients which reduces crops yield, resulting to an increase in food insecurity (Bandara & Cai, 2014). The study further stated about 70% of rural households in South Asia depend on agricultural activities for livelihood which makes them vulnerable to climate change. As result, their findings

projected that by 2030, the GDP of South Asian countries will fall from -0.8% to -3.4% (Bandara & Cai, 2014). Again, Howard and Sterner (2014) found that climate change drive food prices which threaten food insecurity due to the inability of poor household to afford food for consumption. The authors highlighted that the adverse effects of climate change on food security have the potential of increasing poverty rate and a possibility of leading to the situation of the Malthusian theory which postulated if population growth is left unchecked, it will outpace food production thereby leading to hunger and starvation (Howard & Sterner, 2014).

2.3.3 Climate Vulnerability and Food Security

Many studies have investigated the effect of climate vulnerability variables such as drought and storms on food security. These effects are mainly observed in regions that are highly impacted by climate change, such as Africa and Southeast Asia (Thornton et al., 2014; Gnonlonfoun et al., 2019; Ntali & Lyimo, 2022; Molua et al., 2020; Austin et al., 2020; Temam et al., 2019; Hayashi et al., 2018; Wichern et al., 2019). The following paragraphs will critically review their findings.

Thornton et al. (2014) investigated the repercussions of climate variability and extreme events on biological and food systems, particularly focusing on the developing world. Their findings underscored the potential escalation of food insecurity due to increasing climate variability in the future. Additionally, the study highlighted critical knowledge gaps, such as understanding the timing and interactions of various climatic stresses on plant growth and development, as well as their impacts on crops, livestock, and farming systems. Similarly, Gnonlonfoun et al. (2019) assessed the resilience of agroforestry systems to climate change, proposing that some systems exhibit greater resilience than others. Through a survey of 233 household heads and an evaluation of seven agroforestry systems, they revealed that *Anacardium occidentale* and *Citrus sinensis* parks were more susceptible to climate change effects. It implies that some of the foods have already been impacted by climate change. Therefore, it serves as an alert that climate variability could have a potential effect on crops and vegetables, which can lead to food insecurity in some countries.

Furthermore, the study of Misra (2014), highlighted that, climate change has continued to pose threat to water and food security as both are vulnerable to climate extreme events. the study indicated that global warming is projected to rise from 1.4-5.8-degree Celsius around the end of the 21st century. Consequently, due to the impact of extreme events, rainfall is expected to fall in Sub-Saharan Africa by about 10% in 2050 which will reduce agricultural production in the region. Most of the regions in Africa have similar climatic conditions,

thus, changes in extreme weather events like flooding, drought, and temperature will negatively affect agricultural activities such as fishing, crop production and livestock rearing. As a result, it will affect food trade within the region because low food production from exporting countries will result to food shortage and rise in food prices for food importing countries thereby leading to high food insecurity (Misra, 2014).

Additionally, Molua et al. (2020) explored the vulnerability and damage costs of countries in the sub-region, unveiling significant economic responses to key damage parameters in Southeast Africa. They predicted persistent damage by tropical storms in Madagascar and Mozambique while stressing the need for resilient public and private infrastructure in Mauritius and South Africa. Furthermore, Austin et al. (2020) quantified the potential responses of 11 staple crop yields to projected changes in temperature and precipitation in Rwanda, estimating the most substantial impacts on the potential productivity of maize, bush bean, and Irish potato. While the drier eastern savannah and plateau regions are projected to face severe reductions in potential crop yields, the highlands may experience neutral or even positive impacts through the mid-century. Hayashi et al. (2018) assessed the predictive accuracy and applicability of seasonal climate predictions for rainfed rice areas in Indonesia using the cumulative distribution function-based downscaling method (CDFDM). Field validation demonstrated close alignment between predicted and actual grain yield, indicating the method's potential for enhancing rainfed rice production. Moreover, Wichern et al. (2019) devised a framework amalgamating crop suitability maps with household food availability analysis to quantify household vulnerability to climate-related impacts on crop production and adaptation options' effects. Tested in Uganda, the framework identified four hotspots of household vulnerability, with approximately 30% of households vulnerable to a combination of a 3°C temperature increase and 10% rainfall decline, albeit only 10% adversely affected. Adaptation options for increasing temperatures proved most advantageous in northern Uganda, while drought-related options were more beneficial in the southwest.

Recent research studies, including those conducted by Mbuli et al. (2021) and Ntali & Lyimo (2022), provided crucial insights into the intricate nexus between climate change, livelihood vulnerability, and food security in regions facing significant environmental challenges. Mbuli et al.'s (2021) investigation into the situation of small-scale farmers in Cameroon illuminates the profound challenges they encounter, particularly their heightened susceptibility to climate-induced agricultural losses, which subsequently intensifies food insecurity risks for the wider population. This underscores the urgent need

for targeted interventions to address the adverse impacts of climate change on agriculture and ensure the sustenance of food security in vulnerable communities. On a similar note, the Ntali & Lyimo (2022) study delves into the dynamics of livelihood vulnerability in drought-prone areas of Africa, revealing the multifaceted drivers such as food insecurity, livelihood strategies, and social networks. By pinpointing these key determinants, the study provides a nuanced understanding of vulnerability contexts, paving the way for effective interventions aimed at bolstering resilience and fostering sustainable development. The recommendations put forward by both studies, including the adoption of drought-resilient crops and the utilization of agriculture extension officers, offer practical pathways to address vulnerability drivers and enhance adaptive capacity among affected populations. In essence, the reviewed literature underscores the imperative of collaborative efforts between various stakeholders, including researchers, policymakers, and local communities, to implement evidence-based strategies that safeguard food security and livelihoods amidst the challenges posed by climate change.

2.3.4 Macroeconomic variables and food security

Access to enough secure, nourishing food to support a healthy lifestyle is known as food security, and it is a major concern for all countries. The intricate relationship between macroeconomic issues and food security has been the subject of numerous studies which have acknowledged its complexity. In order to shed light on the ways in which macroeconomic factors affect food security in various situations, the following paragraphs summarize some of the findings from current studies.

Using the VAR approach, Applanaidu et al. (2014) examined the dynamic link between a number of macroeconomic factors such as population, GDP, exchange rate, government spending on rural development, biodiesel production, and food security in Malaysia. Their findings concluded that the variables that will shock food security the most in year ten are the output of biodiesel, the exchange rate, and government spending on rural development. In contrast, in year six, GDP is determined by the population, exchange rate, and year five. Samdrup et al. (2023) assessed the effect of foreign direct investment (FDI) on food security by combining the findings of 24 primary studies using meta-analysis. Their results revealed that FDI as an investment variable has a detrimental effect on food security as opposed to treating it as a flow variable. Again, a study on the effect of credit utilization on household food security was carried out in the Offa district of southern Ethiopia by Boltana et al. (2023). The results demonstrated that using credit increased household food security by a significant amount. Therefore, it is suggested that policymakers concentrate on

establishing favourable conditions for microfinance organizations to handle Ethiopia's food insecurity.

In another study, Osuji et al. (2020) investigated the effects of macroeconomic variables on the national food security of Nigeria. Using data collected in time series from 1995 to 2015 and analysed using the autoregressive distributed lag (ARDL) co-integration test with the Error Correction Model (ECM), The findings indicated that while inflation and the money supply were stable at level 1, food security, interest rates, exchange rates, net exports, and government spending were not stable at their respective levels. Indicating their substantial influence on food security, the study also discovered strong long- and short-term correlations between interest rates, inflation, government spending, and the money supply.

In conclusion of this chapter, the empirical review studies indicated that, climate change elements influence food availability and accessibility which ultimately affect food security. Again, it shows that climate change affect food security through its indirect influence on macroeconomic factors. In addition, the review highlighted that, developing countries in Africa and Asia will be more expose to the risk of climate change due to their vulnerability. Moreover, the empirical review indicated that, there are insufficient studies that specifically examine the impact of climate change on food availability and accessibility in West African countries. For instance, the study of Affoh et al. (2022) stated that, their study is confronted with limitations as they used 25 countries in sub-Saharan Africa that have different climatic condition and they do not also include external variables. As a result, they suggested future research to focus on countries that have similar climatic condition and also to include external factors in order to produce robust results. Again, the study of Pickson and Boateng (2021), suggested that, to better understand the impact of climate change on food security, future research must consider including other dimension of food security such as food accessibility, utilization and stability. Therefore, our study intends to fill these gaps by focusing on West African countries because they have similar climatic conditions and are vulnerable to climate change, including macroeconomic factors as control variables, and using food availability and food accessibility pillars of food security in examining the impact of climate change on food security thereby making our study original.

2.4 The pillars of food security

2.4.1 Food availability

The first pillar of food security is food availability which refers to the production and distribution of adequate quantity and quality of food. Food availability can be through domestic or international (food import and export) production (Chijioke et al., 2011). This

implies that food availability is the pillar of food security that deals with food supply (Wudil et al., 2022). Besides, it is the pillar through which climate change can directly affect food security (Chijioke et al., 2011).

2.4.2 Food accessibility

Food availability is not enough and does not guarantee food security if households lack access to food. Food accessibility is basically deals with the economic access (affordability) to food, as well as social and political factors. (Chijioke et al., 2011). People go hungry not due to the non-availability of food in the market, but due to households' inability to afford the food that is sold in the market (Wudil et al., 2022; Webb & Sheeran, 2006). The work of Holleman et al. (2020) revealed that climate change and extreme weather events adversely affect food accessibility in three ways. Firstly, it causes reduction in food production which drives food insecurity. Secondly it reduces farmers income and other workers whose source of income largely depend on agricultural activities, hence, increasing poverty crisis. Finally, it disrupts food supply to markets, leading to a rise in food prices which reduces households purchasing power because they cannot afford sufficient and safe food thereby exposing them to the risk hunger and food insecurity. The measurement and indicators of food accessibility are; Gross domestic product per capita, food prices, poverty level i.e. population below \$2 a day, and transportation to market (Chijioke et al., 2011).

2.4.3 Food utilization

Food utilization is the third pillar of food security that basically focuses on the nutritional value of a diet. For food security to be achieved, the food that is produced and consumed must be safe and free from diseases, and meet the dietary and nutritional needs of the people. Climate change contributes to degrading the quality of food produce and consume. Extreme weather events such as temperature, wind, and flooding increase the spread of food contamination through bacteria, virus, and parasites which leads to food and waterborne diseases in crop yields, livestock animals, and fish products. In addition, drought reduces the protein present in wheat crops. As a result, it will lead to the production of low quality and unhealthy food which cause undernourishment when eaten thereby influencing food insecurity and unhealthy life system (Firdaus et al., 2019). According to Simon Maxwell and Rachel Slater, about 70% of the 1.5 million people that are diarrhoea patients were infected through bio-contaminated food. Besides, the effects of climate change are projected to increase diarrhoea cases about 10% by 2030. The African continent is expected to be the most affected region due to their vulnerability to climate change (Firdaus et al., 2019).

2.4.4 Food Stability

Food stability entails that food should be available and accessible by people at all times. In spite the abundance of food today, an individual is still regarded as food insecure if he lacks periodic access to safe and nutritious food. Again, the adequate availability of food today, does not make people food secure if there is a scare of food tomorrow. This implies that food stability depends on the first three pillars of food security. Therefore, to achieve food security, all the four pillars of food security must be satisfied simultaneously. The pillars of food security are in priority order with food availability being first follow by food accessibility, utilization and stability thus, indicating their ability of influencing food security.

CHAPTER 3

RESEARCH METHODOLOGY

This study used quantitative research method to examining the impact of climate change on food availability and accessibility in West African climate vulnerable countries. We used this research method because it is suitable to answer our research questions. This chapter explains the source of data for the variables and countries used in the study, model specification, and econometric estimation methods used in the study.

3.1 Source of data and description of selected variables of the study

The study used secondary data obtained from World Bank’s World development indicators (WDI), World Bank’s environmental, social and governance (ESG), and Climate research unit (CRU) of University of East Anglia for the period from 2000 to 2020. The study considered this period due to the availability of data. There are eleven climate vulnerable countries in West Africa, however, we drop one country which is Liberia due data problem and selected ten countries. The selected sample countries are Benin, Burkina Faso, Ghana, Guinea, Ivory Coast, Niger, Senegal, Sierra Leone, Togo, and The Gambia. Furthermore, rainfall, temperature, drought, and greenhouse gas emission are our variables of interest which represent climate change elements while macroeconomic variables such as population density, GDP, trade openness, and food prices as well as political stability and cereal production serve as the control variables. Food availability and food accessibility as pillars of food security are the dependent variables of the study.

Table 3.1: Description of the selected variables

	Unit of Measurement	Source	Expected sign
Dependent Variables			
Food Production index proxy for food availability	Index	WDI	
Agricultural gross domestic product per capita proxy for food accessibility	Index	WDI	
Independent variables			
Rainfall proxied by Precipitation	Millimetre (mm)	CRU	+

Average temperature	Degree Celsius (⁰ C)	CRU	-
Drought	Percentage	World Bank's ESG	-
Greenhouse gas emission	(Annual % change)	WDI	-
Trade openness (food import and food export)	(% of merchandise)	WDI	+
Gross domestic product	(Current USD)	WDI	+
Population density	(People per sq. km of land area)	WDI	-
Inflation, Consumer prices proxy for food price	(Annual %)	WDI	-
Political Stability		WDI	+
Cereal production	(Metric tons)	WDI	+

Note: % means (percentage), USD (United States Dollars) and sq. km (square kilometre)

Source: author's compilation

3.3 Econometric Estimation Approach

This study employed panel data model to analyse the impact of climate change on food availability and accessibility in West African climate vulnerable countries. Since the study used panel dataset, thus, this model is suitable to analyse our study. Panel data model comprises of three different estimation methods which are the Pooled ordinary least square (OLS), Random effect (RE), and Fixed effect (FE) models from which the optimal model for the study is selected. This model was also used by Saiful (2022) to analyse his study.

3.3.1 Model Specification

This study used two sets of models and this is shown below:

Model 1

$$FPI = f(rf, temp, dr, ghg, lngdp, pop_den, top, cp) \dots eq 1$$

$$FPI_{it} = \beta_0 + \beta_1 rf_{it} + \beta_2 temp_{it} + \beta_3 dr_{it} + \beta_4 ghg_{it} + \beta_5 lngdp_{it} + \beta_6 pop_den_{it} + \beta_7 top_{it} + \beta_8 cp_{it} + \varepsilon_{it} \dots eq 2$$

In model 1 above, *FPI* means food production index which is the proxy for food availability and is used as the dependent variable, for country *i* in year *t*. β_0 serves as the constant term, whereas, β_1 to β_8 represent the coefficients of the independent variables of the selected countries at time *t*, and ε_{it} is the error term. In this model, where *rf*, *temp*, *dr*, *ghg*, *lngdp*,

pop_den, *top* and *cp* represent rainfall average temperature, drought, greenhouse gas emission, natural logarithm of gross domestic product, population density, trade openness, and cereal production respectively. Besides, β_1 to β_4 are the climate change elements which are the variables of interest in the study while β_5 to β_8 are the control variables.

Model 2

$$AGDPpc = f(rf, temp, dr, ghg, lngdp, inf, polsta, cp) \dots 3$$

$$AGDPpc_{it} = \beta_0 + \beta_1 rf_{it} + \beta_2 temp_{it} + \beta_3 dr_{it} + \beta_4 ghg_{it} + \beta_5 lngdp_{it} + \beta_6 inf_{it} + \beta_7 polsta_{it} + \beta_8 cp_{it} + \varepsilon_{it} \dots 4$$

In model 2 above, *AGDPpc* means Agricultural gross domestic product per capita which is the dependent variable and is used as the proxy for food accessibility, for country *i* in year *t*. β_0 serves as the constant term, whereas, β_1 to β_8 denote the coefficients of the independent variables of the countries under study at time *t*, and ε_{it} is the error term. In this model, where *rf*, *temp*, *dr*, *ghg*, *lngdp*, *inf*, *polsta*, and *cp* means rainfall, average temperature, drought, greenhouse gas emission, natural logarithm of gross domestic product, inflation proxy for food price, political stability, and cereal production respectively. β_1 to β_4 are the climate change elements which are the variables of interest in the study whereas β_5 to β_8 are the control variables.

3.3.2 Pre-estimation test

The pre-estimation test provides the descriptive statistics of the variables in the study. This test helps to evaluate the standard deviation, mean, maximum, and minimum values of the observations. Besides, this step is crucial in the study because it briefly helps us to understand the behaviour of the dataset by assessing whether the data is normally distributed, and is free from errors that may impede the regression results.

3.4 Estimation Techniques

The study estimated model 1 and 2 by using pooled OLS, fixed effect, and random effect estimation methods.

3.4.1 Pooled OLS model

The pooled ordinary least square is one of the estimations methods use in panel data. This model helps in identifying the line that is most suitable for a dataset by indicating a visual relation that exist between data points (Saiful, 2022). However, the weakness of this model is that, it does take into consideration of the unobserved heterogeneity of the cross-section (Mahrous, 2019) which is the countries in this case and cannot adjust to the time specific

in panel data (Saiful, 2022). The pooled OLS estimation operates like multiple linear regression. Below are the equations of the pooled OLS model:

$$\begin{aligned}
 FPI_{it} &= \beta_0 + \beta_1 rf_{it} + \beta_2 temp_{it} + \beta_3 dr_{it} + \beta_4 ghg_{it} + \beta_5 lngdp_{it} + \beta_6 pop_den_{it} \\
 &\quad + \beta_7 top_{it} + \beta_8 cp_{it} + \varepsilon_{it} \dots \dots eq\ 5 \\
 AGDPPc_{it} &= \beta_0 + \beta_1 rf_{it} + \beta_2 temp_{it} + \beta_3 dr_{it} + \beta_4 ghg_{it} + \beta_5 lngdp_{it} + \beta_6 inf_{it} \\
 &\quad + \beta_7 polsta_{it} + \beta_8 cp_{it} + \varepsilon_{it} \dots \dots eq\ 6
 \end{aligned}$$

3.4.2 Fixed Effects model

Fixed effect model is a panel data estimator whereby the variables are base on time-demeaned. Additionally, unlike pooled OLS, fixed effect model takes into account the unobserved heterogeneity of the countries (Mahrous, 2019) and is suitable to be applied in situations whereby the unobserved individual effects are correlated with the explanatory variables. However, it remains inapplicable when the unobserved individual effects are uncorrelated with the explanatory variables (Saiful, 2022). Below are fixed effect model equations for the study.

$$\begin{aligned}
 FPI_{it} &= \beta_0 + \beta_1 rf_{it} + \beta_2 temp_{it} + \beta_3 dr_{it} + \beta_4 ghg_{it} + \beta_5 lngdp_{it} + \beta_6 pop_den_{it} \\
 &\quad + \beta_7 top_{it} + \beta_8 cp_{it} + \alpha_i + \delta_t + \varepsilon_{it} \dots \dots eq\ 7 \\
 AGDPPc_{it} &= \beta_0 + \beta_1 rf_{it} + \beta_2 temp_{it} + \beta_3 dr_{it} + \beta_4 ghg_{it} + \beta_5 lngdp_{it} + \beta_6 inf_{it} \\
 &\quad + \beta_7 polsta_{it} + \beta_8 cp_{it} + \alpha_i + \delta_t + \varepsilon_{it} \dots \dots eq\ 8
 \end{aligned}$$

Where: α_i controls the country effect in the panel and δ_t is the year dummy.

3.4.3 Random Effect model

Random effect also takes into account of unobserved heterogeneity of the countries in a panel dataset (Mahrous, 2019). However, unlike FE, random effect is applicable in a situation whereby the unobserved individual effect is not correlated with the explanatory variables, (Saiful, 2022). Below are the random effect model equations:

$$\begin{aligned}
 FPI_{it} &= \beta_0 + \beta_1 rf_{it} + \beta_2 temp_{it} + \beta_3 dr_{it} + \beta_4 ghg_{it} + \beta_5 lngdp_{it} + \beta_6 pop_den_{it} \\
 &\quad + \beta_7 top_{it} + \beta_8 cp_{it} + \alpha_i + \delta_t + \varepsilon_{it} \dots \dots eq\ 9 \\
 AGDPPc_{it} &= \beta_0 + \beta_1 rf_{it} + \beta_2 temp_{it} + \beta_3 dr_{it} + \beta_4 ghg_{it} + \beta_5 lngdp_{it} + \beta_6 inf_{it} \\
 &\quad + \beta_7 polsta_{it} + \beta_8 cp_{it} + \alpha_i + \delta_t + \varepsilon_{it} \dots \dots eq\ 10
 \end{aligned}$$

3.4.4 The Breusch Pagan Lagrange Multiplier and Husman tests for optimal baseline model selection

Following the traditional panel data estimation methods, thus, we then used the Breusch Pagan Lagrange Multiplier (B.P. LM) and Husman tests to select the optimal baseline model between pooled OLS, random effect model, and fixed effect model that is used to analysed our study. Breusch Pagan Lagrange Multiplier test is used to choose between pooled OLS and random effect model. Besides, the Husman test is employed to select the optimal baseline model between fixed effect and random effect while taking in account the underlying assumptions in panel data estimations. H_0 : suggests random effect as the optimal baseline model whereas H_1 : assumes fixed effect as the optimal baseline model.

3.4.5 Diagnostics post estimation test

Panel data models (Pooled OLS, fixed effect, and random effect models) are prone to heteroscedasticity and serial correlation problems as a result, we subjected the optimal baseline model to heteroscedasticity and serial correlation and tests. The presence of heteroscedasticity and serial correlation in the model lead to biasness which disregard the classical assumptions. Therefore, to correct these problems, we applied the Driscoll and Karry (1998) estimation method using the optimal baseline model. This method is robust and address the challenges of heteroscedasticity and serial correlation in panel models thereby producing efficient, reliable, and unbiased results (Muhammed et al., 2024).

CHAPTER 4

RESULTS AND DISCUSSION

This chapter presents the results and provides discussions of the finding of the study. Therefore, this chapter will be structured in the following; we will first present the pre-estimation results which is referred to as the descriptive statistics, follow by the optimal baseline model selection between pooled Ols, random effect and fixed effect model. After selecting the optimal baseline model, we then present the findings of our study. However, since our study has two models, therefore the findings for each model will be presented separately. Firstly, we will present and discuss the findings for model 1 which examines the impact of climate change on food availability then follow by model 2 which assess the impact of climate change on food accessibility. Finally, we will present the model diagnostic and post estimation tests results.

4.1 Descriptive Statistics

Table 4.1 below presents the descriptive statistics of the variables used in this study. It shows the mean, standard deviation, minimum, and maximum values. There are 210 observations for each variable. For the variable food production index (FPI), the average value is 85.511, while the minimum is 27.2 and the maximum is 181.33. It implies that, on average, the food production index for the selected West African countries in the study is 85.551. While some countries have a higher FPI with a value of 181.33, others have a minimum FPI of 27.2. This shows the inequality in terms of food security that is present in West Africa. For the variable agriculture gross domestic product per capita (AGDPpc), the mean value is 195.434, while the minimum and maximum are 62.236 and 464.923, respectively. These figures suggest that most of these countries rely on agriculture because, when we look at their gross domestic product per capita, the share of agricultural production to GDP is quite high.

Furthermore, rainfall has a mean value of 97.876, a minimum of 11.33, and a maximum of 255.108. It shows that there are some countries that experienced a low quantity of rainfall while others had a high quantity of rainfall. This could be one of the reasons for inequality in terms of the food production index. For average temperature, it has a mean of 27.9, a minimum of 25.683, and a maximum of 29.775. It shows that most of these countries have a high temperature. For the variable drought, it has a minimum of -2.26 and a maximum of 1.545. It suggests that some countries have experienced a severe drought. For the variable greenhouse gas emissions, the minimum value is 1, while the maximum value is 131. This

means that, some countries were experiencing low emissions, but with the advent of industrialization, they experienced an increase in emissions.

Moreover, GDP has an average value of \$13,080,000,000 and a standard deviation of 15,170,000,000. The lowest and highest GDP values are 487,000,000 and 70,040,000,000 respectively. Besides, the mean and standard deviation values of population density are 85.252 and 50.051 respectively; while the minimum and maximum values are 9.176 and 254.347. This suggest that these countries have experienced a geometric increase in population. As for the variable trade openness, it has mean value of 187.046; whereas the minimum and the maximum values are 1.389 and 5866.667 respectively. Additionally, inflation has an average value of 95.81 and a standard deviation of 58.833. The minimum and maximum values of inflation are 1 and 199 respectively. This implies that prices of basket of good and serves in the sub-region is increasing at high rate. For the variable political stability, it has an average value of 82.11 while its minimum and maximum values are 1 and 173. This suggest that there is a huge disparity of peacefulness among West African countries, as some countries have very low political stability while some have high political stability. Finally, the variable cereal production has an average of 2135926.3, a minimum of 86000, and a maximum of 6100262.3. It implies that the production of cereal has increased substantially recently.

Table 4.1: Descriptive Statistics Results

Variable	Observations	Mean	Std. Dev.	Minimum	Maximum
Food production Index	210	85.511	24.364	27.2	181.33
AGDPpc	210	195.434	89.61	62.236	464.923
Rainfall	210	97.876	54.343	11.333	255.108
Average temperature	210	27.9	1.014	25.683	29.775
Drought	210	-.424	.813	-2.26	1.545
Greenhouse gas emission	210	50.576	35.954	1	131
Gross domestic product	210	13,080	15,170	487	70,040
Population density	210	85.252	50.051	9.176	254.347
Trade openness	210	187.046	506.226	1.389	5866.667
Inflation	210	95.81	58.833	1	199
Political Stability	210	82.11	52.141	1	173

Cereal Production	210	2135926. 3	1459011.6	86000	6100262.3
Note: Gross Domestic values are in billions except the minimum value which is in million, and where AGDPpc (Agricultural Gross Domestic Product per capita), Obs. (Observations), Std. Dev. (Standard Deviation).					

Source: Author's compilation; results obtained from Stata software.

4.2 The Systematic selection of the optimal panel baseline model suitable for analysing model 1 and 2 of the study

The selection of the optimal baseline model follows the traditional panel data estimation process. We do this by estimating the pooled OLS, random effect, and fixed effect models, and then select the optimal model using the B-P LM and Hausman tests for each model of our study. The evidence reported in table 4.2 below reveals that for model 1 of the study, the B-P LM test result is statistically significant at 1%, which means that the B-P LM test selects the random effect model. After confirming this, we then proceed to the next stage by estimating the fixed effect and random effect methods and then use the Hausman test to select the suitable model between random effect and fixed effect. In the same table, the result of the Hausman test indicates a probability value of 0.0000, which is statistically significant at 1% level. This implies that, we accept the alternative hypothesis which suggests that fixed effect is the optimal model baseline. Likewise, in model 2 of our study, the results of the B-P LM test reveal that random effect model is suitable compare to pooled OLS. Furthermore, between random effect and fixed effect, the Hausman test has a probability value of 0.0249, which is statically significant at 5% significance level; hence, we accept the alternative hypothesis which suggest that the fixed effect model is the suitable model to analyse model 2 of our study. Therefore, we used fixed effect model as the optimal baseline model to analyse model 1 and 2 of our study.

Table 4.2: Result of the Systematic Selection of the Optimal Panel Baseline Model Suitable for Model 1 and 2 of the Study

	Model 1	Model 2
Name of test	Significance level	Significance level
BP- LM test	chi2 = 141.91 (0.0000)	chi2 = 240.46 (0.0000)
Hausman test	chi2 = 59.47 (0.0000)	chi2 = 16.03 (0.0249)
Note: The probability values are in parenthesis and BP-LM (Breusch Pagan Lagrange Multiplier).		

Source: Author's computation; results obtained from Stata software

4.3 Model 1: The impact of climate change on food availability

The first objective of this study is to examine the impact of climate change on food availability while controlling macroeconomic factors that may cause direct or indirect effects on the explained variable. As a highlight above, food availability is the first pillar of food security and it is the pillar on climatic factors have direct impact, hence any adverse effect of these factors on food availability will severely affect food security. Following, the selection of the fixed effect as the optimal baseline model through the Hausman test, therefore, we will use the fixed effect model to present our findings as well as compare it with the results of the pooled Ols and the random effect models.

Evidence presented in table 4.3 below reveal that, rainfall proxied by precipitation has positive impact on food availability which implies that an increase in the amount of rainfall by 1 millimetre will lead to an increase in food production index by about 0.757 units holding other factors constant. The probability value of rainfall is less than 1% significance level. This means that rainfall has statistically significant impact on food availability, hence, we accept our alternative hypothesis. Besides, the magnitude of the impact shows that food production index increases by about 0.89% due to the positive effect of rainfall. This finding signifies the important role that rainfall contributes in improving agricultural production and food security. Both crops and livestock require water for their production to take place. Since West Africa is a rainfed sub-region and large number of the population, especially in the rural areas, depend on farming for their livelihood; thus, this positive effect of rainfall on food production will immensely contribute boosting food security, and reduce hunger and poverty which help in improving wellbeing and driving sustainable economic growth and development. However, the interesting part is that, the sub-region experiences only 3 to 4 months of rainfall which is inadequate considering the fact that West Africa is a rainfed region and mainly depend on farming for sustenance, as a result of this, 3 to 4 months of rainfall is insufficient to produce adequate food for the sub-region, therefore hindering the sub-region's drive in attaining zero hunger, food self-sufficiency and food security. This finding is supported by previous studies such as Mekonnen et al. (2021) who examine the impact of climate change on household food security, and Mahrous (2019) who stated that rainfall has positive influence on food security in the East African community region (EAC). However, our finding is in contrast with the results of Suryanto et al. (2023) which revealed that rainfall has adverse effect on food security in central Java, Indonesia due to the flooding it caused in the area.

On the contrary, average temperature has a negative impact on food availability. The coefficients indicate that a rise in average temperature by 1 degree Celsius, will cause a fall in food production index by about 36.55 units holding other factors constant. However, this lacks statistical significance as the probability value of average temperature is greater than 1%, 5% and 10% conventional significance levels. The effect of the magnitude is about -0.43, which means that food production index decreases by about 0.43% due to the adverse effect of temperature. The negative impact of temperature on food production is a clear testimony that climate change is real and global warming is happening. The West African region is located in tropical area which makes the sub-region unfavourable for crops and livestock production due to the hot weather condition which damage food production. Additionally, rising temperature due to global warming will cause heat stress which may discourage farmers from carrying out their farming activities and may even make them to quit from farming due to the unbearable hot weather condition. Therefore, these adverse effects of temperature on food production, will significantly result to rise in food insecurity, hence, increasing hunger and malnutrition in the sub-region. This finding is corroborated by the studies of Pickson and Boateng (2021) who found that temperature has insignificant effect on food security in the long run, and Pickson et al. (2023) who revealed that, temperature has negative effect on food security. The sub-region is already battling with food insecurity crises mainly driven by climatic shock due the region's climate vulnerability. As a result of this, if the challenges of climate change on food security is left unaddressed, it will drastically cause a rise in hunger in the sub-region thereby making it difficult to attain goal number 2 of the UNSDGs 2030.

Similarly, the results show that there is an inverse relationship between drought and food availability which implies that, a prolong absence of rainfall will lead to a reduction in food production index *ceteris paribus*. The probability value is ($<1\%$), which signifies that drought is statistically significant, hence, we accept our alternative hypothesis which assumes that drought has significant impact on food availability. This finding is not surprising considering the fact that the West African region is located in the semi arid area which is semi dry land sub-region and experience low amount of rainfall, usually 3 to 4 periods of rainfall, thus with this short period of rainfall, an erratic rainfall will worsen the situation because it will prolong the dry spell which will significantly reduce food production in the area. Besides, the rising temperature may influence drought period which will grossly damage crops yield and loss of animal production, thereby reducing food availability and food security. Crops and livestock need water for their growth and survival, thus, when there is a long absence of rainfall in a sub-region like West Africa that mainly

depend on rainfall for farming, will undoubtedly lead to a rise in food insecurity which impede economic growth and development in the sub-region. This outcome confirms the climatic theory which postulated that drought causes shortage of food and argues that the famine that occurred in Africa, was as a result of the drought event that occurred in 21 countries in the Africa region during the period of 1984 to 1985. Again, this outcome is inline with the study of Rosalia et al. (2020) who found that drought causes a reduction in food security in Bengawan Solo, Indonesia.

Likewise, GHG carbon emission has negative and significant impact on food availability. The coefficient suggests that when other factors are held constant, a percentage rise in GHG carbon emission is associated with a fall in food production index by about 0.063 units. Besides, GHG is statistically significant at 1% as the probability value is ($<1\%$) statistical significance. Therefore, this means we accept our alternative hypothesis which assumes that green house gas emission has significant influence on food availability. The magnitude impact of GHG on FPI is about -0.07% which implies food production index decreases by about 0.07% due to negative effect of GHG on FPI. The continuous accumulation of greenhouse gases to the atmosphere depletes the ocean layer which causes extreme weather events thereby impeding food production as agriculture is weather dependent. However, this finding is interesting considering the fact that whole of the African region only contributes 4% of the global carbon emission yet, suffers the most from the negative impact of the carbon emission compares to others countries or regions around the globe. This is a clear indication that the African continent in general and the West African region in particular is at the receiving end of this carbon emission. This implies that since the region carbon emission is very small thus the negative impact of the carbon emission on food security is driven by transfer of carbon emission from other countries or regions to the West African sub-region. This carbon emission transfer from larger emitting countries to the African region could be attributed to the region's weak environmental protection polices and the lack of green or ecofriendly investments as a result it causes an adverse effect on food security which retard economic growth and development in the sub-region. This outcome is consistent with the study of Adesete et al. (2022) which found that climate change proxied by GHG emission has an adverse significant impact on food security in Sub-Saharan Africa.

Furthermore, the macroeconomic variables which are included to assess their indirect impact on food availability show a different outcome. Specifically, GDP which is used as a proxy for economic growth has significant and positive impact on food availability. This

implies that an increase in economic growth is connected with an increase in food security. Additionally, results of the magnitude impact reveal that 20% increase in FPI is attributed to the positive effect of GDP. This finding underscores the important role of economic growth in improving food security in West Africa. From supply side point of view, an increase in economic growth which create an opportunity for government to increase the agricultural budget which immensely help in providing additional farming resources and inputs for farmers which enhance food production at low cost. Again, a positive economic growth translates to an increase in national income which also increase individuals' income at micro level, thus, an additional income will enable farmers to increase their agricultural investment hence boost food production. Therefore, an increase in economic growth help in increasing food security in the region which leads to an improvement in wellbeing and sustained economic growth and development in the sub-region. This outcome resonates with the findings of previous studies such as, Affoh et al. (2022) which examined the effect of climate change on food security in SSA and found that GDP has positive influence on food availability in the region, and Suryanto et al. (2023) which revealed that economic growth proxied by GRDP has positive influence on food security in central Java, Indonesia. However, our finding is in contrast with study of Ceesay and Ndiaye (2022) which found that GDP has negative effect on food security in the Gambia. They argued this adverse effect of GDP on food security is as a result of the reduction of the agricultural budget by the government couple with a growing population in the country.

Additionally, trade openness is positively significant which signifies that an increase in food imports and food exports is connected with an increase in food availability. This outcome highlights the significance of international in enhancing food security. From the demand side, food import is crucial in enhancing food security due to the fact that countries with unfavourable weather condition caused by adverse effects of climate change couple with a non-mechanise agricultural system may experience low food production which can contribute to increasing food insecurity, as a result of this, it would trigger the affected countries to import food from countries with excess food supply which help to improve food security. Besides, due to the different climatic and whether condition experience by different countries make it difficult for each country to produce all the foods it consumes. As a result, this, the role of international trade comes into play by enabling countries to trade at each which help in boosting food security. Developed countries like Europe which mechanise their agriculture industry and are less vulnerable from the adverse effect of climate change, enjoys large scale of food production. As a result of this, it enables them to export food to countries that experience low production especially West African

countries thereby enhancing food security in the sub-region. Again, from supply side, food exports help to provide additional income for farmers that export food, thus the increase in farmers income create an opportunity for them increase their agricultural investment, hence, leading to a large scale of production which enhance food security. Again, the increase of farmers' income helps to reduce poverty and enable net food buyers to afford large quantity and quality of foods that they do not produce, thereby improving food security and wellbeing. Additionally, governments of food exporting countries, have the opportunity to benefit from trade openness, as it helps to increase their foreign reserves, appreciate their currencies against those that imports from them which help in driving economic growth and development. This finding aligns with the study of Pickson et al. (2023) which stated that trade openness helps in improving food security in Africa. Besides, cereal production has a positive influence on food availability which means that other factors being equal, an increase in cereal production will lead to an increase in food security in the sub-region. Cereal crops such as rice, maize and wheat are among the staple food in West Africa, therefore, when the production of these crops increase, it immensely helps in improving food security in the area.

In contrast, population density has an adverse significant effect on food availability. The coefficient of the variable denotes an inverse relationship with food availability, thus, other factors held constant, an increase in the total number of people living per square kilometre by 1% is associated with a decrease in food availability by about 0.208%. Besides, the magnitude effect of population density on FPI is about -0.24% which signifies that FPI decrease by about 0.24% due to population density. This outcome suggests that the lack of agricultural mechanization couple with a growing population have potential adverse impact on food security in the West African region. Lands that are meant for agricultural purposes will be used to build residential homes to accommodate the increasing population thereby reducing food production. This implies that population will grow more than food supply, hence, leading to rise in hunger, malnutrition and poverty which hinders the drive of achieving food security and sustainable economic growth and development in the sub-region. This finding confirms the Malthusian theory of population and food supply who postulates that population grow in geometric progression while food production grows in arithmetic progression, therefore, if checks are not put in place, population growth will outpace food supply, thereby causing hunger and starvation. Again, our finding is corroborated by the study of Ceesay and Ndiaye (2022) who revealed that population growth has adverse effect on food security in the Gambia, but the study of Pickson and Boateng (2021) stated that population growth supports food security in Africa which

contradicts our finding, however, our study use population density while the duo used population growth in their study.

Finally, the constant term is negatively significant which means that, without the effects of the explanatory variables, food availability will reduce by about 393.001% the sub-region. Moreover, our R- squared is 0.7923, which is closer to 1 signifies that our model is good and has attain the goodness of fit. Again, the R-square value of 0.7923 (79.23%) means that variation of the dependent variables to the selected independent variables is explained by about 79.23% while the remaining 20.77% is explained by the error term. Besides, F statistic value of 814.70 with its corresponding probability value of 0.0000 which is statistically significant at 1% level, indicates that the model is adequate to explain the relationship between the dependent variable and explanatory variables.

Comparison of the optimal fixed effect bassline model with the pooled Ols and random effect model.

On comparing the fixed effect baseline model with pool OLS and random effect models, first we consider the models characteristics. Pooled OLS does take into consideration of the unobserved heterogeneity of the cross-section that is the countries in this case (Mahrous, 2019), and cannot adjust to the time specific in panel data (Saiful, 2022), whereas random and fixed effect models consider the unobserved heterogeneity. Again, while random effect is not suitable when the unobserved individual effect is correlated with the explanatory variables, Fixed effect method is applicable in situations where the unobserved individuals' effect are correlated with the explanatory variables (Mahrous, 2019). As a result of this, fixes effect is the best model in this study when compare to pooled OLS and random effect model.

Moreover, our findings further reveal that rainfall has positive relationship with food production index proxy for food availability across three models but the positive impact is higher in the optimal fixed effect baseline model compare to the pools Ols and random effect. Besides, Average temperature remain statistically insignificant across all the model but depict negative effect on food production except the random effect model. Again, drought is negative and highly significant at 1% for the fixed effect baseline model but indicate positive and statistically insignificant in the pooled Ols and random effect model. GHG is negative and significant at 1% across all the models. On macroeconomic variables, specifically, economic growth (GDP) and trade openness are positive across all the models but the positive impact is higher in the optimal fixed effect baseline model compare to pools

and random effect models. Additionally, population density is significant across all the three estimations methods but shows negative impact on food production index whereas it indicates positive relation with food production index in the pooled Ols and the random effect.

Finally, the R-square is higher in the optimal fixed effect baseline model (79.23%) compared to the pooled Ols and the random effect model which has an R-square of 48.7% and 69.68% respectively. This means that the error term in the fixed effect model is lower compared to the pool Ols and random effect models, thus, suggesting that the fixed effect model has higher goodness of fit and is more efficient in explaining the variation of the dependent variable to the selected independent variables compare to the pooled Ols and random effect models. Again, this confirms the findings of the Hausman test which selected the fixed effect model as the optimal baseline model to analyse model 1 of our study. Besides, the results of the fixed effect model align more with the previous studies and theories of the study compared to the pooled Ols and random effect model.

Table 4.3: Results of the Optimal Baseline Model for Model 1 of the Study.

Model 1: The impact of climate change on food availability			
Dependent variable: Food Production Index			
	Pooled OLS	RE Model	FE Model
Variables	Coefficients	Coefficients	Coefficients
Rainfall	0.021 (0.036)	0.104* (0.054)	0.757*** (0.265)
Average temperature	-0.753 (1.871)	1.466 (2.703)	-0.365 (4.016)
Drought	1.892 (1.606)	0.636 (1.421)	-7.312*** (2.759)
Greenhouse gas emission	-0.133*** (0.039)	-0.106*** (0.038)	-0.063** (0.03)
LNGDP	2.191 (1.392)	3.69* (1.931)	17.119*** (2.904)
Population density	0.321*** (0.035)	0.347*** (0.045)	-0.208*** (0.074)

Trade openness	0.00039 (0.003)	0.002 (0.002)	0.003* (0.002)
Cereal production	0.00982*** (0)	0.0000145*** (0)	0.0000201*** (0)
Constant	13.811 (64.817)	-104.564 (90.175)	-393.088*** (116.368)
R square	0.4870	0.6968	0.7923
Countries	10		
Observations	210		
<p>Note: * (**) *** indicate statistically significant with P value < 10%, 5% and 1% respectively. The standard errors are in parenthesis. OLS (Ordinary Least Square), RE (Random Effect), FE (Fixed Effect), LNGDP (Natural Logarithm of Gross Domestic Product) and BP-LM (Breusch Pagan Lagrange Multiplier).</p>			

Source: Author's computation; results obtained from Stata software

4.4 Model 2: The impact of climate change on food accessibility

The final objective of this study is to assess the impact of climate change on food accessibility. As stated earlier, food accessibility is the pillar of food security that basically deals with the economic access of food, as a results of this, we take into account of macroeconomic variables such as inflation and GDP to determine their influence on food affordability (accessibility). These Macroeconomic factors have direct impact on food accessibility while the climatic elements exacerbate indirect effect on food accessibility. Following the selection of the fixed effect as the optimal baseline model through the Hausman test, we will use the fixed effect model to present our findings as well as compare it with the results of the pooled Ols and the random effect models.

The results reported in table 4.4 below highlighted that, rainfall is significant in improving food accessibility because the coefficients shows that rainfall has a positive relationship with agricultural gross domestic product per capita which is the proxy for food accessibility in this study. Therefore, when other factors are held constant, a 1-millimetre increase in the amount of rainfall will lead to an increase in food accessibility by about 1.535 units. Besides, rainfall is statistically significant at 5% significance level which implies that rainfall has significant impact on food accessibility, hence, we accept our hypothesis. The magnitude effect of rainfall on AGDPpc suggest that food accessibility increase by about 0.785% due to positive influence of rainfall. This finding implies that rainfall plays a crucial role in boosting food security in the region. Water is a necessity factor in improving crop

yields, livestock production and other farming activities. Therefore, since west African countries mainly depend on rainfall for farming, hence, the positive impact of rainfall implies that it will help in improving food security in the sub-region. Bumper harvest of crops and livestock produce will lead to excess supply of food in market, thereby lowering food prices which help net buyers to easily afford food which will in turn boost food security and drive economic growth and development. This finding confirms the result in model 1 which also reveal rainfall has positive and significant impact on food availability. It also aligns with the study of Mahrous (2019) who found that rainfall has a significant and positive influence on food security in the East African community region.

On the contrary, temperature is inversely related with food accessibility but this lacks statistical significance. The coefficient indicates that an increase in temperature by 1-degree Celsius will cause a decrease in food accessibility by about 12.045 units *ceteris paribus*. This implies that temperature and food security are inversely related, as rising temperature will lead to reduction in food accessibility. Again, the magnitude effect shows that about 6.16% reduction in food accessibility is caused by temperature. This outcome clearly indicates that climate change is real, and global warming is grossly affecting food security in climate vulnerable economies especially West African countries that heavily depend on agriculture for livelihood. Besides, it is important to note that, West African countries are located in the semi humid and tropical areas which experience hot weather condition; thus, this, combine with global warming, will result to an extreme weather events such as heat waves arising from rising temperature, and drought condition, thereby leading to loss of crop yield and livestock production. As a result of this, it will lead to severe food insecurity, hence hindering economic growth and development in the sub-region. This findings is corroborated by the study of Mahrous (2019) who examined the effects of climate change on food security in the East African community region.

Similarly, drought has negative and statistically significant impact on food accessibility, which means that holding other factors constant, prolong absence of rainfall will cause a significant reduction in food accessibility; hence, we accept our alternative hypothesis. The magnitude impact shows that food accessibility decreases by 9.7% due to the adverse effects of drought in the sub-region. This finding suggests that the negative impact of drought on food accessibility could be attributed to rising temperature due to global warming which causes erratic and changes in rainfall pattern. West African countries depend on rainfall for farming; however, the sub-region experience only 3 to 4 months of rainfall, thus, with an increase in dry spell will severely cause a reduction in food production which

hinders food accessibility thereby leading a rise in food insecurity. This finding aligns with the climatic theory, which posited that drought has an indirect effect on food production and food security. Drought which is mainly caused by lack of rainfall, will lead to shortage of food production; as a result of this, it drives food prices, thereby reducing households' purchasing power in affording adequate and healthy food which contribute in increasing hunger and food insecurity. Again, this findings is inline with the study of Rosalia et al. (2020) which posited that drought has a negative influence on food security in Bengawan Solo, Indonesia. Surprisingly, GHG has a directional relationship with food accessibility and is statistically significant at 1% significance level. This signifies an increase in carbon emission is connected to an increase in food accessibility holding other factors constant. This finding is supported by the study of Affoh et al. (2022), whereby their PMG results revealed that carbon emission has positive and effect on food accessibility in Sub-Sharan Africa.

Moreover, our analysis further indicates that income proxied by GDP significantly enhance food accessibility. The co-efficient denotes a positive relationship with food accessibility, thus, a \$1 increase in income is connected with an increase in food accessibility by about 107.958 units *ceteris paribus*. The magnitude effect reveal income proxied by economic growth, drive food accessibility by about 55.2%. This finding suggests that from the demand perspective, it signifies the important role that income play in ensuring that household are able to afford food, which immensely help in improving food security and wellbeing, thereby driving sustainable economic growth and development in the sub-region. This result is supported by the study of Suryanto et al. (2023), which stressed that economic growth proxied by Gross Regional Domestic Product contribute in enhancing food security in central Java, Indonesia; similarly, Soumbara and El Ghini (2023) found that economic growth (GDP) has a positive impact on food security in Morocco. However, these findings are in contrast with the study of Ceesay and Ndiaye (2022) which revealed that an increase in GDP leads to a decrease in food security in the Gambia.

Additionally, political stability and cereal crop production have positive and a significant influence on food accessibility. This suggest that political stability is an important factor in driving food security. This outcome signifies the crucial role of peace and stability in driving economic growth and development. Absence of conflict provides a peaceful and conducive environment which allows farmers, market vendors, and other economic agents to effectively carryout their activities. As a result of this, it enhances the production, distribution, and exchange of food commodities which contributes in improving food

accessibility in particular and food security in general. Again, a stable and crime free country serve as motivating factors for foreign investors because it encourages them to invest in such an environment enhances economic growth and development. Therefore, the indirect positive influence of political stability on food accessibility, contribute in driving food security and economic growth in the sub-region.

On the other hand, inflation has an adverse impact on food accessibility. A percentage rise in inflation is associated with a fall in food accessibility by about 0.025 units *ceteris paribus*. However, this lack statistical significance as the probability value is greater than 1%, 5% and 10% conventional significance levels. The magnitude shows that food accessibility decreases by about 0.013% due to rising food prices. It is important to note that price is one of the determinants of demand and is central in measuring food security, thus a rise in food prices will significantly impede food accessibility as consumer may be unable to afford food, hence, reducing food security. This finding suggests that the adverse impact of inflation on food accessibility is attributed to the negative impact of drought on food accessibility because drought causes food production famine, thus leading to a shortage of food supply in the market, which in turn triggers a rise in food prices, thereby making food expensive and unaffordable for households in the sub-region. As a result of this, the demand for food reduces which accelerates hunger and food insecurity in the area, hence impeding economic growth and development in the West African region. Our results are consistent with the findings of previous studies, such as Wossen et al. (2017) who analysed the effects of climate and price changes on household income and food security in Ghana and Ethiopia, and Adesete et al. (2022) who found that food price proxied by inflation has an adverse effect on food security in Sub-Saharan African countries.

Finally, the constant term is negative and statistically significant at 1%. The coefficient of the constant term indicates that without the effects of the explanatory variables, food accessibility will decrease by about 2124.631 units as a result it will lead to a reduction in food security in the sub-region. Besides, our analysis reported that the model has an R-square of 0.797, which means that variation in the dependent variable to the selected independent variables is explained by about 79.7%, while 20.3% is explained by the error term. Again, F statistic value (814.70) with its corresponding probability value (0.0000) which is statistically significant at 1%, hence, it means that the model is adequate to explain the relationship between the explanatory variables and explained variable.

Comparison of the optimal fixed effect baseline model with the pooled Ols and the random effect models

On comparing the fixed effect baseline model with pool OLS and random effect models, just like model 1 of the study, our findings indicate that rainfall has positive relationship with food accessibility across three models but the positive impact is higher in the optimal fixed effect baseline model compare to the pools Ols and random effect. Average temperature remains statistically insignificant across all the model however, it shows inverse relationship with food accessibility except the pooled Ols model. Again, drought is negative and highly significant at 1% for the fixed effect baseline model and the random effect model but the negative impact is higher in the fixed effect model than the random effect model while it is positively insignificant in the pooled Ols model. GHG is statistically significant at 1% across the models. The results further shows that economic growth (GDP) has positive impact on food accessibility across all the models, but the positive impact is higher in the optimal fixed effect baseline model compare to pools and random effect models. Likewise, political stability remains to have positive impact and statistically significant at 1% across all the models. Inflation has adverse effect of food accessibility in the fixed effect and random effect models but show a positive relationship in the pooled Ols model.

Finally, the R-square is higher in the optimal fixed effect baseline model (79.7%) compared to the pooled Ols and the random effect model which have an R-square of 61.3% and 79.5% respectively. This means that the error term in the fixed effect model is lower compared to the pool Ols and random effect models, thus suggesting that the fixed effect model has higher goodness of fit and is more efficient in explaining the variation of the dependent variable to the selected independent variables compared to the pooled Ols and random effect models. Again, this confirms the findings of the Hausman test which selected the fixed effect model as the optimal baseline model to analyse model 2 of our study. Besides, the results of the fixed effect model align more with the previous studies and theories of the study compare to the pooled Ols and random effect model.

Table 4.4: Results of the Optimal Baseline Model for Model 2 of the Study.

Model 2: The impact of climate change on food accessibility			
Dependent variable: AGDPpc			
	Pooled OLS	RE Model	FE Model
Variables	Coefficients	Coefficients	Coefficients
Rainfall	0.489*** (.113)	0.896** (.35)	1.535** (.741)
Average temperature	6.039 (5.685)	-0.563 (9.676)	-12.045 (11.142)
Drought	0.585 (5.19)	-11.95*** (4.483)	-18.963** (7.78)
Greenhouse gas emission	-0.419*** (.119)	0.281*** (.084)	0.321*** (.083)
LNGDP	58.138*** (4.452)	104.573*** (6.321)	107.958*** (6.428)
Inflation	0.118* (.07)	-0.015 (.042)	-0.025 (.041)
Political Stability	0.32*** (.085)	0.12** (.052)	0.115** (.051)
Cereal production	0.000075** (0)	0.000081 (0)	0.00001** (0)
Constant	-1342.031***	-2297.533***	-2124.631***
R square	0.613	0.795	0.797
Country	10		
Observation	210		
BP-LM test	chi2 = 240.46 (0.0000)		
Hausman test	chi2 = 16.03 (0.0249)		
Note: * (**) *** indicate statistically significant with P value < 10%, 5% and 1% respectively. The standard errors are in parenthesis. AGDPpc (Agricultural Gross domestic product per capita) proxy for food accessibility, OLS (Ordinary Least Square), RE (Random Effect), FE (Fixed Effect), LNGDP (logarithm of Gross domestic product) and BP-LM (Breusch Pagan Lagrange Multiplier).			

Source: Author's computation; results obtained from Stata software.

4.5 Model Diagnostics test Results

Panel datasets are likely to suffer from the heteroscedasticity and serial correlation problems, hence, when not taken into account may produce spurious estimation results which may lead to inefficient and bias study. It is against this backdrop, we decided to subject the optimal fixed effect baseline model in both model 1 and 2 of the study to diagnostics tests; heteroscedasticity and serial correlation. Evidence presented in table 4.5 below reveal that, the fixed effect model is heteroscedastic and serially correlated for both model 1 and 2 of the study. Specifically in model 1, the results shows that heteroscedasticity and serial correlation have probability values of 0.000 and 0.0057 respectively which is statistically significant at 1%. Likewise in model 2, the result shows that both heteroscedasticity and serial correlation are statistically significant because their probability values are less than 5% significance level. Thus, we accept the alternative hypothesis and reject the null hypothesis. This means that there is presence of heteroscedasticity and serial correlation in the fixed effect baseline model for both model 1 and 2 of the study. Therefore, to correct these problems in both of the models, we apply the Driscoll and Kraay robust estimation method. This estimation method is robust and helps to address the presence of heteroscedasticity and serial correlation problems in fixed effect models Driscoll and Karry (1998), hence, producing efficient and unbiased results for our study.

Table 4.5: Model Diagnostic Test Results

		Model 1	Model 2
Name of diagnostic test	Type of test	Sig. level	Sig. level
Heteroscedasticity	Modified Wald test	chi2 = 170.06 (0.0000)	chi2 = 309.16 (0.0000)
Autocorrelation	Wooldridge test	F = 13.022 (0.0057)	F = 28.210 (0.0005)
Note: The probability values are in parenthesis			

Source: Author's computation; results obtained from Stata Software.

4.4.1 Fixed effect Robust regression results with Driscoll-Kraay Standard Errors Estimation method for model 1 and 2 of the study.

One of the key assumptions underlining classical linear regressions is the minimisation of the residuals to ensure that the model has a constant variance over time. The standard error associated with the regression describes the average distance that the observe values falls from the actual fitted regression line. However, heteroskedasticity in the regression model

causes standard error to be bias, meanwhile, a robust error could fix the issue of heteroskedasticity. A model with this issue could be improved using a robust estimator. This explains the choice of the Driscoll-Karry model to correct this anomaly in the model. Therefore, following the confirmation of the presence of heteroscedasticity and serial correlation in the optimal baseline fixed effect model for both model 1 and 2 of the study, thus, we decided to apply the Driscoll-Kraay standard errors estimation method to solve these problems which ensures that the result of our study is robust, efficient and unbiased. Below are the findings;

To start with, table 4.6 below reports the Driscoll and Kraay standard errors estimation method for model 1 of the study which examines the impact of climate change on food availability. Interestingly, the findings reveal that the coefficients of the independent variables in the Driscoll-Kraay Standard Errors method regression results are the same with that of an optimal fixed effect baseline model both in terms of directions and magnitude. However, we observed that, the standard errors change between the robust and the baseline models which also affected significance levels of the explanatory variables. Nevertheless, the significance level still remains within the conventional significance levels (1%, 5% and 10%) for all the variables that are statistically significant in the baseline model. For instance, the results indicated that, the standard errors for rainfall increase by 6% compare to the baseline model, but, the statistical significance remain the same. On the other hand, the standard errors for average temperature decline by 27% compare to baseline model but it still remains statistically insignificant. Similarly, the standard errors of drought and greenhouse gas emission decrease by 7% and 10% respectively. While significance level of drought remains the same, GHG experience an increase in statistical significance level from 5% to 1%. Likewise, the standard errors of GDP and trade openness decrease by 29% and 50% respectively; as a result, the statistical significance level of trade openness changes from 10% to 1% compared to the baseline model, but GDP remains the same. In contrast, population density's standard errors increase by 47% compared to the baseline model, hence leading to change in the statistical significance level from 1% to 5%.

Moreover, table 4.7 below reports the Driscoll-Karry standard errors estimation method for model 2 of the study which assess the impact of climate change on food accessibility. Just like model 1, evidence in model 2 shows that there is no difference between baseline model and Driscoll and Kraay robust model in terms of the coefficients of the explanatory variables including the direction of the coefficients. Nevertheless, the standard errors of the robust model vary with the baseline model. The findings highlight that the stand errors for

rainfall, average temperature and drought decrease by about 32.93%, 10.28% and 21.03% respectively compared to the baseline model. As a result, the statistical significance level of both rainfall and drought changes from 5% to 1% compare to the baseline model but average temperature still remains statistically insignificant. In the same vein, the results further indicated that GDP and inflation standard errors decrease by about 2.4% and 14.63% respectively; however, the statistical significance level remain unchanged. On the other side, the evidence shows that greenhouse gas emission standard error increases by about 93.98%, hence changing the statistical significance level from 1% in the baseline model to 10% in the robust Driscoll and Kraay model. Besides, Political stability and cereal production standard errors remain the same in both the robust Driscoll and Kraay model and the baseline model.

In conclusion, from the foregoing, it could be inferred that there was tremendous improvement in the two models using the Driscoll-Karry estimators. The amount of variation and biases resulting from the errors have been largely minimised. Additionally, it reveals the coefficients are not biased in the presence of cross-sectional dependence. More importantly, estimators are robust to the presence of omitted variables, which is important in panel data where there may be unobserved factors influencing the outcome.

Table 4.6: Fixed Effect Model Robust Regression Results with Driscoll-Kraay Standard Errors Estimation Method

Model 1: The impact of climate change on food availability			
Dependent variable: Food Production Index			
Variables	Coefficients	Standard Errors	P Value
Rainfall	0.757	0.280	0.014
Average temperature	-0.365	2.922	0.902
Drought	-7.312	2.575	0.010
Greenhouse gas emission	-0.063	0.027	0.032
LNGDP	17.119	2.070	0.000
Population density	-0.208	0.109	0.071
Trade openness	0.003	0.001	0.000
Cereal production	0.000	0.000	0.000
Constant	-393.088	61.667	0.000
R square 0.7923			

F-Statistics (Prob.)	0.0000
Countries	10
Observations	210
Note: LNGDP (logarithm of Gross domestic product).	

Source: Author's computation; results obtained from Stata Software

Table 4.7: Fixed Effect Model Robust Regression Results with Driscoll-Kraay Standard Errors Estimation Method

Model 2: The impact of climate change on food accessibility			
Dependent variable: AGDPpc			
Variables	Coefficients	Standard Errors	P Value
Rainfall	1.535	0.497	0.006
Average temperature	-12.045	9.997	0.242
Drought	-18.963	6.144	0.006
Greenhouse gas emission	0.321	0.161	0.059
LNGDP	107.957	6.274	0.000
Inflation	-0.025	0.035	0.490
Political Stability	0.115	0.051	0.037
Cereal Production	0.000	0.000	0.036
Constant	-2124.631	202	0.000
R square 0.7969			
F-Statistics (Prob.) 0.0000			
Countries 10			
Observations 210			
Note: AGDPpc (Agricultural Gross domestic product per capita) and LNGDP (logarithm of Gross domestic product).			

Source: Author's computation; results obtained from Stata Software

4.6 Dumitrescu and Hurlin Causality test for model 1

To provide further understanding regarding the impact of climate change on food availability in West Africa, we apply the heterogeneous causality test developed by Dumitrescu and Hurlin (2012). This test help to examine the direction of the causality of selected variables for model 1 of our study. The result of the causality test which is presented in table 4.8 below, indicates that, there is evidence of the existence of

bidirectional causality between rainfall and food availability at 1% and 10% statistical significance levels. This implies that rainfall causes food availability whereas food availability also cause rainfall. Rainfall contributes in food production which boost food security because water is a necessity input in farming. This outcome confirms our optimal fixed effect baseline model above for model 1 which reveal that rainfall has positive and significant impact on food availability. Additionally, greenhouse gas carbon emission and food availability have a two-way direction and are statistically significant. On the other hand, there is unidirectional causality between average temperature and food availability moving from food availability to average temperature. This means that average temperature does not granger cause food availability, whereas food availability causes average temperature. Furthermore, drought and food availability are statistically insignificant as the probability values are greater than 1%, 5% and 10% significance levels. This implies that, there is no causality between drought and food availability. Furthermore, economic growth and food availability are found to have a one-way causality running from economic growth to food availability. This means that economic growth causes food availability and not the opposite. Additionally, there is a bidirectional causality between population density and food availability at 1%, 5% and 10% significance levels. However, there is found to be no causality between trade openness and food availability. Nevertheless, cereal production and food availability have a two-way causality at all conventional statistical significance levels. These findings further confirm and strengthen the outcome of our robust Driscoll-Kraay standard errors fixed effect estimation results for model 1 of the study.

Table 4.8: DH Heterogeneous Causality Test Results for Model 1

Null hypothesis	W-bar statistics	Z-bar statistics	P. value
RF \neq FPI	1.7410	1.6569	0.0975
FPI \neq RF	2.2144	2.7155	0.0066
AT \neq FPI	1.2110	0.4718	0.6371
FPI \neq AT	2.3424	3.0016	0.0027
DRT \neq FPI	1.5190	1.1604	0.2459
FPI \neq DRT	1.3981	0.8901	0.3734
GHG \neq FPI	2.0311	2.3056	0.0211
FPI \neq GHG	2.5631	3.4951	0.0005
LNGDP \neq FPI	2.1061	2.4734	0.0134
FPI \neq LNGDP	1.0276	0.0618	0.9507

POP ≠ FPI	11.0214	22.4086	0.0000
FPI ≠ POP	8.5401	16.8602	0.0000
TO ≠ FPI	1.0403	0.0902	0.9282
FPI ≠ TO	1.4405	0.9850	0.3246
CP ≠ FPI	2.4837	3.3176	0.0009
FPI ≠ CP	4.9102	8.7434	0.0000
Note: FPI (Food Production Index) proxy for food availability, RF (Rainfall), AT (Average temperature), DRT (Drought), GHG (Greenhouse gas emission), LNGDP (logarithm of Gross domestic product), POP (Population density), TO (Trade openness) and CP (Cereal production).			

Source: Author's computation; results obtained from Stata Software

4.7. Dumitrescu and Hurlin Causality test for model 2

To better understand the impact of climate change on food accessibility for model 2 of our study, we utilize the Dumitrescu and Hurlin heterogeneous causality test. The test result which is presented in table 4.9 below reveal that there is one-way causality between rainfall and food accessibility running from food accessibility to rainfall. Likewise, there is unidirectional causality between drought and food accessibility, political stability and food accessibility, economic growth and food accessibility, and between cereal production and food accessibility. Additionally, inflation and food accessibility are found have bidirectional relationship. This implies that inflation which serve as a proxy for food prices granger cause food accessibility vice versa. On the other hand, there is no causality between average temperature and food accessibility, and between greenhouse gas emission and food accessibility because the probability values are statistically insignificant at all conventional significance levels. These Dumitrescu and Hurlin causality test results confirm and support our previous Driscoll-Kraay standard errors outcome in model 2 which substantiate and reinforce the findings of our study.

Table 4.9: Dumitrescu and Hurlin Heterogeneous Causality Test Results for Model 2

Null hypothesis	W-bar statistics	Z-bar statistics	Prob.
RF ≠ AGDPpc	0.9328	-0.1502	0.8806
AGDPpc ≠ RF	2.1699	2.6160	0.0089
AT ≠ AGDPpc	0.6303	-0.8267	0.4084

AGDPpc ≠ AT	1.6572	1.4696	0.1417
DRT ≠ AGDPpc	1.0304	0.0680	0.9458
AGDPpc ≠ DRT	1.7783	1.7403	0.0818
GHG ≠ AGDPpc	0.3734	-1.4011	0.1612
AGDPpc ≠ GHG	1.1402	0.3135	0.7539
LNGDP ≠ AGDPpc	5.5492	10.1723	0.0000
AGDPpc ≠ LNGDP	1.5403	1.2081	0.2270
INF ≠ AGDPpc	2.3759	3.0767	0.0021
AGDPpc ≠ INF	2.7291	3.8663	0.0001
POLSTA ≠ AGDPpc	1.3472	0.7763	0.4375
AGDPpc ≠ POLSTA	4.0208	6.7546	0.0000
CP ≠ AGDPpc	2.1809	2.6405	0.0083
AGDPpc ≠ CP	1.3366	0.7528	0.4516
<p>Note: AGDPpc (Agricultural Gross domestic product per capita) proxy for food accessibility, RF (Rainfall), AT (Average temperature), DRT (Drought), GHG (Greenhouse gas emission), LNGDP (logarithm of Gross domestic product), INF consumer price (Inflation) proxy for food price, POLSTA (Political stability) and CP (Cereal production).</p>			

Source: Author's computation; results obtained from Stata Software

CHAPTER 5

CONCLUSION, POLICY IMPLICATION, AND FUTURE RESEARCH DIRECTION

This chapter highlights the conclusion of the study which is divided into three parts. The first part highlights summary of the study's findings, the second part provide practical policy recommendations for actions and the final part provide suggestions for future research directions.

5.1. Conclusion of the study

Climate change and food insecurity remain to be a global concern as the two issues continue to attract discussions from global leaders, international organization, policymakers and academicians and are among the 17 UNSDGs 2030. Agriculture through which food security is achieved is weather dependent as a result of this, it is the sector that is heavily affected from the adverse effect of climate change. Previous studies have discussed the link between climate change and food security, however, in the context of West Africa, these issues still remain underexplored. West Africa is among the most venerable sub-regions to the impact of climate change mainly due to its dependence on rainfed agriculture for livelihood. As a result, this study examines the impact of climate change on food security in West Africa by specifically focusing on the two objectives: firstly, to examine the impact of climate change on food availability, and to assess the impact of climate change on accessibility in West African climate vulnerable countries. Food availability and food accessibility are pillars of food security, as a results of this, the study has two models.

Model 1 of study examines the impact of climate change on food availability and model 2 assess the impact of climate change on food accessibility while controlling macroeconomic factors such as GDP, trade openness, inflation, political stability, and as well as cereal production due to their direct or indirect effect on food availability and food accessibility. To achieve our objectives, we employed static panel data estimation methods to analyse our study. After carefully following the traditional steps of estimating static panel datasets, the Hausman test selected fixed effect method as the optimal baseline model to analyse both model 1 and 2 of our study. Consequently, since fixed effect panel models are prone to heteroscedasticity and serial correlation problems, we subjected the fixed effect model to diagnostic tests. The results indicate that fixed effect method is heteroscedastic and serially corelated. As a results of this, we employed the Driscoll and Kraay estimation method. This method is robust and it helps to address the presence of heteroscedasticity

and serial correlation in fixed effect models, thereby producing efficient and unbiased results. Below are the highlights of the findings of our study.

Our study reveals a mix of findings in terms of magnitude and directions of the impact of the explanatory variables to the explained variable. To begin with, evidence from model 1 found that rainfall has positive and significant impact on food availability which means that an increase in the amount of rainfall is association with an increase in availability. On the other hand, average temperature, drought, and greenhouse gas carbon emission all have negative impact on food availability but average temperature lacks statistical significance. This suggests that climate change factors such as drought, GHG, and average temperature have adverse effects on food security in West Africa which lead to rise in hunger, malnutrition, and poverty, thereby impeding economies in West African countries as well the achievement of goal number 2 of the UNSDGs 2030. Additionally, the macroeconomic factors of GDP and trade have direct link with food availability while population density has an adverse effect on food availability. These outcomes indicate that while population density significantly reduce food security, economic growth, and trade openness drive food security in the sub-region. Besides, cereal production immensely helps in enhancing food security in the area. Thus, as discussed in our results and discussion above, these findings are supported by previous studies, and also confirms the theories highlighted in the study. Furthermore, the causality test result shows that, there is bidirectional causality between rainfall and food availability, green house gas emission and food availability, population, food availability, cereal production, and food availability. Again, there is unidirectional causality between average temperature and food availability, and between GDP and food availability. However, no causality is found between drought and food availability, and between trade openness and food availability.

Moreover, the findings for model 2 of our study reveal that climate change variables have mix impact on food accessibility. Specifically, rainfall is found to have positive and significant impact on food accessibility while temperature and drought adversely affect food accessibility. Additionally, the findings show that, macroeconomic factors matter in influencing food accessibility. For instance, economic growth is found be an essential factor in promoting food accessibility. Again, political stability and cereal production help in improving food accessibility. However, inflation significantly decrease food accessibility. In the case of the causality test, we found that there is one way causality between rainfall and food accessibility, and between drought and food accessibility. In the contrast, no causality exists between temperature and food accessibility, and between greenhouse gas

emission and food accessibility. The outcome further indicates that GDP and food accessibility have no causality. However, there is presence of unidirectional causality between inflation and food accessibility, and between political stability and food accessibility.

In summary, to answer our research questions, our study found that, rainfall significantly help improving food availability and accessibility pillars of food security, whereas other climatic factors such as average temperature and drought have negative impact on two pillars of food security. Likewise, greenhouse gas emission has negative effect on food availability, but shows a positive relationship with food accessibility. Besides, GDP and trade openness are found to be key macroeconomic factors that help in accelerating food security in the West African region. Again, political stability and cereal production significantly aid in deepening food security in the area. In contrast, population density and food prices proxied by inflation are found to be deterrent in achieving food security in the sub-region. Therefore, the adverse effects of climate change couple with rising food prices and population density on food availability and accessibility will significantly dampen food security in the sub-region, hence, leading to an increase in hunger and malnutrition which hinder the efforts of achieving zero hunger by 2030 as enshrined in the UNSDGs 2030, thereby reducing wellbeing and impeding sustainable economic growth and development.

5.2. Policy Recommendation

The negative effect of climate change on food security has policy implications for the West African region. The region has low level of food security, with 85.511 on average food production index. Therefore, continuous deterioration in climate change will continue to pose significant risk to food security in the region. In addition, the vagaries of climate change will drive down the productivity of agricultural sector including farming for food production. Thus, based on the findings of our study, we provide the following policy directions for governments, policymakers and other stakeholders at national and regional level for action. Below are the policies:

1. Lower carbon emission

Despite Africa's minimal contribution to global carbon emission, the continent particularly the West African sub-region heavily relies on fossil fuel consumption for daily activities such as electricity, cooking and transportation. This emission depletes the atmosphere which leads to extreme weather events, hence affecting farming activities which reduce food production. As a result of this, the sub-region

should endeavour to reduce carbon emission through energy transition, tax holiday for lower emitting firms, and the introduction of carbon market. This will immensely contribute in reducing carbon emission which will help to boost food production, thereby improving food security and wellbeing in the sub-region.

2. Develop strong regulations that aimed at protecting the environment

The interesting issue is that, Africa contributes only 4% of the global emission but remains the most vulnerable continent to climate change. This implies that the African continent is at the receiving part of the adverse effect of global emission. Due to this, governments in this region should claim compensation damages from larger emitting countries through sustainable agricultural finance and green projects. Additionally, government should impose fines on individuals that practice activities that degrade the environment such as deforestation and bush burning. This will help to improve carbon storage and ensure greener and ecofriendly environment, hence, increasing agricultural production and productivity within the sub-region.

3. Promote climate smart agriculture

West African governments should invest in smart agriculture, which climate is climate resilient. Smart agriculture is resilient to drought, low precipitations, and other negative consequences of climate change. Additionally, governments should train and encourage farmers to engage in climate smart agricultural practices. For instance, famers should be encouraged to use natural resources to carry out their farming activities instead of applying unstainable farming activities such as the use of non-renewables fossil fuels energy to power machines in carry out farming activities and the application of non-organic fertilizers like nitrogen which all contribute to carbon emission, hence, degrading the environment, which negatively affect food production. As a result, farmers should be supported and encourage to use natural resources like renewable energy. These practices will not only help in ensuring ecofriendly environment but also ensures sustainably improvement in agricultural productivity thereby reducing hunger and poverty which accelerate sustainable economic growth and development.

4. Provide farmers with drought resistance crops

Since West Africa is located in the semi-arid region, in which drought is adversely affecting food production, therefore, government and international organizations like FAO should collaborate and provide farmers with drought resistance crops. This will help to boost food security and accelerate economic growth and development in the sub-region.

5. Promote free trade within countries in the West Africa

West African countries have already signed the trade liberation treaty which allows the free movement of people and goods within its member states, however, the lack of political will make the implementation of the policy ineffective. Our findings shows that trade openness is key in improving food security in sub-region, therefore, government in the sub-region should promote the implementation of free trade for agricultural commodities so as increase food supply, hence accelerating the achievement of food security in the area. Besides, policymakers should encourage each country to focus on producing food item that it has less cost compare advantage than the other countries and then trade among themselves. This will help to lower food prices in the sub-region which will make food accessibility easier thereby increasing food security.

6. Promote peace within the Sub-region and beyond

Peace is crucial in ensuring sustainable development. Our findings reveal that political stability enhance food security. An environment free from violence and conflict allow farmers and food vendors to carry out their farming and food trade activities freely without any disruption, thus, enhancing food security. Therefore, government, internation peace organizations and civil society organizations should collaborate and promote peace and stability through dialogue and sensitization in order achieve food security and sustainable development within the sub-region.

7. Increase agricultural investment

Agriculture is the largest contributor to the economic growth of west African countries as most of the engage in agricultural activities to earn a living. However, the sub-region is still food insecure and underdeveloped. As a result of this, governments in the sub-region should commit investment in modern farming technologies to boost agricultural productivity in order to enhance food security.

Besides, government should collaborate with donor partners and increase the agricultural financing by providing grants to farmers so as to enable them to buy sophisticated farming technologies and other farming inputs which will enable them to have large scale of food production at low cost. As a result, it will enhance food security, improve, income, and alleviate poverty which help in driving economic growth and development.

8. Stabilize food prices

Rising food prices is a major factor that affect food security in sub-region, therefore policymakers should use effective fiscal and monetary polices to stabilize food prices and stimulate consumption. Moreover, governments should provide good the infrastructure such as roads, food storages and clean and efficient energy. This will help to help reduce food production cost and food price which improves food affordability thereby enhancing food security. Besides, West African countries should speed up the implementation of the single currency policy. This will help to reduce transaction cost especially on exchange rates, thereby easing trade transactions and stabilizing food prices within the sub-region which enhances food security.

9. Encourage public private partnership for agricultural investment

West African governments should collaborate with the private sectors in order to facilitate the investment and financing of climate resilient agriculture for achieving food security and tackling the climate related problems.

10. Research and Innovation

In this era of climate change, research and innovation are key in addressing climate change and food insecurity which requires multidisciplinary approach. Scholars and research institutions should be empowered to develop seeds and introduce innovative and efficient farming mechanisms are resilient to climate change so as to increase agricultural productivity which help in boosting food security.

In conclusion, therefore, we believe that if these policies are taken into consideration and implemented accordingly, it will immensely help to achieve food security, address climate change and alleviate poverty thereby enhancing sustainable economic growth and development in the sub-region which are all inline with the UNSDGs 2030 agenda.

5.3 Future Research Direction

This study has limitations as a result, we provide suggestions for future research to take into consideration. Firstly, the major limitation of this study is the availability of data. There is incomplete availability of data for some of the indicators of food availability and accessibility for some countries in West Africa like Liberia. Therefore, future research should consider incorporating this and include other countries when data becomes available. Secondly, this study focusses on only two pillars of food security among the four which is: food availability and accessibility, thus, we encourage future research to consider the other two dimensions of food security which is; food utilization and food stability when examining the impact of climate change on food security in West Africa. Finally, we recommend future research to include climate vulnerability index variable and compare with other sub-regions like East Africa or North Africa to ascertain with sub-region is more vulnerable to the impact of climate change on food security within the African region as well as to employ dynamic panel model in the analysis in order to have more robust results.

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APPENDIX

Appendix 1: Article Summary from Current Studies

No.	Authors	Title	Objective	Variables	Methods	Findings /limitations
1.	Affoh et al. (2022)	The impact of climate variability and change on food security in 25 Sub-Sharan African countries: Perspective from Panel Data Analysis	To investigate the effects of climate variables like rainfall, temperature, and CO2 emission on food security in 25 sub-Sharan African countries from 1985 to 2018 focusing on three pillars of food security.	Dependent Variable Cereal yield, AGDP, and cereal dietary energy supply. Independent Variables Rainfall, temperature, CO2 emission, GDP, population growth, inflation, cereal production, and land under cereal production.	Panel ARDL	Rainfall has positive significant effect on food availability, accessibility, and utilization dimensions of food security, whereas temperature has adverse effects. CO2 found to have positive influence on food availability and accessibility. Limitation Authors used 25 countries that have different climatic condition, hence, suggest future research to focus on countries that have similar climatic conditions and also to include external variables so as to have robust results.

2.	Robert Becker Pickson and Elliot Boateng (2021)	Climate change: a friend or foe to food security in Africa?	To assess the effects of climate change on food security in 15 African countries.	Dependent variable: Cereal availability proxy for food security Independent variables: Rainfall, temperature, cultivated area under cereal production, population growth, and GDP per capita	Panel data	Rainfall, GDP per capita, and cultivated area under cereal production have positive significant effect on food security, whereas temperature and population growth have negative effects. Authors suggest future research to include other dimension of food security such as accessibility, utilization and stability in order to better understand the situation of food security in Africa.
3.	Emediegwu et al. (2022)	The impacts of climate change on agriculture in sub-Saharan Africa: A spatial panel data approach	To analyze the economic impact of changes in weather variables on sub-Saharan African	Dependent variable: Millet yield Independent variables: average temperature, wet day frequency,	Panel data	vapor pressure deficit, wet day frequency and temperature are important determinants of millet yield

			pearl millet yield based on panel data for 1970–2016.	and vapor pressure deficit		
4.	Pickson et al. (2023)	The impacts of climatic conditions on cereal production: implications for food security in Africa	Examine the effects of climatic factors on food security:	Dependent variable: Cereal production Independent variables: Land under cereal production, rural population, trade openness, average temperature, and precipitation proxy for rainfall	Panel ARDL	
5.	Rosalia et al. (2020)	Spatial Analysis of the Impact of Flood and Drought on Food Security Index	To spatially analyze the impacts of climate change, specifically flood and drought	Dependent variable: Food security index Independent Variables: Flood index, Drought index,	Panel data model	Found that flooding and drought decrease food security while GRDP and HDI enhance food security.

			on the level of food security in the Bengawan Solo watershed.	Human development index, Inflation Farm size, total population, and Gross regional domestic product		
6.	Adesete et al. (2022)	Climate change and food security in selected Sub-Saharan African Countries	To assess the relationship between climate change and food security in Sub-Sharan Africa.	Dependent Variable: The inverse Prevalence of malnourishment rate proxy for food security Independent Variables: Greenhouse gas emission, GDP per capita proxy for Income, Population growth, food supply, and Food price proxied by inflation.	Dynamic panel data model using GMM	GHG and food price have adverse effect on food security whereas income and food supply enhance food security

7.	Wossen et al. (2018)	Impacts of climate variability and food price volatility on household income and food security of farm households in East and West Africa	To examine the effects of climate change and price changes on household income and food security in Ethiopia and Ghana			Authors found that climate change and food price have negative effect on food security and household income
8.	Ceesay and Ndiaye (2022)	Climate change, food security and economic growth nexus in the Gambia: Evidence from an econometrics analysis	To analyze the relationship between climate change, economic growth, and food security.	Dependent variable: Food production proxy for food security: Independent variables: GDP, perception Agriculture value added (current \$), rainfall, population	VAR and ARDL	Average rainfall, GDP, and population have negative impact on food security while GDP per capita and agriculture value added have positive effect.

				growth, and GDP current.		
9.	Sid' Ahmed Soumbara and Ahmed El Ghini (2023)	Asymmetric effects of climate variability on food security in Morocco: evidence from the nonlinear ARDL model	to examine the asymmetric effects of average temperature and rainfall on the Moroccan food security. using annual data from 1961 to 2020.	Dependent variable: Food Production Index (FPI), Independent variables: Temperature, rainfall, GDP, and Inflation	ARDL	The study shows that RF has a long-term relationship with FPI, with increased RF leading to increased FPI and decreased RF leading to decreased FPI. FPI responds more strongly and persistently to a positive shock in RF than to an adverse shock. The study also identifies an asymmetric relationship between FPI and RF, with increased TP enhancing food output in the long run and a decrease reducing food production in the long run Limitation Non-climate factors like co2 emission were not included to assess their effects on food security.

10.	Walaa Mahrous (2019)	Climate change and food security in EAC region: a panel data analysis	To analyze the impact of global climate change on food security in the East African Community (EAC) region, using panel data analysis for five countries, over 2000-2014	Dependent variable: Food production Index (FPI) as proxy for food security. Independent Variables: Rainfall, Temperature, land area under cereal production, and population size	Panel data analysis	Findings show that food security in EAC is adversely affected by temperature. However, precipitation and increasing areas cultivated with cereal crops will be beneficial to ensure everyone's food security. Limitation

Appendix 2: Definition of selected variables of the study

Variables	Definition	Related Study
Dependent Variables		
Food Production index proxy for food availability	Food production index which measure the food availability aspect of food security includes crop variety and quantity that is produced in a particular country (Soumbara & El Ghini, 2023). Again, according to the definition given by World Banks’s WDI, food production index entails food crops that are regarded edible and have nutritional value.	Soumbara and El Ghini (2023) and Tetteh et al. (2022)
Agricultural gross domestic product per capita proxy for food accessibility	Agricultural gross domestic product per capita is an indicator that help in determining consumers ability to afford food (Chijioke et al., 2011). Thus, it is an essential indicator that help in measuring food accessibility. It is derived by dividing country’s Agricultural gross domestic product (AGDP) by its total population, and it is measured in US dollars. Food access can be influence by climatic and economic factors (Connolly-Boutin & Smit, 2015).	Chijioke et al., (2011) and Affoh et al. (2022)
Independent variables		
Rainfall proxied by Precipitation	Rainfall refers to the supply of water in the form of rain from the atmosphere to the surface of the earth (Tetteh et al., 2022).	Ceesay and Ndiaye (2022) and Tetteh et al. (2022)
Average temperature	Temperature refers to the degree of hotness or coldness of a place given at a particular period of time. Temperature varies globally and is a key factor that influence food production (Tetteh et al., 2022).	Tetteh et al. (2022) and Mekonnen et al. (2021)

Drought	According to World Bank's WDI, drought refers to the absence of rainfall in a particular place over a long period of time. World Bank climate data use standardised precipitation-Evaporation index (SPEI) to measure drought.	Rosalia et al. (2020)
Greenhouse gas emission	According to World Bank's WDI, GHG emissions are composed of CO2 totals excluding short-cycle biomass burning (such as agricultural waste burning and savanna burning) but including other biomass burning (such as forest fires, post-burn decay, peat fires and decay of drained peatlands), all anthropogenic CH4 sources, N2O sources and F-gases (HFCs, PFCs and SF6).	Adesete et al. (2022)
Gross domestic product	According to World Bank's WDI, GDP at current refers to the total monetary value of goods and services produce by residents in a country during a particular period of time excluding products produce base on subsidies.	Affoh et al. (2022) and Suryanto et al. (2023)
Population density	Population density refers to the number of people living per square kilometre of a land area. According to World Bank's WDI, population density is midyear population divided by land area in square kilometres. It includes all residents regardless of legal status or citizenship except for refugees not permanently settled in the country.	Pickson and Boateng (2021)
Trade openness (food import and food export)	Trade openness refers to the export and imports of foods between or among countries. We compute the trade openness by using the formula below: $Trade\ openness = \frac{Food\ export}{Food\ import} \times 100$	Pickson et al. (2023), Brenton et al. (2022), and Horn et al. (2022)

Inflation, Consumer prices proxy for food price	Inflation, consumer price index, refers to the yearly percentage changes in the cost to the average consumer affording a basket of goods and services (Tetteh et al., 2022).	Soumbara and El Ghini (2023), and Bandara and Cai (2014)
Political Stability	According to the World Bank's WDI, political stability measures the perception of the likelihood of political instability and/or politically-motivated violence, including terrorism.	Aloui and Maktouf (2024)
Cereal production	According to the World Bank's WDI, Cereal production refers to crop harvested for dry grains which is used as food. This variable influences food security in West Africa because cereal crops like maize, rice, and millet are among the staple foods in the sub-region.	Mumuni and Aleer (2023)

