

Navigating the Effects of Climate Change and Fiscal Policy on Food Security in Sub Saharan Africa

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Received August 02, 2025; Revised September 04, 2025; Accepted September 12, 2025

Abstract: The interplay between climate change, fiscal policy and food security is complex and vital for Sub-Saharan countries which predominantly rely on rain-fed agriculture. The rapid rising of temperatures; unpredictable dry spells and episodes of excessive rains affect food production exacerbating existing vulnerabilities related to food insecurity and poverty due to reduced income to farmers and entire population who rely on agricultural supply chain. This study therefore is geared towards determining the effect of climate change and fiscal policy on food insecurity Sub Saharan Africa. A dynamic panel model using the System of Generalized Method of Moments (GMM) estimators was employed in this covering 28 countries. Results indicate that Rainfall and temperature exhibited significant but opposing effects on food security. Increased rainfall was associated with a small but statistically significant improvement in food security, while higher temperatures led to a significant decline. Additionally, Increased government spending on agriculture positively and significantly enhanced food security metrics. Finally, findings indicate the interaction term of institutional quality and fiscal policy positively and significantly impact food security with a notably strong coefficient. The study recommends that governments in sub-Saharan Africa should (i) develop climate-smart agricultural strategies by investing in water management (e.g., water harvesting, conservation techniques, irrigation infrastructure, and drought-resistant crop varieties); (ii) Increase budget allocations to agriculture to meet Maputo and Malabo declaration commitments and facilitate small-scale loans to farmers and (iii) Implement institutional reforms alongside targeted fiscal interventions to maximize the impact of agricultural and food system investments through robust institutions.

Keywords: Climate Change, food Security, fiscal policy, Sub-Saharan Africa

Cite This Article: Caspah Lidiema, Sonal Katyal, “Navigating the Effects of Climate Change and Fiscal Policy on Food Security in Sub Saharan Africa.” *Journal of Finance and Economics*, vol. 13, no. 3 (2025): 124-138. doi: 10.12691/jfe-13-3-5.

1. Introduction

Sub-Saharan Africa faces the compounded challenge of guaranteeing food security in the face of the changing climate and complexities of fiscal policy [1,2]. Climate change, characterized by rising temperatures, irregular rain patterns, and extreme weather events, is a major threat to agricultural production, and may result in reduced crop yields and livestock production [3,4]. Rising temperatures, unpredictable droughts, and severe storms are compounding the problems of food production, which affect not only farmers' incomes but also the entire population that relies on fragile agricultural supply chains. These shocks increase poverty and deteriorate food insecurity, with malnutrition emerging as a widespread health consequence in shock-prone and financially constrained environments [5,6].

The agricultural industry in sub-Saharan Africa is largely rain-fed and highly vulnerable to climate change, leading to lower yields and increased food insecurity [7].

Changes in temperature and precipitation patterns also result in the disruption of traditional farming practices and water scarcity for irrigation as well as the increased prevalence of pests and diseases that result in less farming output [8]. These climate-induced stressors comprise the existing challenges of land degradation, soil infertility, and lack of access to technology, which further weakens agricultural systems weak [9]. The impacts of climate change are most challenging for smallholder farmers, who contribute substantially to farming in sub-Saharan Africa, as they possess a limited capacity to adapt and rely on a livelihood that is sensitive to climate [10]. West Africa is one of the regions most affected by climate change and is expected to have reduced crop yields and consequently less food production, thereby jeopardizing food security [11].

To address the negative effects of climate change on agriculture and food security, evidence suggests that there is a need to invest in climate-smart agricultural practices such as drought-tolerant crop varieties, efficient irrigation technologies, and soil conservation practices [12,13]. These methods not only increase agricultural yield but also make agricultural systems more resilient to climate-

related shocks and help guarantee sustained food production by altering climatic conditions. The purpose of climate-smart agriculture is to increase and enhance adaptive capacity and mitigate it in fallen swoops. Mainstreaming climate risk management into agricultural policy and planning is critical to developing resilience and ensuring food security in the long term in sub-Saharan Africa, where climate change is identified as the most prevalent challenge [14].

Fiscal policies, including government spending, taxation, and borrowing, play a crucial role in shaping agricultural development, infrastructure investment, and social safety nets, which are vital for mitigating the adverse effects of climate change on food security [15]. Therefore, the intricate interplay between climate change, fiscal policy, and food security is a critical issue for Sub-Saharan Africa (SSA), necessitating a comprehensive understanding of their individual and collective impacts on agricultural production, food distribution, and overall nutritional well-being across the region [16]. Given that sub-Saharan Africa is highly dependent on rain-fed agriculture and is increasingly exposed to extreme weather events, the interplay of climate change with fiscal policy not only creates a complex landscape but also demands innovative and context-specific solutions to safeguard food security and promote sustainable development. Thus, there is a need for a comprehensive approach that combines climate-smart agriculture, smart fiscal interventions, and strong institutions to build resilience and ensure equitable access to food for all populations [17]. The urgency of addressing food security in sub-Saharan Africa is amplified by a rapidly growing population, which is projected to reach 1.9 billion by 2050, placing immense pressure on existing agricultural systems [18,19,20,21].

Fiscal policies can play a pivotal role in determining the food security prospects of sub-Saharan Africa by affecting agricultural investment, infrastructure development, and social protection schemes [22]. Government support through agricultural Research and Development extension services and irrigation infrastructure can increase agricultural productivity and food availability [23,24]. Investment in rural infrastructure (roads, storage, and market infrastructure) is an important strategy for reducing postharvest losses, improving farmers' market access, and enhancing the efficiency of food supply chains. Agricultural input prices, consumer food prices, and farm incomes are affected by taxation policies and consequently have a bearing on food security. Fertilizers, seeds, and other inputs receive subsidies that could help reduce the cost of production for farmers and incentivize the adoption of improved technologies, leading to increased agricultural output [25].

Therefore, to reduce poverty food insecurity, governments should integrate and monitor food production, storage, and distribution systems, while ensuring timely grain provision. Most SSA economies achieved independence and focused on agricultural expansion, but a hunger crisis led to the prioritization of nutrition via agricultural policies [26]. Therefore, addressing this complex nexus among climate change, fiscal policy, and food security requires an integrated approach that considers the multiple dimensions of food

security and the different requirements of various actors [6]. This involves facilitating multi-sectorial policy coherence; inter-sectorial cooperation among government agencies, civil society organizations, and the private sector; and enhancing the role of local communities in decision-making processes [27].

In addition, African countries have adopted several measures to address food shortages through the Maputo, Malabo, and Kampala declarations, which address the comprehensive African Agricultural programme. Unfortunately, Africa is the only region in the world where increased export production has caused a decline in per capita food production [26]. The impact is severe malnutrition, child stunting, wasting, underweight, and increased maternal mortality. Maputo [28] and Malabo [28] declare that African Union member states reflect a commitment to increase agricultural investments and speed up agricultural growth in the continent. These declarations include clear milestones for agricultural expenditure, productivity, and trade, with the explicit goals of modernizing the agricultural sector and improving food security throughout the continent. The Maputo Declaration called for a 10% budgetary allocation target for agriculture and 6% productivity growth every year. Ten years later, the Malabo Declaration expanded these objectives to include inclusive growth, climate resilience, and the eradication of hunger by 2025 [28]. Despite these commitments, most African countries have battled Maputo and Malabo Declarations to set their targets [29]. Elements, including lack of funds, lack of institutional capacity, and lack of politics, will continue to hinder progress towards achieving these targets. Overlapping policies also hinder agricultural progress [30].

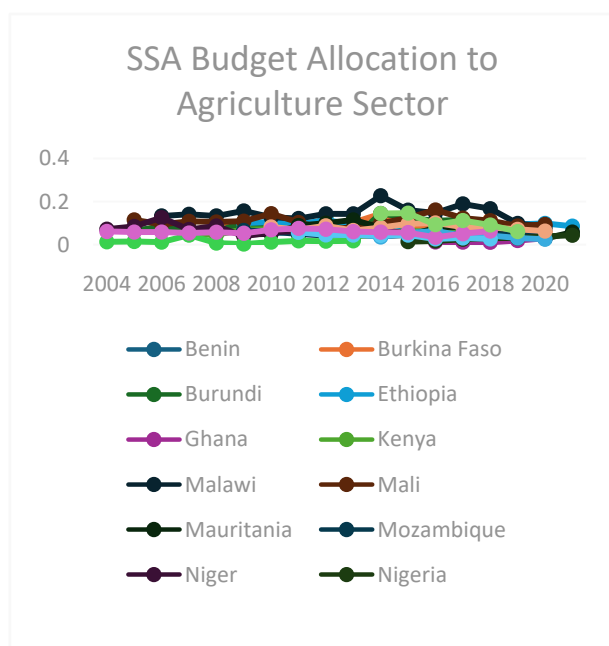
Therefore, without urgent coordinated action to integrate climate adaptation with increased public investment and robust policy implementation, SSA risks entrenching cycles of food insecurity, malnutrition and poverty. However, the African Union has continued its commitment to food security through the launch of the Kampal Declaration under the CAADP Strategy and Action Plan (2026-2035), which introduces a shift from a traditional focus on agricultural production to a broader agri-food system transformation approach [31].

1.1. Stylized Facts on Climate Change, Fiscal Policy, and Food Security in SSA

- i. Climate Change Impacts: From the global droughts recorded, SSA experiences a third, with the Horn of Africa enduring some of the worst droughts in decades [6]. It is predicted that because of increased temperatures, staple crop yields in some regions may decrease by as much as 50% by 2050 [32].
- ii. Food Insecurity: One in five Africans goes to bed hungry, encompassing 140 million people with acute food insecurity [33]. Despite this, malnutrition rates remain high because of falling calorie availability and food affordability as a result of high prices.
- iii. Fiscal Policy Challenges: Few SSA countries meet the Maputo target of allocating 10% of their national budgets to agriculture [33].

- iv. Systemic vulnerability: Over 90% of agriculture in SSA is rain-fed, with less than 1% of the arable land being equipped for irrigation. Weak institutional frameworks limit the implementation of climate-smart policies and hinder adaptation efforts [2].

From this perspective, figure 1 indicates that only a handful of countries, such as Malawi, Burkina Faso, and Mali, occasionally met or exceeded the 10% Maputo/Malabo target. Malawi, in particular, stands out, with peaks above 20% (notably around 2014), but these high allocations were not sustained. However, most countries, including Ghana, Nigeria, Mozambique, and Seychelles, consistently allocated less than 10% of their budgets to agriculture, falling short of Maputo and Malabo commitments. Implications for Maputo and Malabo Goals from figure 1 indicate that, first, the issue of Unmet Commitments in the sense that, despite ambitious declarations, most SSA countries have not consistently met the 10% budget allocation target for agriculture; second, this indicates the Challenge for Productivity Goals. The declining trend in recent years raises concerns about achieving the Malabo Declaration's broader goal of doubling agricultural productivity by 2025, as underinvestment in agriculture persists.



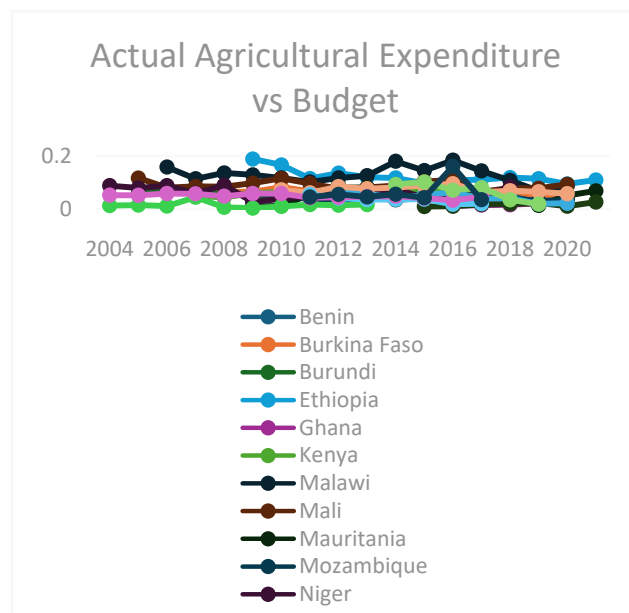
Source: Author representation based on FAO, 2024. MAFAP data hub

Figure 1. SSA Budget Allocation to Agriculture Sector

Figure 2 tracks the actual percentage of national expenditure spent on agriculture by several sub-Saharan African countries from 2004 to 2021 from MAFAP data hub [92]. Similarly, this shows that only Malawi, Burkina Faso, and Mali-occasionally met or exceeded the 10% target in actual expenditure. In fact, data show that in the later years (2018–2021), actual expenditure on agriculture generally declines or stagnates, with almost all countries spending well below the 10% benchmark.

Comparing figure 1 (budget allocations) and 2 (actual expenditures) reveals two key insights. First, while some countries budget close to or above the 10% agriculture target set by the Maputo and Malabo Declarations, actual spending is often lower and more volatile, indicating

challenges to budget execution. Second, the persistent gap between planned and actual investments highlights issues in policy implementation and suggests that meeting stated commitments alone is not sufficient to achieve the intended impact on agricultural development.



Source: Author representation based on FAO, 2024. MAFAP data hub

Figure 2. Actual Agricultural Expenditure vs Budget

According to data from FAO's Monitoring and Analysing Food and Agricultural Policies (MAFAP), a significant portion of agricultural budgets in Sub-Saharan Africa is directed toward subsidies for producers (22%) and consumers (9%), with only 16% going to infrastructure and 18% to research and development and extension services-R&D spending remains below the African Union's target of 1% of agricultural GDP (Pernechele et al. 2021, FAO, 2024). Additionally, the data indicate that infrastructure investments in agriculture are heavily reliant on donor funding rather than domestic budgets, making them vulnerable to external financial shifts. External shocks, such as inflation, debt burdens, and global crises (e.g., COVID-19 and the war in Ukraine) strain the government resources needed for agricultural investment [34,35]. This complex nexus highlights the urgency of aligning fiscal policies with sustainable agricultural practices to address the dual threats of climate change and food insecurity in Sub-Saharan Africa.

1.2. Statement of the Problem

Sub-Saharan Africa (SSA) is confronted with a growing food security crisis largely due to climate change, fiscal underinvestment, and institutional capacity limitations. With over 95% of all cultivated land being rain-fed, the region is extremely sensitive to temperature increases, unanticipated rainfall, and extreme disturbances including droughts and flooding [36,37]. These climate changes are expected to decrease staple crop yields by 50% by 2050, adversely affecting the livelihoods of the rural poor and the food production systems. Smallholder farmers, the key players in SSA agriculture, are particularly vulnerable because of their limited access to irrigation infrastructure

and adaptive technologies, and less than 1% of arable land currently under irrigation [36].

Despite the commitment under the Maputo Declaration to devote at least 10% of their national budgets to the agricultural sector, the majority of SSA countries have persistently failed to meet this goal by prioritizing resources for competing health, education, and servicing debt priorities. This lack of investment perpetuates dependence on rainfed systems, and the uptake of climate-safe agricultural practices is low, leaving the region vulnerable to climate stress [38]. Institutional barriers, including weak governance and fragmented policy implementation, hinder the effective implementation of the climate adaptation strategies outlined in the Malabo Declaration [39]. Consequently, only a few countries are on track to meet regional food security targets, and monitoring and technology transfer remain inadequate.

Few empirical studies have analyzed the combined influence of climate change and fiscal factors on food security in sub-Saharan Africa. Those who have attempted this have only provided suggestions on how to improve food security [40,41,42]. The majority of research has been conducted on individual countries, and those that tackled SSA regions have only used climate change variables. In addition, most studies employed time-series data and may, therefore, fail to explain the influence of climate change and fiscal policy level on regional food security in SSA. Therefore, this study investigates and fills this gap in the literature on the extent to which these factors affect food security in Sub-Saharan Africa using panel data estimation techniques. Therefore, the specific objectives of this study are to (i) determine the effect of climate change on food security in sub-Saharan Africa, (ii) examine the effect of fiscal policy on food security in sub-Saharan Africa, and (iii) Evaluate how Institutional Quality moderates the impact of Fiscal Policy on Food Security in Sub-Saharan Africa.

2. Literature Review

2.1 Theoretical review

This study is underpinned by six key theories. The Climate Theory of Food Insecurity presents a hypothesis that demonstrates that climatic disturbances and alterations cause agricultural disruptions and food system breakdowns, resulting in food insecurity [43]. This theory demonstrates the direct and visible effects of extreme weather events, including droughts, floods, heatwaves, and cyclones, on agricultural production, livestock output, and food supply chain stability. This theory applies most strongly to areas that depend on rain-fed farming practices and experience significant climate variations [44,45]. Second, the Food Availability Decline (FAD) theory is rooted in 1798 Malthusian principles and explains food insecurity as a result of a diminished total food supply, which exceeds population food requirements [46]. According to this theory, when population growth exceeds food production capabilities, widespread hunger and malnutrition occur [47,48]. In addition, Amartya Sen's Food Entitlement Decline (FED) theory shifts the focus from aggregate food supply to individual access to food through

entitlements [49]. Individuals obtain food entitlements through their right to income, assets, market access, and social support networks [50,51]. According to Wheeler and Von Braun [52], climate change destabilizes food systems and leads to volatile food prices, thus affecting food entitlements, financial constraints, and job losses.

Other theories include the Keynesian Economic Theory developed by John Maynard Keynes in 1936: Governments should always intervene in economies to maintain stable aggregate demand levels to achieve full employment [53]. Studies indicate that the application of Keynesian theory shows how governments can use fiscal policies to handle climate-related food security issues and help vulnerable populations [54,55]. The main operations of the Keynesian Economic Theory exist by Stimulating Aggregate Demand: Countercyclical Spending, Price Controls and Subsidies and Investments in Public Goods. Another key theory is the Social-Ecological Systems (SES) theory, which allows researchers to study how human societies interact with natural environments [56]. This theory demonstrates how social and ecological systems maintain a reciprocal relationship, which is essential for addressing environmental and social issues. SES theory suggests that food systems should be analyzed as dynamic adaptive systems that result from multiple social, economic, and ecological influences. Finally, the food system resilience theory has emerged as an essential framework for analyzing and strengthening food systems against various shocks and stresses, including climate change impacts and economic and social disturbances. The Food and Agriculture Organization (FAO) defines food systems as all processes and infrastructure that feed a population through production, processing, distribution, consumption, and waste management [57]. A system demonstrates resilience when it preserves its fundamental operations and organizational framework during disturbances and can restructure itself to maintain essential performance [58,59]. Food system resilience theory combines these concepts to create a comprehensive framework for evaluating food security maintenance under rising uncertainty.

2.2 Empirical Review

2.2.1 Climate change and Food security

Food security across Africa is at risk because it is directly affected by climate, affecting not only agricultural production systems, but also market trade operations. The connection between climate change and food security in Sub-Saharan Africa (SSA) has become essential, because this area faces dual environmental challenges and economic vulnerabilities. Research has shown that climate change has multiple effects on agricultural production and food security. Scientific literature demonstrates that temperature variations and unpredictable rainfall patterns are the main factors. Research conducted in Southern Africa shows that climate change negatively affects agricultural trade because precipitation changes create positive effects, whereas temperature fluctuations produce no significant impacts. Research by Sabola [60] demonstrates the necessity for adaptive strategies to combat agricultural damage from climate change, while

improving food security.

The combination of climate scenarios with agronomic models by Ringler et al. [61] predicted a 3.2% decrease in cereal yield by 2050 under moderate warming conditions. Adesete et al. [62] analyzed 30 SSA countries from 2000 to 2019 using dynamic panel GMM models, which showed that increasing greenhouse gas emissions by 1% would increase malnutrition prevalence by 0.26%. Affoh et al. [63] performed detailed research on 25 SSA nations from 1985 to 2018 and showed that rainfall enhances food availability, accessibility, and utilization in the long term. Food availability and accessibility were negatively affected by rising temperature. Rahal and Elloumi [38] demonstrated, through a coefficient-of-variation analysis, that temperature variability reduces food security through both direct production losses and indirect supply chain disruptions.

Lefe et al. [64] examined how climate variability through precipitation changes temperature fluctuations and how CO₂ emissions affect food security across 40 sub-Saharan African (SSA) countries during 2000-2021. The authors developed a composite food security index through Principal Component Analysis (PCA), which measures all four dimensions: availability, accessibility, utilization, and stability. The Panel Corrected Standard Error (PCSE) technique revealed that increased precipitation directly leads to better food security outcomes in SSA. Research has established that higher rainfall amounts typically lead to improved agricultural yields, which enhances both food availability and accessibility. Additionally, hotter conditions can reduce crop yields, expand evapotranspiration, and exacerbate pest and illness episodes, all of which pose risks to food development and reliability. Berhanu and Wolde [65] highlighted regional disparities, with East Africa experiencing a 15-20% decline in maize yields due to prolonged droughts, in contrast to the limited gains in West African root crops.

Britto et al. [66] investigated how climate change affects agricultural land use in vulnerable regions, particularly in sub-Saharan Africa. According to their study, climate change leads to substantial changes in the agricultural output, water resource availability, and pastureland conditions. Researchers support a dual knowledge framework that merges academic insights with traditional knowledge to enhance the ability of agricultural systems to adapt to changes. A complete understanding of land management and sustainable agriculture under climate change requires an integrated approach. Jahansoozi et al. [67] investigated how climate change affects rural households' ability to maintain food security and resilience in Mashhad Township through their research. This study demonstrates that climate-related stressors reduce agricultural output while increasing food prices. This study confirms a positive relationship between climate change resilience and food security through statistical analysis, which demonstrates that rural households need diversified income streams and agricultural infrastructure improvements to survive climate challenges.

The research of Bununu et al. [68] investigated the relationships between land cover transformations and climate variations and their combined effects on food

security systems. Their study demonstrated how human-caused climate change produces land-use changes, while simultaneously creating climate change effects. Through their research on Nigeria's secondary data, the authors demonstrate how climate change affects food security while showing the need for unified solutions to handle these connected problems. Habte et al. [69] documented the successful adoption of drought-resistant maize varieties by Ugandan farmers, which resulted in a 30% increase in arid regional production.

2.2.2. Fiscal Policy and Food Security

The effects of fiscal policy on food security in Sub-Saharan Africa (SSA) consist of economic growth, public debt management, and broader socioeconomic factors. Research shows that fiscal policies directly affect inflation rates in SSA, which subsequently affects food security. Additionally, Olaoye et al. [37] across 44 SSA countries from 2003 to 2020 demonstrated that positive fiscal policy shocks through public debt have a statistically significant impact on inflation. Food security suffers when inflation increases because it increases food prices, which reduces access to vulnerable groups. This study indicates that maintaining public debt levels below 60.59% of GDP serves as a critical factor for controlling inflation, which leads to better food security outcomes.

A study conducted by Janjua et al. [70] analyze how economic growth, trade openness, and foreign direct investment (FDI) affect poverty rates in SSA. Economic growth is an essential factor, yet its direct connection to poverty reduction remains uncertain because of the existing income distribution problems. The main obstacle to food security is poverty because it prevents people from obtaining sufficient nutritious food. The authors propose new economic policy designs that equally distribute growth benefits to enhance food security.

The implementation of fiscal policy mechanisms together with fiscal interventions serves as an essential tool to tackle these problems. The implementation of specific fiscal measures, including social protection and infrastructure investment, helps reduce climate vulnerability. Dasgupta and Robinson [71] evaluated Ethiopia's Productive Safety Net Programme using difference-in-differences models and found a 12% reduction in household food insecurity during droughts. The 2022 International Monetary Fund (IMF) report advocated for public infrastructure spending, demonstrating through a conceptual economic model that irrigation investments reduce post-shock rural-to-urban migration by 18%, thereby preserving agricultural capital [6].

Climate finance and agricultural adaptation have shown mixed efficacy in international climate funding efforts. Doku and Phiri [72] analyzed panel data from 43 SSA nations from 2006 to 2018, revealing that each 1% increase in climate finance reduces food price volatility by 0.7%, contingent on institutional transparency. However, Phiri and Doku [73] analyzed 43 SSA economies and found that climate finance helps improve food availability in sub-Saharan Africa but does little for food access, stability, or utilization. Other factors, especially FDI and government effectiveness, play a larger role in enhancing the overall food security.

Henderson et al. [74] discussed the potential of

sequential decision-making algorithms to enhance regulatory frameworks in the realm of public policy. While their focus is primarily on law and public policy, the proposed methodologies can be adapted to improve fiscal policy decisions that directly affect food security. By leveraging advanced algorithms, policymakers can better assess the outcomes of fiscal interventions on food prices and availability, thereby ensuring more effective responses to food insecurity. Conversely, Oyelami et al. [75] used fixed-effects regressions to indicate that corruption erodes 30-40% of climate adaptation benefits, emphasizing the need for governance reforms. Trade integration and market policies contribute to buffering localized shortages. The 2022 IMF report stressed that harmonizing cross-border trade protocols could reduce intra-SSA food price disparities by up to 25% [6].

The intersection of fiscal policy and food security in Africa is a critical area of research, particularly in light of the continents' unique challenges and opportunities. Mokoena and Mazenda [76] conducted a ridge regression analysis to explore the relationship between government spending on emancipation programs and multidimensional poverty in South Africa. Their findings suggest that, while health-related expenditures have a significant impact on reducing poverty, investments in housing and social security do not yield similar results. This study demonstrates that fiscal policies should focus on health and well-being to reduce poverty, which will indirectly improve food security.

In a broader context, Xiong et al. [77] studied the worldwide food security situation and showed that Africa and South Asia experienced the worst food security problems. This study demonstrates how machine learning produces an imputed database for 169 countries to show that proper fiscal policies solve food insecurity problems. The authors propose humanitarian relief, together with expanded social safety nets, as fundamental elements of fiscal strategies to enhance food security in underperforming economies. Ahmed et al. [78] studied Bangladesh, but their research revealed price instability patterns in staple crops that apply to African food systems through their analysis of rice and wheat markets. This study demonstrated that stable food prices play an essential role in maintaining food security. Fiscal policies must establish price-monitoring systems and volatility control measures, because African countries face identical food inflation and market instability problems.

2.2.3. Institutional Quality in moderating Effect of Fiscal Policy on Food Security

The moderating role of institutional quality in the context of food security is a critical area of research, particularly in regions facing significant challenges such as South Asia and Africa. Azimi and Rahman [79] investigate the interplay between food insecurity, environmental degradation, and health outcomes in South Asia, highlighting how institutional quality can mitigate the adverse effects of inflationary shocks on food security. Their study revealed that poor institutional quality exacerbates health constraints, suggesting that enhancing institutional frameworks could improve food security and health outcomes. In Africa, the relationship between food security and health outcomes is further complicated by

climate change [80]. Their research showed that climate change has negative effects on health outcomes; however, the impact of climate change on health outcomes differs from one region to another. This shows that there is a need for region-specific approaches that consider the role of institutional quality in addressing food security challenges, as good institutions could act as a shield against the adverse effects of climate change on food security and good health. Omri and Kahia [81] explore the association between institutional quality, natural resources, and multidimensional well-being in Saudi Arabia. Their study demonstrated that proper resource management, combined with robust institutional systems, leads to better human well-being.

Abayomi et al. [82] developed a model that shows how institutional pressures such as coercive, normative, and mimetic forces affect behavioral intentions toward mobile banking adoption. This framework can be used to study food security, where similar institutional pressures may affect stakeholders' intentions and actions in food systems, and thus, affect food security. Klostermeyer et al. [83] addressed the security challenges in video game development and emphasized the need to integrate security considerations into the development process. This insight can be applied to food security, where integrating quality and safety measures into food production and distribution processes is essential. The absence of such integration may lead to vulnerabilities that compromise food security, indicating that institutional quality factors must be robust and well-implemented to mitigate risks.

Qingshi et al. [84] and Qazi and Al-Mhdawi [85] examined the interrelationships among quality and safety metrics within the Global Food Security Index (GFSI). Their findings revealed that food security depends on proper regulatory systems and availability of clean drinking water. This study demonstrates that institutional quality factors, including effective governance and regulatory oversight, play a crucial role in controlling the relationship between food safety and security. This study demonstrates that institutional quality factors influence food security through three main channels: regulatory frameworks, cultural influences, and standardization practices. The research findings establish essential knowledge for future studies to improve food security programs and achieve sustainable development targets.

In conclusion, the literature consistently highlights institutional quality as a moderating factor affecting food security. Strong institutions enable effective resource management and economic development, and help reduce the negative impacts of external shocks, including climate change and inflationary pressures. Policymakers should prioritize institutional development to improve food security and health outcomes in vulnerable areas. Research on institutional quality factors and food security requires an understanding of the multiple moderating influences in this critical field.

3. Research Methodology

3.1. Data and Target Population

Food security was measured using the Global Food

Security Index (GFSI) developed by the Economist Intelligence Unit (now under the Economist Impact). This index is a comprehensive tool for assessing food security across 113 countries through quantitative and qualitative indicators [86]. Climate change was measured using two variables. That is, rainfall (Average Precipitation in depth) and temperature changes in degrees Celsius, as recorded by the University of Anglia Climate Research Unit (CRU). Fiscal Policy proxied by government agriculture expenditure (% of total government expenditure) as a measure of fiscal policy in line with the Maputo Declaration (2003), which Declaration (2014) was extracted from the Regional Strategic Analysts and Knowledge Support System (ReSAKSS) [93]. This study also employs institutional quality from World Governance Indicators as a moderating variable. The average of the six dimensions of governance (voice and accountability, political stability and the absence of violence/terrorism, government effectiveness, regulatory quality, rule of law, and corruption control) was used. Because this was a rate, it was not transformed. Arable land, population, and GDP growth data from World Bank Development Indicators were also included.

The research therefore considered nine observations from 28 countries for the twelve-year period (2012 to 2023) under study. These countries are Angola; Benin; Botswana; Burkina Faso; Burundi; Cameroon; Chad; Cote d'Ivoire; Democratic Republic of Congo; Ethiopia; Ghana; Guinea; Kenya; Madagascar; Malawi; Mali; Mozambique; Niger; Nigeria; Rwanda; Senegal; Sierra Leone; South Africa; Sudan; Tanzania; Togo; Uganda; Zambia. As the changes in these variables are continuous, the population will have 336 observations for each variable under study. This Period was chosen because the comprehensive Global Food Security Index for Country Profiles was available only for 2012.

This study employs a dynamic generalized method of moment estimators developed for dynamic panel model system GMM estimators, as suggested by Arellano and Bond [87] and Blundell and Bond [88,89]. The system GMM estimation technique was used because of its efficiency, consistency, and ability to minimize biases arising from omitted variables, endogeneity, and unobserved effects. The methodology of this study provides a robust framework for understanding the complex relationships among climate change, fiscal policy, and food security in sub-Saharan Africa, offering valuable insights for policymakers and stakeholders. The study also relied on descriptive statistics to provide an overview of the key variables and trends in the data, while a correlation analysis was conducted to examine the relationships between climate variables, fiscal policy indicators, and food security outcomes.

3.2. Model Specification

A general form of the dynamic panel data model is expressed as follows:

$$Y_{it} = \alpha Y_{i,t-1} + \beta' X_{it} + \eta_i + \epsilon_{it} \quad (1)$$

Where:

- Y_{it} is the Dependent variable for individual i at

time t

- $Y_{i,t-1}$ is the lagged dependent variable
- X_{it} represents a vector of explanatory variables
- η_i is an unobserved individual-specific effect, and
- ϵ_{it} is the idiosyncratic error term

The lagged dependent variable $Y_{i,t-1}$ introduces a correlation with η_i (the unobserved individual-specific effect), which, according to Arellano and Bond [87], creates bias in traditional estimators, such as fixed effects or random effects, necessitating advanced estimation techniques that go beyond traditional panel data estimators. The Arellano-Bond estimator overcomes this by using instruments derived from lagged levels and differences in the variables. The key Assumption under the Arellano and Bond's [87] GMM system is that there is No Serial Correlation. This was measured using the Arellano-Bond test for AR(2) for differenced errors. In addition, there should be no over-identification, as measured by the Hansen/Sargan test for instrument validity.

From equation 1 above we can rewrite the general liner model specification as

$$FS_{it} = \alpha FS_{i,t-1} + \beta_1 Rn_{it} + \beta_2 Tr_{it} + \beta_3 FP_{it} + \eta_i + \epsilon_{it} \quad (2)$$

Where:

- FS_{it} is the food security index of country i at time t
- $FS_{i,t-1}$ is the lagged food security index (capturing dynamics),
- Rn_{it}, Tr_{it} and FP_{it} are rainfall, temperature, and fiscal policy variables respectively
- η_i is the unobserved country-specific effect
- ϵ_{it} is the idiosyncratic error term

When Control variables are included, equation 2 above will change to

$$FS_{it} = \alpha FS_{i,t-1} + \beta_1 Rn_{it} + \beta_2 Tr_{it} + \beta_3 FP_{it} + \gamma_1 GDP_{it} + \gamma_2 Pop_{it} + \gamma_3 Land_{it} + \eta_i + \epsilon_{it} \quad (3)$$

Where:

- GDP_{it}, Pop_{it} and $Land_{it}$ are control variables (GDP growth rate, Population, Arable Land)

Finally, to incorporate Institutional Quality (IQ) as a moderating variable in the effect of Fiscal Policy (FP) on Food Security (FS) within the dynamic panel GMM framework, the model can be extended to include an interaction term between Fiscal Policy and Institutional Quality. Equation (3) is transformed into Equation (4) and is indicated below:

$$FS_{it} = \alpha FS_{i,t-1} + \beta_1 Rn_{it} + \beta_2 Tr_{it} + \beta_3 FP_{it} + \beta_4 IQ_{it} + \beta_5 FPIQ_{it} + \gamma_1 GDP_{it} + \gamma_2 Pop_{it} + \gamma_3 Land_{it} + \eta_i + \epsilon_{it} \quad (4)$$

Where:

- IQ_{it} is Institutional Quality-the moderating variable
- $FPIQ_{it}$ interaction term capturing the moderating effect of institutional quality on fiscal policy

- β_3 captures the direct effect of fiscal policy on food security when institutional quality is zero.
- $\beta_4 IQ_{it}$ captures the direct effect of institutional quality on food security.
- β_5 captures how institutional quality modifies (moderates) the effects of fiscal policies on food security. A significant β_5 value implies that the impact of fiscal policy depends on institutional quality.

4. Empirical Findings and Discussion

4.1. Descriptive Statistics

Based on summary statistics, this analysis examines the complex relationships among climate variables, fiscal policy measures, and food security across 336 observations. The descriptive statistics are presented in [Table 1](#).

The Global Food Security Index descriptive statistics demonstrate substantial variations among the countries under study, with a mean score of 46.20 and a standard deviation of 5.49. The range, which spans 32.80 to 66.40, indicates significant disparities in food security within the sub-Saharan African economies. Rainfall patterns demonstrate substantial heterogeneity, with average precipitation ranging from 144.00 to 3,122.90 mm depth and significant variability in precipitation across countries (high standard deviation of 532.95). High kurtosis suggests more frequent extreme values (heavy rainfall events), which can lead to floods and impact agricultural productivity. The temperature data has an average temperature of 25.12°C and a low standard deviation of 3.10. It has a negative kurtosis (-0.87) and skewness (-0.38), which means that it is less peaked and thick-tailed than a normal distribution. This further indicates that most sub-Saharan African countries do not experience too much extreme temperature variations frequently, with the majority of countries falling into a moderate range of 18.06°C. to 30.01°C.

Government spending on agriculture as a percentage of total expenditure shows remarkable variation, averaging 7.43% and ranging from a minimum of 0.36% to 40.32%. A high standard deviation (6.76) and strong positive skewness (1.81) indicate that most countries allocate relatively modest portions of their budgets to agriculture. GDP growth rates display considerable volatility, with a mean of 4.12%, but an enormous range from -20.49% to 21.08%. Negative skewness (-1.80) indicates that economic contractions, together with very low growth rates, occur more frequently. Arable land constitutes an average of 19.02% of the total land area across countries, with significant variation (standard deviation of 14.56%). The negative kurtosis (-0.40) suggests that more countries have relatively higher percentages of arable land. Population sizes vary dramatically, from approximately 2.1 million to 227.9 million people, with high positive skewness (2.82) reflecting the presence of several very populous countries alongside many smaller nations. The

strong positive skew and high kurtosis indicate that food security challenges may be more acute in highly populous countries, owing to greater food demand and pressure on resources. Finally, the Worldwide Governance Indicators showed a mean score of 28.86 with substantial variation (standard deviation of 15.54). Scores range from 3.35 to 72.93, indicating significant disparities in institutional quality and governance effectiveness across countries. The substantial variation in institutional quality scores suggests that effective policy implementation may be constrained by the governance capacity in many regions.

4.2. Interpretation and Discussion of Study Results

This section presents the results of the regression model based on the GMM system as described in the methodology. The discussion will be centered on the three objectives of this study: (i) to determine the effect of climate change on food security in sub-Saharan Africa; (ii) to examine the effect of fiscal policy on food security in sub-Saharan Africa; and (iii) to evaluate how Institutional Quality moderates the impact of Fiscal Policy on Food Security in Sub-Saharan Africa. The results in [Table 1](#) indicate the analysis for both the one-step and two-step systems of GMM with Models 2 and 4, indicating the interaction effect of institutional quality with fiscal policy, whereas Models 1 and 3 do not.

4.2.1. Effect of Climate Change on Food Security in Sub Saharan Africa

The findings from this study revealed that climate factors, namely rainfall and temperature, have significant and opposing relationships with food security. Both rainfall and temperature are expressed in natural logarithms, which means that their coefficients represent elasticities or semi-elasticities with respect to the food security index (FS).

The rainfall as a natural logarithm ($L0.lrain$) has a positive and weakly significant impact on food security, with a coefficient of 18.66 ($p = 0.052$). This implies that a 1% increase in rainfall is associated with an increase of approximately 0.19 unit in the food security index, indicating the significance of precipitation for crop production and food availability. The coefficient of rainfall ($L0.lrain$) in Model 2 is 0.214 ($p = 0.00506$), which is positive and statistically significant at the 1% level. A 1% increase in rainfall results in a 0.00214 unit increase in the food security index when other factors are held constant. The effect size is much smaller in Model 2 than in Model 1 (18.66, $p = 0.052$), but is now highly significant, indicating that after controlling for institutional quality and its interactions, the positive effect of rainfall on food security becomes more evident and robust. These results are consistent with the findings of Affoh et al. (2022) and Lefe et al. (2024), who showed that rainfall enhances agricultural yield and food availability in the long run.

Table 1. Summary of Descriptive Statistics

	Unit of measurement	Obs	Mean	Std. Dev.	Kurtosis	Skewness	Minimum	Maximum
FS	Global Food Security Index (GFSI),	336	46.20	5.49	2.05	0.91	32.80	66.40
Rain	Average Precipitation in depth	336	1,052.45	532.95	1.85	0.79	144.00	3,122.90
Temp	Temperatures changes in degrees Celsius	336	25.12	3.10	(0.87)	(0.38)	18.06	30.01
FP	Government agriculture expenditure (% of total government expenditure)	336	7.43	6.76	4.47	1.81	0.36	40.32
Land	Arable land (% of land area)	336	19.02	14.56	(0.40)	0.88	0.46	52.25
POP	Total Population by census and estimates	336	36,347.32	40,389.38	8.65	2.82	2,108.62	227,882.95
GDPR	Annual percentage growth rate of GDP at market prices	336	4.12	4.03	10.38	(1.80)	(20.49)	21.08
INST	Worldwide Governance Indicators (WGI)	336	28.86	15.54	0.26	0.72	3.35	72.93

In Model 3, the coefficient of current rainfall ($L0.lrain$) was 0.24227 ($p = 0.04276$), indicating that a 1% increase in rainfall was associated with an approximately 0.0024 unit increase in the food security index. This positive and statistically significant effect highlighted the critical role of adequate precipitation in supporting agricultural productivity and enhancing food security. Model 4, which accounts for institutional quality and its interaction with fiscal policy, shows that the positive effect of current rainfall remains statistically significant, but slightly smaller (coefficient = 0.21489, $p = 0.03617$). This means that, even after controlling for governance factors, a 1% increase in rainfall still led to roughly a 0.0021 unit increase in food security, reaffirming the importance of rainfall. The positive association shows that the increased availability of rainfall has a positive influence on food security via a positive effect on agricultural production and crop and livestock water supply. Nevertheless, the marginal significance of these results indicates that despite being a strong effect, it should be interpreted cautiously. These findings provide evidence that appropriate water resource management and adaptation measures to address rainfall variability are essential because climate change will precipitate more erratic rainfall patterns.

The food security index decreases by about 0.13 units when temperature rises by 1% according to Model 1 ($L0.ltemp$). The Model 2 coefficient of -0.526 ($p < 2e-16$) shows a negative relationship between the temperature increase and food security index decrease. Model 1 showed a negative effect of -13.16 ($p = 0.015$), but Model 2 showed a more significant negative effect of -0.526 ($p < 2e-16$). The negative effect is consistent with Model 1 (-13.16, $p = 0.015$), but the magnitude is much smaller, and the significance is even stronger in Model 2. This negative and statistically significant effect indicates that higher temperatures are harmful to food security because they cause crop heat stress, reduce yields, and increase water loss through evapotranspiration. The coefficients for lagged temperature effects ($L1.ltemp$ and $L2.ltemp$) are not statistically significant in either Model 1 or Model 2, indicating that the negative impact of temperature is most pronounced in the short term rather than persisting over multiple years. The findings of this study are consistent with those of Rahal and Elloumi [38], Lefe et al. [64], and Berhanu and Wolde [65], who showed that temperature variability reduces food security through reduced yield. This finding highlights the sensitivity of food systems to temperature increases, which leads to decreased crop production and food insecurity. The changes in magnitude between model1 and model 2 are

due to the inclusion of interaction effects in Model 2, which likely absorb some of the variation previously attributed to climate variables in Model 1.

Interestingly, in Model 3, the current temperature ($L0.ltemp$) in Model 3 has a coefficient of 0.49544 ($p = 0.00339$), suggesting that a 1% increase in temperature corresponds to an increase of approximately 0.0050 units in the food security index. This positive temperature effect is somewhat counterintuitive given the usual expectation that higher temperatures can stress crops. This may reflect specific local conditions or nonlinear temperature effects that were not captured in the model. However, in Model 4, which incorporates the interaction effect between institutional quality and fiscal policy, current temperature becomes statistically insignificant and near zero (coefficient = -0.00973, $p = 0.94101$), indicating that when institutional quality is considered, temperature no longer has a direct measurable impact on food security. This shift suggests that institutional factors may mediate or confound the relationship between temperature and food security or that temperature effects are more complex and possibly nonlinear.

4.2.2. Effect of Fiscal Policy on Food Security in Sub Saharan Africa

The findings show that agricultural government spending, as a percentage of total expenditure, has a positive relationship with food security. In Model 1, the coefficient of fiscal policy ($L0.FP$) equals 0.1160 ($p = 0.026$), which shows that higher government agricultural spending leads to better food security. The effect size indicates that fiscal investments in the agricultural sector substantially improve food access, stability, and utilization through infrastructure development, research support, and farmer assistance programs. Model 2, which includes the interaction effects of institutional quality, shows that the coefficient for fiscal policy increases to 0.474 ($p = 0.00201$) after including institutional quality and its interaction with fiscal policy, yet remains statistically significant and positive. The results in Model 3 show that government spending on agriculture as a percentage of total expenditure has no significant direct effect (estimate = 0.02306, $p = 0.84148$). In Model 4, the direct effect of fiscal policy ($L0.FP$) becomes marginally significant (estimate = 0.2721, $p = 0.08932$), suggesting a weak positive influence of institutional quality on food security.

The findings of this study agree with those of Dasgupta and Robinson [71] and Baptista et al. [6], who show that fiscal policy measures can help preserve agricultural

capital and, hence, enhance food security. In addition, through fiscal policy on climate financing, these findings agree with the results of Doku and Phiri [72] and Phiri and Doku [73] who found that fiscal policy through climate financing not only enhances food availability in Sub-Saharan Africa but also reduces food price volatility by 0.7 percent.

This suggests that increasing the share of government expenditure on agriculture continues to improve food security; however, the results indicate that fiscal spending alone may not be sufficient to improve food security unless it is supported by other factors. The results highlight the need to interpret fiscal policy effects in conjunction with institutional quality, because the direct effect is limited without accounting for governance. The persistence of significance levels highlights the importance of government commitment to supporting the agricultural sector through budgetary allocations, actual spending on extension services training, and the provision of subsidies to support farmers and consumers. This should be performed in conjunction with broader governance factors. Overall, the results highlight the importance of sustained and targeted government spending on agriculture as a policy lever to bolster food security, particularly in the face of climate change.

4.2.3. Institutional Quality in moderating Effect of Fiscal Policy on Food Security

Institutional Model 2 introduces institutional quality (L0.Inst) and its interaction with fiscal policies (L0.FPInst and L1.FPInst, respectively). Institutional quality alone has a strong and highly significant positive effect on food security, with a coefficient of 0.330 ($p < 2e-16$), indicating that better institutional environments directly enhance food security outcomes. The interaction terms (L0.FPInst: 0.698, $p = 0.00681$; L1.FPInst: 0.296, $p = 0.00605$) were also positive and statistically significant, suggesting that the beneficial impact of fiscal policies on food security is amplified in countries with higher institutional quality. Similar results are observed in Model 4, where institutional quality (L0.Inst) and its interaction with fiscal policy (L0.FP_Inst). Institutional quality has a positive and statistically significant effect on food security (estimate = 0.20445, $p = 0.02285$). This finding confirms that better governance and institutions directly enhance food security outcomes. More importantly, the interaction term between fiscal policy and institutional quality is highly significant and positive (estimate = 0.22948, $p = 0.00866$), indicating that the effectiveness of government spending on agriculture in improving food security is substantially amplified in countries with stronger institutions. These results agree with the literature review by Azimi and Rahman [79], Wang et al. [80], and Omri and Kahia [81], who indicated that strong institutional systems help address food security challenges, such as mitigating inflationary pressure and enabling people to access food easily.

This moderating effect underscores that the impact of fiscal policy can only be felt through critical interdependence with the quality of institutions. This emphasizes the importance of good governance in translating fiscal resources into tangible food security

improvements. In other words, government spending on agriculture, as per Maputo [28] and Malabo [28], will only be more effective in improving food security when implemented within the context of strong and effective institutions. This finding underscores the importance of not only increasing fiscal resources for agriculture, but also strengthening governance, transparency, and policy implementation to maximize the impact of such spending.

4.2.4. Macro-economic Effects

Regression results from Models 1 and 2, as indicated in Table 2, suggest that the current GDP growth rate (L0.gdpr) and second lag (L2.gdpr) do not significantly influence current food security, given that the p-values are above the 5% significance level thresholds. However, the first lag in GDP growth (L1.gdpr) was highly significant and positive in both models (Model 1: 28.97, $p = 0.00024$; Model 2: 0.232, $p < 2e-16$). This indicates that the higher GDP growth in the previous period is strongly associated with improved food security in the current period. The magnitude of the effect is much larger in Model 1 but remains significant and positive in Model 2, suggesting that the benefits of economic growth for food security may take time to materialize, likely through increased income, employment, and resources for food access. In Model 3, Current GDP growth (L0.gdpr) has a positive and marginally significant effect (0.7461, $p = 0.0519$), whereas the coefficient diminishes in magnitude and loses significance (0.215319, $p = 0.15186$) in Model 4. These results are consistent with the long-run GMM findings by Akinbode [90] and Algifabri and Heriqbaldi [91], where GDP per capita reduced hunger in SSA, but the short-term effect highlights the complexity of growth's immediate impact without institutional support. This finding supports the hypothesis that economic growth enhances food access through higher income and investments in agriculture.

In both models, the effect of population size (L0.lpop) on food security was negative, but not statistically significant. The coefficients are -4.27 ($p = 0.307$) and -0.208 ($p = 0.106$) for Models 1 and 2, respectively, suggesting that even after controlling for other factors, changes in population size do not have a robust direct impact on the food security index in this dataset. The negative sign could imply that, all else being equal, larger populations may put some pressure on food security, but the lack of statistical significance means that this effect is not reliably different from zero. In Model 3, the natural log of population (L0.lpop) shows a positive and marginally significant effect on food security (coefficient = 0.48034, $p = 0.08399$). Similarly, in Model 4, the coefficient remains positive but becomes statistically significant (0.29224, $p = 0.01228$), which is consistent. This contrasts with the findings of Akinbode [90], who found that population growth increased hunger in Sub-Saharan Africa (SSA). However, the marginally significant positive effect in Model 4 might reflect economies of scale in food production or urbanization benefits (e.g., better infrastructure or market access). This suggests that, when institutional quality is accounted for, population growth may exert a more robust, albeit smaller, positive influence on food security. As highlighted by Qingshi et al. [84], this could imply that stronger

institutions mitigate negative Malthusian pressures (e.g., resource scarcity), enabling population growth to align with improved food systems.

Arable land was included as a percentage of total land size and appeared with three lags. In Model 1, the current value (L0.land) is strongly negative and highly significant (-16.76, $p < 0.001$), as is the second lag (L2.land = -10.09, $p = 0.004$), whereas the first lag (L1.land) is negative but not significant (-7.60, $p = 0.166$). This negative relationship was unexpected, as more arable land is typically associated with higher food security. However, this could reflect issues, such as land degradation, inefficient land use, and other confounding factors in the dataset. However, while Arable land shows a negative effect in Model 1, in Model 2, after accounting for institutional quality and its interaction with fiscal policy, the effect of arable land becomes positive and statistically significant for the current value (L0.land = 0.232, $p = 0.010$), whereas the lags remain positive, but not significant. In Model 3, arable land (L0.land) has a strong

positive and significant effect (0.44324, $p = 0.00846$). These results align with the study by Qingshi et al. [84], which emphasizes the critical role of arable land in food production. This shift in sign and significance suggests that when controlling for the quality of institutions and their interaction with fiscal policy, the expected positive relationship between arable land and food security emerges. This highlights that the benefits of arable land for food security are more pronounced in environments with supportive institutions and effective fiscal policies.

4.3. Post-Estimation Analysis

Performing diagnostic tests in the Arellano-Bond [87] system GMM framework is critical for ensuring estimator validity, reliability, and compliance with the model assumptions. Three key diagnostic checks were performed, as presented in Table 3. These include Instrument Validity/Hansen Tests, Serial correlation tests, and Wald test, the results of which are discussed below.

Table 2. One-step and two-step System GMM Estimations

	Dynamic linear panel estimation (onestep)				Dynamic linear panel estimation (twostep)			
	Model 1		Model 2		Model 3		Model 4	
Variables	Estimate	Pr(> z.rob)	Estimate	Pr(> z.rob)	Estimate	Pr(> z.rob)	Estimate	Pr(> z.rob)
L1.FS	0.87678	< 2e-16***	0.48466	< 2e-16***	0.14798	0.48518	0.712846	1e-05***
L0.lrain	18.6627	0.05226.	0.21438	0.00506**	0.24227	0.04276*	0.21489	0.03617*
L1.lrain							0.277749	0.10938
L0.ltemp	-13.16039	0.01544*	0.52626	< 2e-16***	0.49544	0.00339**	-0.009734	0.94101
L1.ltemp	6.74095	0.11852	-0.05161	0.60655	-0.04507	0.63907	0.143968	0.28372
L2.ltemp	-2.28173	0.3794						
L0.FP	0.11603	0.02615*	0.4745	0.00201**	0.02306	0.84148	0.272098	0.08932.
L0.land	-16.75557	0.00008***	0.23194	0.01035*	0.44324	0.00846**	0.180541	0.2259
L1.land	-7.60126	0.16605	0.08688	0.61075				
L2.land	-10.09023	0.00426**						
L0.lpop	-4.27121	0.30678	0.20812	0.0668.	0.48034	0.08399.	0.29224	0.01228*
L1.lpop					0.45846	0.01026*		
L0.gdpr	-6.99331	0.26442	0.1449	0.61778	0.7461	0.0519.	0.215319	0.15186
L1.gdpr	28.96563	0.00024***	0.23246	< 2e-16***	0.05241	0.07773.		
L2.gdpr	-3.50308	0.40372						
L0.Inst			0.33002	< 2e-16***			0.20445	0.02285*
L0.FP_Inst			0.69801	< 2e-16***			0.229479	0.00866**
L1.FP_Inst			0.29634	0.00605**				
No. of Instruments	85		77		86		64	
AR(1)	-1.3399	0.1803	-1.5044	0.1325	-2.1268	0.03343	-1.5689	0.1167
AR(2)	0.53395	0.5934	0.097418	0.9224	-1.7924	0.07306	-1.9974	0.04578
Hansen Test	13.069	1	13.51	1	16.135	1	19.267	1
Wald test	7300	2.20E-16	8112.4	2.20E-16	152.9	2.20E-16	80.232	1.33E-12
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1								

Table 3. Diagnostic tests results

Test	Model 1	Model 2	Model 3	Model 4
No. of Instruments	85	77	86	64
AR(1)	-1.3399 (0.1803)	-1.5044 (0.1325)	-2.1268 (0.03343)	-1.5689 (0.1167)
AR(2)	0.53395 (0.5934)	0.09742 (0.9224)	-1.7924 (0.07306)	-1.9974 (0.05578)
Hansen Test	13.069 (0.75592)	13.51 (0.062055)	16.135 (0.50647)	19.267 (0.50811)
Wald test	7300 (2.20e-16)	8112.4 (2.20e-16)	152.9 (2.20e-16)	80.232 (1.220e-12)

4.3.1. Serial Correlation Test

The AR(1) test checks for first-order serial correlations in the differenced residuals: The results show that Models 1, 2, and 4 have AR(1) p-values greater than 0.05 (0.1803, 0.1325, and 0.1167, respectively), indicating no significant first-order autocorrelation. Model 3, however, has a p-value of 0.03343, which is significant and is expected in GMM models owing to differencing. The presence of AR(1) autocorrelation in Model 3 is not a concern, suggesting that the model behaved as anticipated. The AR(2) test is crucial for validating System GMM estimations, as a significant second-order autocorrelation indicates a model misspecification. In the table, all models have AR(2) p-values above 0.05 (ranging from 0.05578 in Model 4 to 0.9224 in Model 2), suggesting that none of the models suffer from problematic second-order autocorrelation. This supports the validity of the instrument selection and the model specification.

4.3.2. Hansen Test of Overidentifying Restrictions

The Hansen test was used to evaluate the overall validity of the instrument. The test statistics and p-values show that Models 1, 3, and 4 have relatively high p-values (0.75592, 0.50647, and 0.50811, respectively), suggesting that the instruments are valid and uncorrelated with the error terms. Model 2 had a lower p-value of 0.062055, which is close to the conventional cutoff of 0.05, implying a borderline case in which instrument validity should be interpreted cautiously. Overall, the Hansen test results support the appropriateness of the instrument sets, although a relatively large number of instruments requires careful consideration.

4.3.3. Wald Test

The Wald test evaluates the joint significance of the explanatory variables in each model. In the results, all models have extremely low p-values (less than 0.0001), indicating that the set of explanatory variables is highly significant in explaining the dependent variable. This means that the models have strong explanatory power and the variables included are meaningful predictors.

5. Conclusion

This study revealed that climate factors (rainfall and temperature) have significant but opposing effects on food security. First, the empirical results conclude that climate change has a significant influence on food security in Kenya. Rainfall and temperature had significant but opposing effects on food security. Rainfall was associated with a small but statistically significant increase in the food security index (FS). In contrast, temperature led to a statistically significant decline in the FS index, reflecting crop heat stress, reduced yield, and greater water loss. Second, this study concludes that increased agricultural spending improves food access, stability, and utilization through infrastructure development, research, and farmer support programs. The findings further reveal that fiscal policies directed at climate financing can also enhance food availability and reduce food price volatility in sub-Saharan Africa. In addition, the results also

conclude that while fiscal policy enhances food security, it is not sufficient. However, when institutional quality and its interaction with fiscal policies are included, this effect is enhanced, reinforcing the need for strong governance mechanisms. Therefore, this finding emphasizes the need not only to increase fiscal resources for agriculture but also to strengthen governance, transparency, and policy implementation to maximize the positive effects on food security.

6. Policy Implications and Recommendations

The findings of this study have important policy implications for food security in sub-Saharan Africa. The study findings revealed that rainfall was associated with a small but statistically significant rise in food security, whereas temperature led to a statistically significant decline in the FS index. To address the impacts of climate change on food security, there is a need for government policies that require investments in water management (water harvesting and conservation techniques), irrigation infrastructure, and adapting drought-resistant crop varieties to build climate resilience in agricultural systems against rainfall variability and temperature increases. Policies need to concentrate on climate-smart agriculture, weather shock early warning systems, and social safety nets to protect vulnerable populations during periods of drought and heat stress. Adaptation of households to changing climatic conditions can be achieved through agricultural extension service strengthening and livelihood diversification promotion, which will maintain food security despite temperature increase and rainfall variation.

The study's findings also show that increased government spending or budget levels enhance food security. Therefore, this study proposes that there is a need to increase budget allocations to agriculture to meet the Maputo and Malabo [28] declaration commitments. Government-initiated financial inclusiveness must be facilitated by making small-scale loans available to farmers to invest in adaptive technologies and practices. This study also recommends the need to expand farmer training programs to improve the knowledge of sustainable and climate-resilient farming spearheaded by the government.

Finally, the study demonstrates that institutional quality improves food security independently, while also creating a positive effect when interacting with fiscal policy, which means that better governance through transparency and accountability and effective government operations leads to improved food security results. Fiscal policies designed to support food security achieve better results when operating in strong institutions. Policymakers should implement institutional reforms along with specific fiscal interventions to maximize the impact of supporting agricultural and food system investments through robust institutions.

Funding Statement: The authors did not receive any funding for this study.

Author Contributions: Caspah Lidiema and Sonal Katyal are authors of this manuscript. The authors have read and approved the final manuscript.

Conflict of Interest Declaration: The authors declare that they have no affiliations with or involvement in any organization or entity with any financial interest in the subject matter or materials discussed in this manuscript.

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