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# Climate change and food security in selected Sub-Saharan African Countries

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## Abstract

This study examined the nexus between climate change and food security in Sub-Saharan African Region (SSA). With focus on 30 countries within the region, the study employed the dynamic panel data analysis using the one-step and two-step system generalized method of moments (GMM) model. The time observed spanned from 2000 through 2019. The study found that increase in greenhouse gas emission would lead to an increase in prevalence of malnourishment rate, resulting in a decrease in food security in SSA. In addition, climate change and food price have a negative significant effect on food security, while income and food supply have a positive significant impact on food security in SSA. The findings also revealed that the decline in carbon emission is expected to boost agricultural supply and productivity, reduce the prevalence of malnourishment rate and promote food security. Thus, the study recommends that SSA region should be more deliberate about meeting its targets towards achieving zero net emission. Furthermore, the region should improve its domestic food production capacity by implementing policies that will support improvement in agricultural production in the region.

**Keywords** Climate change · Greenhouse gas emission · Food security · Income · Sub-Saharan Africa

**JEL** O13 · O44 · O55 · Q19 · Q54 · Q56

## 1 Introduction

The problems of greenhouse emissions have become a global issue that has attracted the aggressive attention of policy-makers and global world leaders in recent times. Ambitious efforts towards significant reduction of $CO_2$ emissions globally commenced in 2015 after the Paris accord agreement. As the United Nations concluded its Climate Change Conference (COP 26) meeting in 2021, countries set aggressive and determined targets towards

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transitioning to cleaner and green energy (United Nations Climate Change Conference, UK, 2021). These efforts are very important, necessary, and are expected to be timely in order to see a shift to a world free of greenhouse emission.

Climate change affects several aspects of livelihood, which includes food security, environment degradation, poverty, etc. Climate change and its variability are significant drivers of the global rise in hunger (FAO et al., 2018). Food security is indispensable to survival, while food insecurity is a reflection of a dysfunctional food system (Capone et al., 2019; El Bilali et al., 2020). According to Food and Agriculture Organization (FAO), food security is described as a situation where there is physical, social, and economic access to sufficient, safe, and nutritious food for all people at all times to have an active and healthy life (FAO, 2009). Food security addresses goal 2 and 3 of sustainable development goals (SDGs), which is zero hunger and good health and mental wellbeing. Achieving food and nutrition security has remained a major health challenge in developing countries, particularly in regions like SSA.

Climate change influences food security on several fronts, which includes a direct and indirect impact on several aspects of food security, particularly in the agricultural and livestock sectors (García, 2013). Food insecurity increases the risk of malnutrition and contributes to poor health particularly in the vulnerable children and women. This in turn negatively affects their educational performance and yields poor productivity.

According to the committee on world food security, food security is established on four pillars, namely food availability, food access, food utilization, and food stability. Food availability speaks to sufficiency and consistency in the quantities of food produced and supplied in the country. Food access is about the physical access and affordability of food, while food utilization is the proper use of food in terms of basic nutrition and knowledge (Ericksen, 2008; FAO et al. 2013). Food stability is a continuous access to and supply of adequate food at all times, irrespective of sudden shocks that hit the economy. Evidently, there is a dynamic relationship between food security and climate change. On the one hand, the search for food security has several implications on climate change; conversely, climate change has impact on all classes of food security. In addition, the struggle for the control and ownership of the limited agricultural and natural resources has resulted to security challenges in major parts of the world (Ani et al., 2021).

In Africa, it is projected that global warming over the next century will increase with an average of 3–4 °C, which is expected to be above the global annual mean (Boko et al., 2007; Thompson et al., 2010). SSA in particular will experience intermittent high rain intensity (Christensen et al., 2007; Thompson et al., 2010). This will be in addition to existing sensitivity to rain variability in SSA because of the predominance of rain-fed agriculture in the region. In the same vein, food inflation in the region has been on an exponential rise since the pandemic, while household income is eroding sharply, especially after the event of the lockdown policies of the government following the covid-19 pandemic. Households in SSA in particular faced multiple challenges which includes eroding disposable income, high level of poverty, high food cost and food supply constraint. According to the World Bank, over 40 million people feel into poverty in 2020 which is largely driven by higher food prices and energy price. These factors will definitely raise major concerns on food production and food security in Africa.

Therefore, this paper need to ask how detrimental is the impact of climate change on food security in SSA? In addition, what will be the effect of food supply, food inflation and income on food security in the region? Unearthing these questions is very important for the SSA region because the pandemic-induced hardship has worsened food security in the already plagued African nations. Africa houses the second highest number of people with food insecurity after Asia with an alarming 25.9% (346.6 million) in 2020 from 17.7% (203.5 million) in 2014. More precisely, West Africa is the most affected region in the continent with about 28.8% of its population (115.7 million) exposed to food insecurity in 2020 from 8.6% in 2014 (Otekunrin et al., 2021; FAO et al. 2021).

Providing answers to the questions raised above is the basic thrust of this paper. Specifically, the study contributes to the extant literature by providing fresh evidence on the relationship between climate change and food security in Sub-Saharan Africa. The study will examine thirty (30) Sub-Saharan African countries spanning from 2000 to 2019. The remaining parts of this paper are organized as follows: Sect. 2 presents the literature review on climate change and food security. Section 3 gives the theoretical framework, the methodology and the model used in the study. Section 4 contains presentation and analysis of results as well as the interpretation of findings. The final section concludes the paper.

## 2 Brief review of empirical literature

This section undertakes the review of the empirical studies on the relationship between climate change and food security.

The work of Ani et al. (2021) unravelled the impact of the changing nature of climate on food and human security within the Nigerian context. They employed both qualitative and quantitative approaches (primary and secondary data source) on the six geopolitical zones. They found that climate change significantly affects food security negatively in Nigeria. There was also evidence of armed confrontations over natural resources which leads to insecurity in the country. Similarly, Otekunrin et al. (2021) studied food insecurity particularly among the farming households in Nigeria. They employed the multi-stage sampling technique on a cross section of 211 farming households. More precisely, they used the household food insecurity access scale approach to measure food insecurity, while they used ordered logit method for analysing the factors influencing food insecurity. Their study found that the percentage of food secure farming household was 12.8%, while 87.2% was exposed to food insecurity. In addition, demographic and economic factors such as the age of the farmer, lead household's years of schooling, gender, the farm size and experience, and access to extension service had significant impact on food insecurity among the observed farming households. The study therefore recommends the promotion of education-related intervention programs and the provision of rural infrastructural facilities such as boreholes, power supply and healthcare services.

Tarasuk et al. (2019) examined the socio-demographic and geographic drivers of food insecurity among households in the Canadian economy. They observed a wide sample of households (about 120,909) spanning from 2011 to 2012. The 18-item Household Food Security Survey Module was used to access food security. Furthermore, they determine the presence and severity of food insecurity among households by using the multivariable binary and multinomial logistic regression. Their result indicated there is food insecurity among households, and, it varied from region to region. It was 11.8% in Ontario, while it was 41.0% in Nunavut. They concluded that the probability of food insecurity and its severity depends on the province, source of income, level of education and structure of households.

Furthermore, a study by Verschuur et al. (2021) used an extreme event attribution (EEA) approach and was combined with an explanatory framework that examined climate change impact on worsening food production shocks in Lesotho. More precisely, they evaluated how crops are sensitive to climate change and gave some insights into its implications for food security. They found climate change to be a very important driver of food production shocks in Lesotho in 2007. The findings also revealed that the fragile state of the agricultural sector worsens their trade dependency. This can affect the country's ability to build resilience to climate change impact both in the present and in the future.

Ringler et al. (2010) employed a comprehensive climate change scenario (CCC) on 17 Global Circulation Model (GCMs) which was selected based on their relative performance for Sub-Saharan Africa. Their result showed a high prediction of hotter temperature coupled with complex precipitation changes for the period 2050. This implies that climate change will have adverse impact on crop yield and growth in the future. It will also lead to rise in food prices which will lower food affordability, reduced calorie availability, and growing childhood malnutrition in Sub-Saharan Africa.

Molotoks et al. (2021) studied the future impacts of climate variability, population changes, and land use on food security in a global context. They used the food estimation and export for diet and malnutrition evaluation (FEEDME) modelling framework to determine the per capita calories. They also used two representative concentration pathway scenarios from the intergovernmental panel on climate change to account for climate variability. They incorporated land use and population change in their model together with three shared socio-economic pathways (SSP). Their findings showed that changes in population made the SSP scenarios have larger impact on future food insecurity. In addition, their findings showed that population growth is the dominant driver of changes in undernourishment in a global context. The study therefore recommends that improvement in maternal health care and increasing food access will mitigate all consequences of the projected population growth.

More recently, Affoh et al. (2022) examined the relationship between climate variables and food security utilization on 25 SSA countries spanning from 1985 to 2018. Using panel autoregressive distributed lag, they found that rainfall positively and significantly affect access to food, availability of food and its utilization in the long-run. On the other hand, temperature negatively impact access to food and its availability, while it does not affect food utilization. They further estimated the model for robustness check using panel fully modified ordinary least squares (FMOLS) and dynamic ordinary least squares (DOLS) and found a causal relationship between food availability and CO2 emission in the short run. In addition, food utilization was strongly connected with temperature, while the link with food accessibility was rather causal. They recommended that governments in the region should provide adequate funding on food production by providing subsidy to farmers and promoting proper irrigation system in the country.

Despite the increased empirical efforts on the impact of climate change on food security, there appears to be a dearth of studies in developing countries compared to what is available in the developed world. This study extends the body of literature by seeking to shed more light on the complicated relationship between climate and food security in SSA.

## 3 Research methodology

### 3.1 Theoretical framework

There are different ways of modelling food security, which are food consumption, utilization or malnourishment rate. This paper uses a combination of conventional demand, supply and utility theories. This is because the utility derived from food can be related to the satisfaction obtained by a consumer or household from the food consumed. Higher food consumption of utility would result in the decline in the prevalence of malnourishment rate. These were some of the assumptions proposed by this paper for the theoretical framework:

### 3.1.1 Assumptions

1. There is a positive direct link between utility and food security due to the impact of food satisfaction (nutrition) on malnourishment rate.
2. The economy produces food and non-food commodities
3. Consumer and household's utility is influenced by factors that influences food demand and supply.
4. Climate change is an important determinant of food supply and food security.
5. Utility derived from food is negatively related to prevalence of malnourishment rate and positively related to food security.
6. Demand for food is greater than domestic supply of food in most SSA countries. The excess demand is cushioned with food imports.
7. Food utility is characterised with a Cobb–Douglas function whereby the inputs would be factors affecting food security including climate change and the output is food security.

### 3.1.2 The Combined and Modified Demand, Supply and Utility Theories

$$\mathrm{U_f} = \mathrm{f(Z)} \tag{1}$$

Z = Basket of food commodities $X_1, X_2, X_3,\ldots\ldots\ldots, X_n$

$$\mathrm{Z} = \left(\mathrm{X_1},\ \mathrm{X_2},\ \mathrm{X_3}, \ldots\ldots\ldots, \mathrm{X_n}\right) \tag{2}$$

$$\mathrm{U_f} = \mathrm{f}\left(\mathrm{X_1},\ \mathrm{X_2},\ \mathrm{X_3}, \ldots\ldots\ldots, \mathrm{X_n}\right) \tag{3}$$

Z = f(climate change, other factors(OF)).

### 3.1.3 Other factors (OF)

(1) Income (Y)
(2) Population growth (POPGR)
(3) Food supply (FS)
(4) Food price (FP)

Other abbreviations.

(1) Food Utility ($U_f$)
(2) Climate Change (CLC)
(3) Food Security (FSEC)
(4) Prevalence of malnourishment rate (PRM)
(5) Error term ($\varepsilon$)

Therefore,

$$\mathrm{U_f = f(climate\ change,\ other\ factors)} \tag{4}$$

Link between food utility, prevalence of malnourishment rate and food security.

(i) Food utility is negatively related to prevalence of malnourishment rate (PRM)
$\mathrm{U_f} \sim$ -PRM.
(ii) Food utility is positively related to food security
$\mathrm{U_f} \sim$ FSEC.
(iii) Food security (utility) translates to the inverse of the prevalence of malnourishment rate (100—MR).
$\mathrm{U_f} \sim$ FSEC ~ (100—MR).

### 3.1.4 Interpretation of (i) to (iii)

If the utility derived from the consumption of the basket of food commodities ($X_1$, $X_2$, $X_3$,………,$X_n$) rises, consumers or household would extract higher nutrients. This would in turn lead to the decrease in the prevalence of malnourishment rate and an improvement in food security.

### 3.1.5 The Model

$$\mathrm{FSEC = Z = u\left(X_1,\ X_2,\ X_3, \ldots\ldots\ldots, X_n\right) = f(climate\ change,\ other\ factors)} \tag{5}$$

$$\mathrm{FSEC = Z = u\left(X_1,\ X_2,\ X_3, \ldots\ldots\ldots, X_n\right) = f(CLC,\ OF)} \tag{6}$$

CLC—climate change, OF—other factors

$$\mathrm{FSEC = f(CLC,\ OF)} \tag{7}$$

Transforming Eq. 7 to a Cobb–Douglas function,

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

A = the technical knowledge required for food production and this is constant.
Take the natural logarithm of both sides of Eq. 8

$$ln(FSEC) = ln\left[A(CLC)^{\alpha}(OF)^{\beta}\right] \tag{9}$$

$$ln(FSEC) = ln[A] + ln\left[(CLC)^{\alpha}\right] + ln\left[(OF)^{\beta}\right] \tag{10}$$

$$ln(FSEC) = ln[A] + \alpha ln[CLC] + \beta ln[OF] \tag{11}$$

$$\text{Let } ln[A] = \text{ constant } (\rho) \tag{12}$$

$$ln(FSEC) = \rho + \alpha ln[CLC] + \beta ln[OF] \tag{13}$$

OF = Y, POPGR, FS, FP.
Equation 14
Mathematical model

$$ln(FSEC) = \rho + \alpha ln[CLC] + \beta_1 ln[Y] + \beta_2 ln[POPGR] + \beta_3 ln[FS] + \beta_4 ln[FP] \quad (14)$$

Equation 15
Econometric model

$$ln(FSEC) = \rho + \alpha ln[CLC] + \beta_1 ln[Y] + \beta_2 ln[POPGR] + \beta_3 ln[FS] + \beta_4 ln[FP] + \varepsilon \quad (15)$$

#### 3.1.6 Apriori expectations

$\alpha < 0$ (negative).
$\beta_1 > 0$ (positive).
$\beta_2 < 0$ (negative).
$\beta_3 > 0$ (positive).
$\beta_4 < 0$ (negative).
$\beta = \beta_1 + \beta_2 + \beta_3 + \beta_4$.

#### 3.1.7 Explanation of Figure 1

The initial demand, supply and utility curves are D, S and U, respectively. Initial equilibrium point on the demand and supply curve is E, while that of the indifference and budget line is U. The utility curves represent the level of food security. The higher the utility derived from food the higher the food security and vice versa.

In the event of climate change, this would directly impact the volume of goods produced in a country, leading to the leftward shift in food supply curve to $S_1$ from S. As a result, equilibrium quantity falls to $Q_1$ with equilibrium point $E_1$ from $Q_3$ with equilibrium point E. Less food is now available for consumption, which means that food demand would decline at the same magnitude with food supply. Due to the decline in equilibrium food quantity, utility curve shifts downward to $IC_1$ from IC. This signifies a decline in satisfaction derived from food or a deterioration of food security. The difference between $U_2$ and U represents the **total price effect** of climate change on food security. As food price increases due to low supply and high demand, consumer's real income falls, causing utility to move inward to $U_1$ along $IC_1$ from U on IC. This is the **income effect** of climate change on food security, which causes equilibrium quantity to decrease to $Q_2$ from $Q_3$. Higher food price would then cause consumers to slash their demand for food and increase the demand for non-food commodities instead. This causes equilibrium quantity to fall further to $Q_1$ from $Q_2$, which shows the **substitution effect** of climate change on food security. Due to the substitution effect, utility (food security) moves to $U_2$ from $U_1$ along the same indifference curve ($IC_1$). The new utility is lower than U on indifference curve (IC). The addition of the income and substitution effect equates the total price effect.

### 3.2 Measurement and description of variables

CO2 emission was selected as a proxy to climate change as it has been used by previous literatures like Affoh et al. (2022) and Ani et al (2021). The selection of inflation rate (food price), income (real GDP) and population growth rate as control variables was justified with Affoh et al. (2022), which examined the relationship between climate variables (rainfall amount, temperature, and carbon dioxide (CO2) emission) and

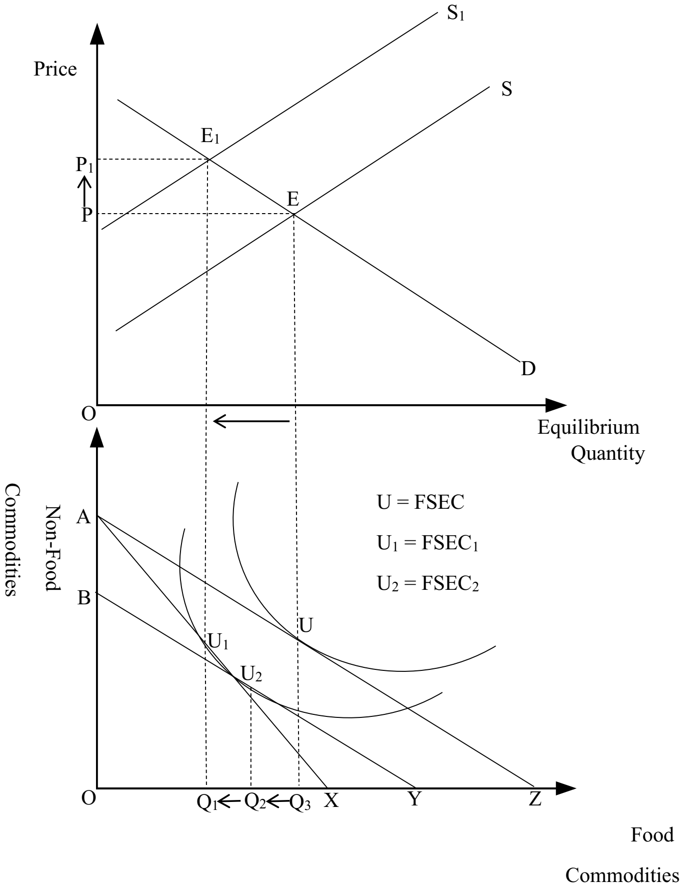

**Fig. 1** Graphical Illustration of the Impact of Climate Change on Food Security Using the Concept of Demand, Supply and Utility Theories. Source: Drawn by the author(s) with the aid of Microsoft Word

food security (proxy with food availability, accessibility, and utilization). This aforementioned literature also used cereal production which justifies the use of aggregate food production (supply) as one of the factors that affects food security.

| S/N | Label | Description | Unit of Measurement | Apriori Expectation | Source |
|---|---|---|---|---|---|
| 1 | FSEC | The inverse of prevalence of malnourishment rate (100—PRM) was used as proxy to food security | Percentage (%) | | FAOSTAT |
| 2 | CLC | Climate change (CLC) which was proxy with greenhouse gas emission (GHG) | Megatonne (mt) | **Negative** | WDI |

| S/N | Label | Description | Unit of Measurement | Apriori Expectation | Source |
|---|---|---|---|---|---|
| 3 | FS | Food supply represented with the value of food production | Thousand US dollar | **Positive** | FAOSTAT |
| 5 | INCOME/GDPPC | GDPPC represents real GDP per capita which was used as a proxy to INCOME | US dollar | **Positive** | WDI |
| 6 | FP | Food price proxy with inflation rate in each SSA country. This is because food index takes a large proportion of consumer price index in the countries | Percentage (%) | **Negative** | WDI |
| 7 | POPGR | Population growth rate | Percentage (%) | **Negative** | WDI |

*WDI* World Development Indicators from World Bank

*FAOSTAT* Food and Agriculture Organization Corporate Statistical Database.

**Data duration** The time duration for all data used in this paper ranges between 2000 and 2019. Thirty (30) Sub-Saharan African countries was used for the panel data analysis due to data availability.

### 3.3 Analytical technique

The first step in a panel data analysis is to know the number of cross sections (N) and time period (T) in the panel data that would be examined. Afterwards, the pre-estimation analysis can be conducted. These includes the descriptive statistics, graphical analysis, unit root test, multicollinearity test, cointegration test, cross-sectional dependence test. The unit root test is used to check for stationarity of the variables used in this study. Under panel data analysis, there are mainly two types of unit root tests—first-generation and second-generation unit root tests. The choice of the type of unit root test to be adopted will be determined by the outcome of the cross-sectional dependence test. Pesaran's Covariate Augmented Dickey Fuller (CADF) test was used to check for cross-sectional dependence.

### 3.4 Model estimation technique

Dynamic panel data analysis, specifically the panel generalized method of moments (GMM) was employed in this paper. This is because of some reasons as outlined by Arellano and Bond (1991) as well as Arellano–Arellano and Bover (1995) and Blundell and Bond (1998). According to these literatures, the following conditions are necessary for dynamic panel data analysis:

1. The number of cross sections (N) must be large, while time period (T) is small. In this paper, the number of cross sections is large (30), which is greater than the time period (20) of the panel data used.

2. There must be linear functional relationship among the variables considered.
3. The dependent variable must be dynamic, that depends on its past values.
4. Independent variables are correlated with past and possibly current realizations of the error. This implies that they are not strictly exogenous.
5. Fixed individual effects
6. GMM estimators used to address heteroskedasticity and autocorrelation within individual cross sections.
7. There are basically two GMM estimators (difference and system). The difference GMM estimator was developed by Arellano and Bond (1991) and it only estimates difference equation and uses the lag of the differenced variables as instruments. The first-differenced GMM estimators are used to eliminate individual effects. Arellano and Bover (1995) as well as Blundell and Bond (1998) revealed the potential weakness of the first-differenced GMM estimator. One of this weakness is that the lagged values of a variable at levels is often rather poor instruments for the variable at its first-differenced form, especially if the variable is close to a random walk. Hence, in order to account for this weakness, they developed the system GMM estimator which includes both lagged levels and differences as instruments. Blundell and Bond (1998) also argued that the system GMM estimator has superior properties in terms of small sample bias.

### 3.5 Model specification

In line with the objectives and theoretical framework of this paper, the model to be estimated is specified thus:

Food security = f [Climatechange, OF]
OF = FP, INCOME, POPGR, FS.

#### 3.5.1 Recall

Food security = FSEC.
Climate change = CLC.
Food price = FP.
Income = INCOME.
Population growth rate = POPGR.
Food production/supply = FS.

The inclusion of inflation rate (food price), income (real GDP) and population growth rate as control variables was justified with Affoh et al. (2022), which examined the relationship between climate variables (rainfall amount, temperature, and carbon dioxide (CO2) emission) and food security (proxy with food availability, accessibility, and utilization). This aforementioned literature also used cereal production which justifies the use of aggregate food production (supply) as one of the factors that affects food security.

$$FSEC = f[CLC, INCOME, FS, POPGR, FP]$$

$$FSEC = \alpha + \beta_1\left(CLC_{it}\right) + \beta_2\left(INCOME_{it}\right) + \beta_3\left(FS_{it}\right) + \beta_4\left(POPGR_{it}\right) + \beta_5\left(FP_{it}\right) + \varepsilon$$

**Table 1** Descriptive Statistics for the Variables. Source Authors compilation (2022)

| Variable | Obs | Mean | Min | Max |
|---|---|---|---|---|
| GHG/CLC | 494 | 58.011 | 1.740 | 525.050 |
| INFR/FP | 509 | 9.579 | −8.238 | 513.907 |
| POPGR | 520 | 2.528 | 0.032 | 5.605 |
| GDPPC/INCOME | 520 | 2026.139 | 258.629 | 10,644.020 |
| PRM | 494 | 21.399 | 3.400 | 67.500 |
| FPRD/FS | 520 | 6,737,960 | 159,568 | 5.87e+07 |

# 4 Estimation and interpretation of results

## 4.1 Pre-estimation analysis

### 4.1.1 Descriptive analysis

Table 1 shows the descriptive statistics for the series on greenhouse gas emission (GHG) in megatonne (mt), inflation rate (INFR), population growth rate (POPGR), GDP per capita (GDPPC) in US dollar, prevalence of malnourishment rate (PRM) in percentage (%) and food production (FPRD) in thousand US dollar. All the series were collected for 30 Sub-Saharan African countries (SSA), and they range between the period of 2000 to 2019. Greenhouse gas emission (GHG) was used as a proxy to climate change (CLC), inflation rate was used as a proxy to food prices (FP), GDP per capita was used as proxy to income level (INCOME), the inverse of prevalence of malnourishment rate (100—PRM) was used as proxy to food security, and food production (FPRD) was used as proxy to food supply (FS).

The average green gas emission equivalent of CO2 in the 30 SSA countries used in this paper is 58.01mt. This is 38.33% below the average greenhouse gas emission of 94.07mt in Europe. The minimum level of greenhouse gas emission in SSA between 2000 and 2019 is 1.74mt (Gambia—2005), while the maximum GHG is 525.05mt (South Africa—2014). The average value of prevalence of malnourishment rate in the selected SSA countries is 21.40%, which is slightly below the global average of 22%. Prevalence of stunting is highest at 67.50% (Angola—2000) and lowest at 3.40% (South Africa—2003 & 2004) in SSA. The mean value of inflation rate in the 30 SSA countries was 9.58%, while the minimum value was −8.23% (Ethiopia—2001) and maximum is 513.91% (DR Congo—2000). The average population growth rate for the selected SSA countries is 2.53%, while the mean of income is $2026.14 per person.

### 4.1.2 Graphical analysis

## 4.2 Measuring the progress on SDG 13 on climate change

The values for GHG emission between 2000 and 2018 was extracted from World Bank development indicators (WDI), while values between 2019 and 2030 were estimated using an autoregressive model of order one (AR(1)). Trend was accounted for in the AR(1) model because the series on the average GHG carbon emission were upward trending.

The UN SDG 13 targets the reduction in greenhouse gas emission by 45% by 2030 from 2010 levels and reach net-zero emissions by 2050. However, among the 30 SSA countries used in this paper, average GHG emission rose by 24.3% between 2010 and 2020 at an average level of 1.32mt per year. If average GHG emission at the selected SSA continues to increase at this rate, it could rise by 29.51% to 96.38 mt by 2030 compared to 2020 level. This would be partly due to the continuous exploration, production and consumption of crude oil in some SSA countries like Nigeria, Angola, and Ghana as well as increased manufacturing activities in nations like South Africa. This would be a drawback on SSA's effort towards addressing climate change and achieving net-zero carbon emission by 2030 (Fig. 2).

Figure 3 shows the average volume of greenhouse gas emission (GHG) in the top ten countries among the 30 Sub-Saharan Africa (SSA) nations considered in this paper. South Africa has the highest GHG at 466.23 megatonne (mt), which confirms the fact that the

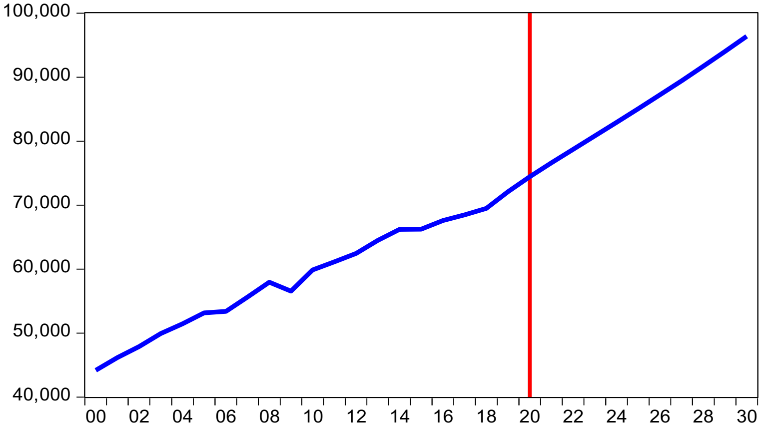

**Fig. 2** Average Greenhouse gas Emission in SSA (2000–2030). Source Authors compilation (2022)

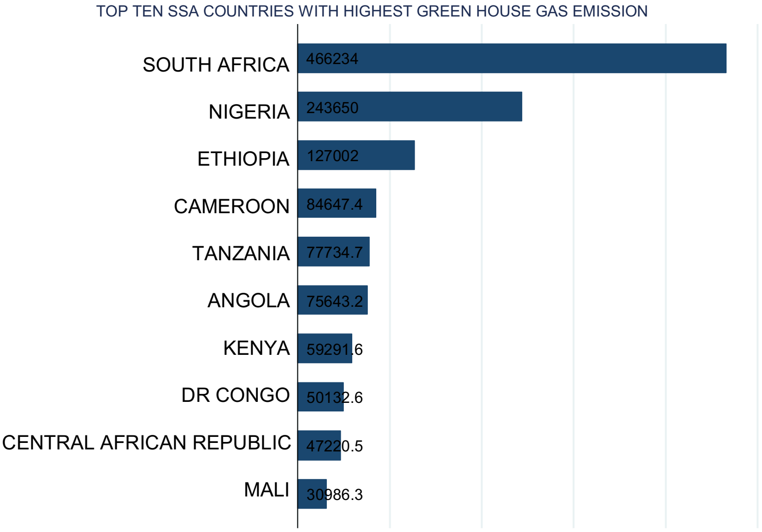

**Fig. 3** Bar plot of the top ten SSA countries (out of the selected African countries) with the highest GHG emission. Source: Authors compilation (2022)

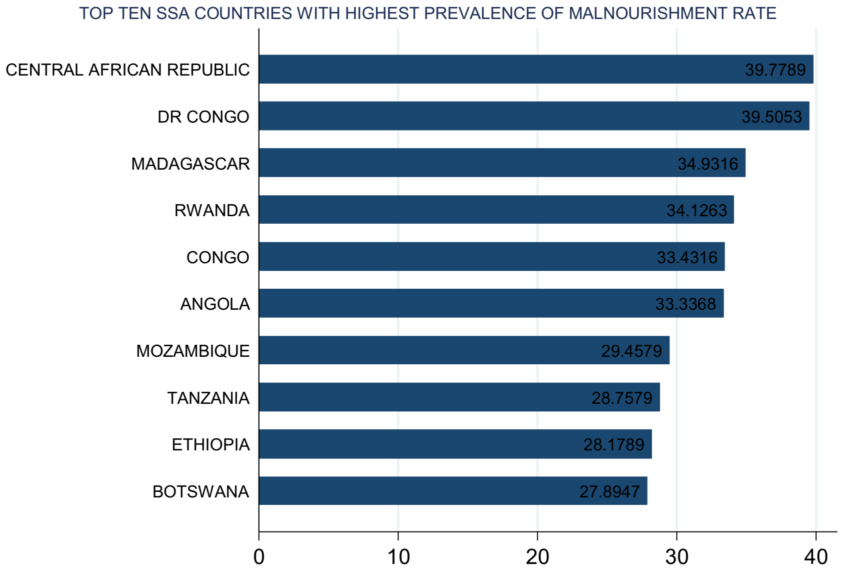

**Fig. 4** Bar plot of the top ten SSA countries (out of the selected African countries) with the highest prevalence of malnourishment rate. Source: Authors compilation (2022)

country is the highest greenhouse gas emitter in Africa generally. Also, South Africa can be regarded as the country with the highest GHG in Southern Africa due to the presence of a significant number of industries. In fact, South Africa is the most industrialized nation in Africa. Nigeria (243.65mt) ranks as the second gas emitter in SSA and can be considered as the nation with highest greenhouse gas emission in West Africa.

Figure 4 is the graphical representation of prevalence of malnourishment rate for top ten SSA countries between the period of 2000 and 2019. Out of the top-ten ranked countries, three (CAR, DR Congo and Congo Brazzaville) are from Central Africa region, five (Madagascar, Rwanda, Mozambique, Tanzania, Ethiopia) from East Africa and two (Angola and Botswana) from Southern Africa. This implies that countries with high malnourishment rate are prevalent in Central Africa, East Africa and Southern Africa). Central African Republic ranks as the country with the highest average prevalence of malnourishment rate among all the 30 countries used for analysis in this paper.

### 4.2.1 Cross-sectional dependence test

Pesaran's test of cross-sectional independence = 6.977, Pr = 0.0000.

It is very important to examine the cross-sectional dependence of a panel data series. This is because it would signify if there is a spillover impact of any policy impact among the countries used in the panel. With respect to the context of this study, it would statistically confirm whether climate change in any of the countries considered would have multiplier impact among them. Cross-sectional dependence test would also indicate the type of unit root test that would be conducted (either first or second generation test).

According to the Pesaran's test of cross-sectional independence, the null hypothesis is rejected because the probability value of the test statistic is less than 5%. This implies that there is no cross-sectional independence among the countries. Otherwise, it means that there is cross-sectional dependence among the countries. In view of this, change in any of the variables used in this paper in one of the SSA country would have an impact on the other countries.

### 4.2.2 Unit root test

The data on INCOME, food supply (FS), climate change (CLC) and food price (FP) were transformed by taking their natural logarithm to account for the problem of unit root. Hence, LINCOME, LFS, LCC and LFP were the natural log form of INCOME, FS, CLC and FP respectively. Due to the presence of cross-sectional dependence, the conventional cointegration test like the Kao test was not adopted. This is why the Pesaran's CADF was employed, as it accounts for cross-sectional dependence.

According to Pesaran's CADF test in Table 2, two variables (LCC and LINCOME) were stationary at first difference only (I(0)) at 5% significance level while four variables (FSEC, LFS, LFP and POPGR) were stationary at level and first difference (I(0) and I(1)).

### 4.2.3 Multicollinearity test

The variance inflation factor was used to check for degree of multicollinearity among the explanatory variables (LCC, LINCOME, LFS, POPGR and LFP) used in this paper. From Table 3, the VIF for all the explanatory variables were less than 5, which means a low degree of multicollinearity among these variables.

## 4.3 Model estimation and interpretation

According to Hansen (1982), the GMM estimator is efficient. This implies that it produces an efficient estimate even when N is greater than T. The system GMM estimator combines

**Table 2** Pesaran's covariate augmented Dickey Fuller (CADF) test. Source: Authors compilation (2022)

| Variables | Probability values | | Remark |
|---|---|---|---|
| | Level | First difference | |
| FSEC | 0.001 | 0.000 | I(0) and I(1) |
| LCC | 0.087 | 0.039 | I(1) |
| LINCOME | 0.651 | 0.000 | I(1) |
| LFS | 0.004 | 0.000 | I(0) and I(1) |
| LFP | 0.000 | 0.000 | I(0) and I(1) |
| POPGR | 0.000 | 0.005 | I(0) and I(1) |

**Table 3** Variance inflation factor for the independent variables. Source Authors compilation (2022)

| Explanatory variables | R-squared | 1 – R-squared = B | VIF = 1/B |
|---|---|---|---|
| LCC | 0.597 | 0.403 | 2.484 |
| LINCOME | 0.555 | 0.446 | 2.245 |
| LFS | 0.595 | 0.405 | 2.469 |
| POPGR | 0.010 | 0.990 | 1.010 |
| LFP | 0.066 | 0.934 | 1.071 |

moment conditions for the differenced equation with moment conditions for the model in levels. On the other hand, the difference GMM estimator uses only first-differenced data as instruments in order to eliminate the fixed effects and address the problem of endogeneity.

Bond et al. (2001) outlines the procedures to choose the most preferred between the system and difference GMM. Firstly, an autoregressive model has to be estimated by pooled OLS and fixed effects approach. This model would include the lagged dependent (endogenous) variable. The pooled OLS lagged dependent variable estimator is considered an upper bound while that of the fixed effect is a lower bound estimate. Afterwards, the system and difference GMM would be estimated. Lastly, the difference GMM estimator would be compared to the fixed effects estimate. If it is less than or close to the fixed effects estimate, the system GMM is most preferred. On the other hand, if the difference GMM estimate is greater than that of the fixed effect or closer to the pooled OLS, the difference GMM is most preferred.

According to Table 4, the coefficient of lagged variable on food security in the one-step (0.736) and two-step difference (0.728) GMM were less than that of the fixed (0.922) and pooled OLS (0.985) model. It is closer to the fixed effects model estimate, which implies that the system GMM estimate is most preferred. Hence, this justifies the use of system GMM in this paper (Table 5).

**Table 4** Choosing between system GMM and difference GMM. Source Authors compilation (2022)

| Estimators | Coefficients |
|---|---|
| Pooled OLS | 0.985 |
| Fixed effects | 0.922 |
| One-step diff GMM | 0.736 |
| Two-step diff GMM | 0.728 |
| One-step system GMM | 0.629 |
| Two-step system GMM | 0.630 |

**Table 5** Choosing between the one-step and two-step GMM. Source Authors compilation (2022)

| Variables | One-step system GMM | Two-step GMM |
|---|---|---|
| FSEC (− 1) | 0.629 | 0.630 (0.000)** |
| LCC | − 1.941 | − 1.391 (0.048)* |
| LINCOME | 2.433 | 2.391 (0.000)** |
| LFS | 2.499 | 2.260 (0.000)** |
| POPGR | − 0.306 | − 0.121 (0.809) |
| LFP | − 0.398 | − 0.374 (0.000)** |
| CONST | − 40.759 | − 42.766 (0.000)** |
| No. of observations | 436 | 436 |
| F-statistic | 27,515.02 | 22,751.55 |
| Groups/instruments | 26/25 | 26/25 |
| AR (1) | 0.002 | 0.095 |
| AR (2) | 0.772 | 0.846 |
| Hansen statistic | – | 0.209 |
| Sargan statistic | 0.000 | 0.000 |

Both the one-step and two-step GMM were estimated. However, the probability value of the Sargan test in the one-step GMM model was less than 5%, which means that instruments are not valid. Also, the one-step system GMM does not follow the AR(1) process because the probability value (0.002) is less than 5%. This means the presence of serial correlation in the one-step GMM equation. These inconsistencies led to the estimation of the two-step GMM. The probability value of the Hansen statistic from the two-step GMM model is low and greater than 5%. This means that the null hypothesis of over-identifying restrictions is rejected, which implies that the instruments in the two-step GMM are valid. The model also follows both the AR(1) and AR(2) process because their probability values are greater than 5%. As a result, the two-step GMM was chosen and used for analysis in this paper.

According to Table 6, climate change has a negative significant effect on food security in Sub-Saharan Africa (SSA) at 5% significance level. This implies that an increase in green house carbon emission would lead in an increase in prevalence in of malnourishment rate, resulting in a decrease in food security in SSA ceteris paribus. This corroborates the findings of Kralovec (2020) and Muringai et al. (2020), which found that declining water resources, higher temperature and rising CO2 emission have a negative effect on food security due to the impact on agricultural productivity. Also, Verschuur et al. (2021) found out that climate change was a major driver of food insecurity in the drought that was experienced in Lesotho-South Africa in 2007. Hence, a 1% increase in GHG emission results in 1.391% decline in food security or rise in prevalence of malnourishment rate. This paper projects from AR(1) model that average GHG gas emission could increase by 29.51% in SSA by 2030 compared to 2020 levels. From the result of the two-step GMM, food security could fall by or prevalence of malnourishment rate could rise by 0.4105 (41.05%) to 28.13% by 2030. In addition, food price (FP) has a negative significant effect on food security in SSA ceteris paribus. An increase in food price would weigh on consumer real income and decrease their food consumption, resulting in higher prevalence of malnourishment rate and decline in food security. A 1% increase in food price in SSA leads to 0.374% decrease in food security.

**Table 6** Two-step GMM interpretation. *Source* Authors compilation (2022)

| Variables | Two-step GMM |
|---|---|
| FSEC (− 1) | 0.630 (0.000)** |
| LCC | − 1.391 (0.048)* |
| LINCOME | 2.391 (0.000)** |
| LFS | 2.260 (0.000)** |
| POPGR | − 0.121 (0.809) |
| LFP | − 0.374 (0.000)** |
| CONST | − 42.766 (0.000)** |
| No. of observations | 436 |
| F-statistic | 22,751.55 |
| Groups/instruments | 26/25 |
| AR (1) | 0.095 |
| AR (2) | 0.846 |
| Hansen statistic | 0.209 |
| Sargan statistic | 0.000 |

On the other hand, from the two-step GMM result, food supply (FS) and household income (INCOME) have a positive significant effect on food security in SSA ceteris paribus. This implies that as income and food supply increases, food security is expected to improve in Sub-Saharan Africa. This is in line with theoretical expectation and conforms with the conclusion of Tarasuk et al. (2019) which found out that higher income helps protect against food insecurity. However, this is in contrast with the findings of Affoh et al. (2022), which used food availability, accessibility and utilization as proxies to food security. They concluded from their result that climate change (CO2 emission) has a positive impact on food availability and accessibility while it does not have a significant effect on food utilization. If income increases by 1%, food security is expected to improve by 2.391% in SSA. Also, a 1% increase in food supply or production (FS) would lead to 2.260% improvement in food security or decrease in prevalence of malnourishment rate.

Summarily, this paper concludes that climate change and food price have a negative significant effect on food security, while income and food supply have a positive significant impact on food security in SSA. Climate change has the highest negative impact while food supply has the most positive effect. This shows the importance of controlling climate change and increasing food productivity to improve food security in Sub-Saharan Africa.

## 5 Conclusion and policy recommendations

This paper examined the relationship between climate change and food security in Sub-Saharan Africa. It also investigated the effect of food supply, food inflation and income on food security in SSA. All the series were collected for 30 Sub-Saharan African countries (SSA) for the period spanning 2000 to 2019. Greenhouse gas emission (GHG) was used as a proxy to climate change (CLC), inflation rate was used as a proxy to food prices (FP), GDP per capita was used as proxy to income level (INCOME), the inverse of prevalence of malnourishment rate (100—PRM) was used as proxy to food security and food production (FPRD) was used as proxy to food supply (FS). The dynamic panel data analysis was employed, using the one-step and two-step panel generalized method of moments (GMM) model. The two-step GMM was the preferred model by using the procedure outlined by Bond (2001) in choosing between one-step and two-step GMM. The result of the two-step GMM estimation equation shows that climate change and food price have a negative significant effect on food security, while income and food supply have a positive significant impact on food security in SSA.

Based on the findings, this paper recommends that:

1. Sub-Saharan African countries should be intentional and determined in meeting their targets towards reducing carbon emission. This can be done via shifting towards cleaner energy (like solar, liquified natural gas) from the high dependence on fuel and coal. The government can form partnership with the private sector to help upgrade the power plants that relies on brown energy like crude oil and coal. On the part of developed countries, they can provide SSA countries with an incentive to preserve their forests. For instance, the Congo Basin is the second-largest tropical rainforest globally and it covers SSA countries like Cameroon, DR Congo, Republic of the Congo, Equatorial Guinea, Central African Republic and Gabon. The incentives would help these countries prevent revenue loss from timber export. Shit towards renewable energy and incentives to SSA countries to preserve their forests would help reduce carbon emission and incidence of

climate change in SSA. According to the result of this study, the decline in carbon emission is expected to boost agricultural supply and productivity, reduce the prevalence of malnourishment rate and promote food security.

2. The domestic production capacity of SSA should be improved by increasing the investment and accessibility to farm inputs as well as increase the finance or funds available to farmers and investors in the agricultural sector. All these factors would in turn increase the local production of food and reduce the vulnerability to external shocks from changes in global price of commodities. Theoretically, an increase in food supply would lead to the decline in food prices, which would positively impact food security.
3. Policies in SSA countries should be targeted towards the improvement of income. This would boost consumers and households' purchasing power and capacity to demand for more food, which would increase the accessibility to food and lead to the reduction in malnourishment rate. The resulting impact of this is the enhancement of food security in SSA.

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## Declarations

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