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Article

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Is climate finance aiding food security in developing countries? A focus on Sub-Sahara Africa

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ABSTRACT

This study seeks to find out whether climate finance (CF) geared toward 35 Sub Saharan Africa (SSA) countries is assisting to achieve food security in the continent. To achieve this objective, we adopted FAO's classification of food security of 4 main dimensions: food availability, access, stability and utilization and use principal component analysis (PCA) to generate food security indexes corresponding to the different dimensions of food security. The data was analyzed using system generalized methods of moments (GMM) whereas panel quantile regression (PQR) was employed as a sensitivity analysis. Our findings show that climate finance is more useful in securing food availability but fails to enhance food access, stability and utilization. Further analysis shows that other factors such as foreign direct investment and government readiness have more impact in enhancing the different dimensions of food security whilst rural population, agricultural spending, agricultural land and capacity have more adverse effects on food security. Relevant policy implications based on our analysis are discussed.

PUBLIC INTEREST STATEMENT

Global warming is a significant human concern. Despite minimal contributions to climate change, African countries suffer disproportionately due to limited resources for mitigation and adaptation to climate change. Industrialized economies, major contributors to climate change, have committed climate funds to aid less developed nations. Our study assesses the impact of climate finance on ensuring food security in 35 Sub-Saharan African countries, crucial given the region's vulnerability to food scarcity due to climate change. Results reveal that while climate finance may promote food availability, it falls short in enhancing access, stability, and utilization. Other factors like government readiness, agricultural spending and foreign direct investment are found to be contribute to different dimensions of food security. Policy implications arising from our findings are discussed.

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1. Introduction

Climate change is the most pressing environmental issue facing the planet and amongst the most feared repercussions of climate change in Africa are its effects on food systems and food security (Masipa, 2017). The challenges arising from climate change, such as changing rainfall patterns, rising temperatures, rising sea levels as well as worsening food and water security (Tadesse, 2010), are most unfortunate for African countries who have contributed the least to environmental degradation and yet suffer the most from its adverse effects. These adversities are further compounded as African countries do not have the necessary institutional, technological and financial capacity to reduce emissions and build resilience against climate change (Doku et al., 2021a, 2021b; Mekonnen et al., 2021; Mekonnen & Hoekstra, 2014). It is for this reason, a group of industrialized economies (Annex I countries) have sought to bring about 'climate justice' by committing themselves to donating bilateral and multilateral climate

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financing to developing countries (Annex II countries) for purposes of mitigating and adapting to climate change and since then, there has been increasing policy discussions on climate finance, resilient agricultural practices and food security in developing countries (Gassner et al., 2019).

An important policy question this study addresses is whether climate financing issued to Sub-Saharan African (SSA) countries is helping to enhance food security in the continent and there are some important stylized facts, policy concerns and gaps in the empirical literature which motivate us to undertake this research.

Firstly, the SSA region currently suffers from the worst levels of hunger in the world and has the highest prevalence of undernourishment which affects almost 21% of the population, compared to other developing regions such as Asia and South America which have prevalence rates of 11.4% and 5%, respectively (Nakai, 2018). Moreover, the Sub-Saharan Africa (SSA) region has the highest prevalence of undernutrition and according to the global hunger index (GHI) scores, five out of the seven countries worldwide faced with alarming rates of hunger are SSA nations (i.e. Central African Republic, Chad, Madagascar, Sierra Leone and Zambia) (Ekholuenetale et al., 2020; Grebmer et al., 2018). The Food and Agriculture Organization (FAO) has predicted that with no sustainable intervention into climate change and food wastage, the world could run out of food by 2050 and start experiencing mass wars and conflicts based on famines especially in prone regions such as Africa (Koubi, 2019).

Secondly, some recent literature argues that the current amounts of climate funding flowing from donor countries to Africa may not be sufficient to address the challenges of climate change facing the continent. For instance, Ngwenya and Simatele (2020) note that whilst Annex 1 countries have committed themselves to mobilizing a total of US\$100 billion by 2020, this falls far short of the World Bank's estimate of US\$200 billion per annum per country required by African nations. More recently, Timperley (2021) and Roberts et al. (2021) point out that Annex I countries have already failed to achieve their targeted funding objective of US\$100 billion by 2020 and these authors highlight propositions of at least \$750 billion a year commitment being planned to be negotiated at the forthcoming COP26 summit meeting. For African countries, these realizations are of interest as climate financing received from donor countries are the main source of funding used to circumvent climate-related environmental changes reflected through heavy rainfall, droughts, flooding and high temperatures. Recently, Stuch et al. (2021) estimates that in the next few decades climate related disasters will reduce crop yield of staple foods by 80–85% in Central and West Africa, 29% in Southern Africa and 32% in East Africa and these figures are concerning since agricultural production is responsible for over 70% of the continent's food supply (Appiah et al., 2019).

Thirdly, very little is known on the effects of climate finance on improving food security and food systems in Africa. The closest studies to ours are those which provide conceptualizations on how climate finance can improve food security through efficient food production. For instance, Lipper et al. (2014) conceptualize on how climate finance can be used to achieve food security through climate-smart agricultural practices. Junghans and Köhler (2016) emphasize the need for a mediator in climate finance administration for small-scale farmers to more effectively promote food security through climate finance support. Chirambo (2017) carried out an extensive literature review on how microfinance institutions can help mobilize climate finance to fight against poverty and food insecurity. Castro-Nunez (2018) demonstrate the compatibility of programs aimed at forest conservation with efforts relating to peace building and sustainable food systems in Colombia. Rahaman and Rahman (2020) documented on how various climate funds influence food security in a single country-Bangladesh. More recently, Sarker et al. (2021) examines the role of climate finance governance at vulnerable hazard-prone chars in Bangladesh and find that whilst the mechanism of climate finance is good enough but implementation is not satisfactory. The main gap in the previous literature is that they only provide conceptual channels through which climate finance influences food security but they do not empirically quantify the effect of climate finance on food security and test whether the effect is significant.

This study differs from the previous scientific literature by investigating whether climate finance issued to the top 35 SSA recipient countries has contributed to ensuring food security in the continent and consequentially test the following hypothesis:

H0: Climate finance has a negative or insignificant impact on food security

H1: Climate finance has a positive impact on food security

We carry out our empirical research in a two-staged process. Firstly, we use principal component analysis to create indices which measure the four dimensions of food security identified by the FAO (i.e. availability, access, stability and utilization) and examine the impact of climate finance on the different dimensions of food security. Secondly, we make use of the generalized method of moments (GMM) of Arellano and Bond (1991) and panel quantile regressions (PQR) of Koenker and Bassett (1978) to estimate empirical functions used to determine the impact of climate finance on food security. On one hand, the GMM estimators are a favorable technique over traditional estimators in the sense that they (i) produce more asymptotically efficient estimates, (ii) address endogeneity issues amongst the variables and (iii) are suitable with panel data whose number of time series observations per country exceeds the number of countries in the panel (Ramos, 2018). On the other hand, the PQR present a unique advantage of being able to examine the impact of climate finance on food security at different levels of quantiles of distribution (Koenker & Bassett, 1978). Consequentially, quantile regressions (i) capture asymmetric dynamics between the dependent variable and its covariates (ii) are not susceptible to outliers, and (iii) are suitable with models containing heteroscedastic standard errors (Koenker & Hallock, 2001).

The significance of this study is that it allows us to identify which specific dimensions of food security are positively, adversely or neutrally affected by climate finance and further identifies whether effects of climate finance differ at different distributional quantiles of the different dimensions of food security. This study contributes new knowledge to the existing literature concerned with determining factors influencing food security by comparing the impact of climate finance on different dimensions of food security against other related factors influencing food security such as FDI (Mihalache-O'keef & Li, 2011; Slimane et al., 2016; Adom et al., 2019), public agricultural spending (Aliyeva et al., 2019; Cuesta et al., 2013; Kovljenic & Reletic-Jotanovic, 2021), agricultural land and capacity (Arshad, 2022; Mulwa & Visser, 2020; Subramaniam et al., 2021; Viana et al., 2022), government readiness (Anser et al., 2021; Mohammadi et al., 2022) and rural population (Adjognon et al., 2021; Davis et al., 2022; Piaskoski et al., 2020). Altogether, we present a rigorous empirical exercise on the impact of climate finance on the different dimensions of food security. Besides making a unique contribution to the empirical literature, our findings contribute to ongoing debate on the effectiveness of climate finance and other related factors in enhancing food security in Africa. In this regard, we contribute to theoretical and policy debate on whether current levels study climate finance issued to African are sufficient enough for attaining 'climate justice' in developing regions.

The remainder of the paper is structured as follows. The next section of the paper outlines the empirical methodology of the study. The third section details the construction of food security indices and discusses the covariate data. The fourth section of the paper presents the empirical results, and the last section concludes the study by providing policy recommendations and suggesting avenues for future research.

2. Methodology

2.1. Model specification and econometric technique

To determine whether climate finance (CF) significantly impacts food security, we specify the following regression model:

$$fs_{it} = \mu_{it} + \alpha_i fs_{it-1} + \beta_i x_{it} + e_{it} \quad (1)$$

Where fs_{it} is the measure of food security, cf_{it} is climate finance from Annex I to African countries and x_{it} is the vector of control variables in the regression and e_{it} represents the country-time specific shocks. All variables are logged to help interpret their findings in elasticities and we hypothesize that $\alpha > 0$, that is, climate finance assist with food security in the SSA region. We use the Generalised Methods of Moments (GMM) technique of Arellano and Bond (1991) to estimate regression (1). To implement the GMM estimators, we apply first-differencing to regression (1) to eliminate country-specific effects i.e.

$$(fs_{it} - fs_{it-1}) = \mu_i + \alpha_i (fs_{it-1} - fs_{it-2}) + \beta_i (x_{it} - x_{it-1}) + (e_{it} - e_{it-1}) \quad (2)$$

To address the endogeneity problem caused by the correlation between $(fs_{it} - fs_{it-1})$ and $(e_{it} - e_{it-1})$, Arellano and Bond (1991) propose the use of lags of the independent variables as instrument variables. In the presence of no autocorrelation between the error term and explanatory term, we use the following moment conditions to calculate the difference estimator:

$$E(fs_{i,t-s}(e_{it} - e_{it-1})) = 0, \quad \text{for } s > 2; t = 3, 4, \dots, T \quad (3)$$

$$E(X_{i,t-s}(e_{it} - e_{it-1})) = 0, \quad \text{for } s > 2, t = 3, 4, \dots, T \quad (4)$$

However, applying the difference estimator by itself is problematic as it eliminates the cross-section dimension of the data and increases measurement error bias. Moreover, Arellano and Bover (1995) as well as Blundell and Bond (1998) show that if the lagged dependent and explanatory variables are persistent over time, lagged levels become weak instruments for the differences regression. We therefore rely on the system estimator which estimates the regression in the first-differences and levels conjointly and this requires the error term not be autocorrelated or correlated with the explanatory terms i.e.

$$E[fs_{i,t+p}\eta_i] = E[y_{i,t+q}\eta_i], \quad \text{for all } p \text{ and } q \quad (5)$$

$$E[X_{i,t+p}\eta_i] = E[X_{i,t+q}\eta_i], \quad \text{for all } p \text{ and } q \quad (6)$$

And the additional moment conditions for the levels regression is:

$$E[(fs_{i,t-s} - fs_{i,t-s-1})(e_{it} + \eta_i)] = 0 \quad \text{for } s = 1 \quad (7)$$

$$E[(X_{i,t-s} - X_{i,t-s-1})(e_{it} + \eta_i)] = 0 \quad \text{for } s = 1 \quad (8)$$

The robustness of the model is evaluated using the Hansen J-test for over-identifying restrictions and second order autocorrelation effects are used to confirm no remaining autocorrelation.

To triangulate the SYS-GMM analysis, a sensitivity exercise will be carried out using panel quantile regression (PQR). PQR is very powerful in examining how covariates influence the shape, scale and location at different points of the response distribution. Quantile regressions are a heterogenous regression method introduced by Koenker and Bassett (1978) and are grounded on the conditional distribution of the independent variables (x) and is carried out by estimating the dependent variable (y) at different quantiles of conditional distribution. The representation of the conditional quantile for a panel y_{it} given x_{it} is specified as:

$$Q_{y_{it}}(\tau|X_{it}) = X_{it}^T \beta_\tau \quad (9)$$

In This study, we model the conditional mean function of food security (FS) on it's set of conditioning covariates (X) which can be expressed as:

$$\min_{\beta} [\theta \sum |FS_t - X_t \beta| + (1 + \theta) \sum |FS_t - X_t \beta|] \{t : FS_t \geq X_t \beta\} \{t : FS_t < X_t \beta\} \quad (10)$$

Where, $\{FS, t = 1, 2, \dots, T\}$ is a random sample on the regression process. $FS = \alpha_t + X_t \beta$, with conditional distribution function of $F_{FS/X}(y) = F(CF_t \leq inv) = F(FS_t - X_t \beta)$ and $\{X_t, t = 1, 2, \dots, T\}$ is the sequences of (row) k -vectors of a known design matrix. The θ^{th} regression quantile, $Q_{FS/X}^{th}(\theta)$, $0 < \theta < 1$ is any solution to minimize problems, β_θ denotes the solution from which the θ^{th} conditional quantile $Q_{FS/X}^{th}(\theta) = x\beta_\theta$. This study uses 4 'quantiles' within the regression which are designated at the 25th, 50th, 75th and 90th quantiles of conditional distribution.

3. Empirical data

The study uses an unbalanced panel data for 35 countries in Sub-Saharan Africa (SSA) region for the period 2006–2016. Our sample includes all African countries excluding Cape Verde, Central African Reepublic, Comoros, Djibouti, Equitorial Guinea, Eswatini, Gabon, Mauritius, Sao-Tome and Principe, Seychelles which were omitted from the study due to many missing data points for these countries. The dependent variable of the study is food security (FS) whilst the main independent variable is climate finance (CF) and the remaining control variables, government agriculture sector expenditure (AGR.GOV), agricultural land use (AGR.LAND), foreign direct investment (FDI), agricultural capacity (AGR.CAP), rural population (RURAL.POP) and governance readiness (GOV.READ). These variables are discussed in more detail in the following sub-sections.

3.1. Dependent variable

The dependent variable of the study is food security (FS) and in accordance with the definition of food security adopted during the 1996 World Food Summit (WFS), we make use of four dimensions of food security, namely, availability, accessibility, stability and utilization. ‘Sub-variables’ of each dimension of food security were pooled together from the FAOSTAT website (i.e. <https://www.fao.org/faostat/en/#data>) and the principal component analysis (PCA) was used to create four indexes which capture the different dimensions of food security. The PCA is a dimension-reduction technique which downsizes a set of times series into a smaller size whilst retaining important information of the larger set. This is done by transforming a set of correlated variables into a new set of uncorrelated variables called principal components to capture the maximum variance between the variables to provide every principal component a linear transformation is written as:

$$PCI^P = \varnothing_1^P \alpha_1^P + \varnothing_2^P \alpha_2^P + \dots + \varnothing_n^P \alpha_n^P \quad (11)$$

where PCI^P represents the P^{th} principal component, α_n^P represents value of the n^{th} variable for the P^{th} component and \varnothing_n^P represents the regression coefficients for the n^{th} variable of the P^{th} component and it is the eigenvector of the covariance matrix between the variables. Table 1 summarizes PCA analysis on the sub-components used to create indexes corresponding to the four dimensions of food security and discussions on these different food security dimensions are provided below.

3.1.1. Availability

The formal definition of food availability is ‘... the amount of food that is present in a country or area through all forms of domestic production, imports or aid ...’ (Burhaci & de Muro, 2016). To capture the different dimensions of food availability, we create an index by applying PCA on five time series variables, namely, (i) Average dietary energy supply adequacy (ii) Average value of food production (iii) Share of dietary energy supply derived from cereals, roots and tubers (iv) Average protein supply (v) Average supply of protein of animal origin. From Table 1, it is indicative that the first three PCA components explain more than 84% of the total variation and this implies that all the indicators contribute in a balanced way to the availability dimension and supports the use of all the analyzed indicators for this dimension.

3.1.2. Access

The formal definition of food access is having ‘... physical, economic and social access to good, nutritious food ...’ (Pinstrup-Andersen, 2009). Firstly, physical access is described as a situation where food is produced and available in one part of a country but for poor infrastructure means, that food cannot be

Table 1. PCA Result for Food Security.

Sub-component		Eigenvalue	Proportion	Cumulative
Availability				
Average dietary energy supply adequacy	PC1	2.3473	46.95%	46.95%
Average value of food production	PC2	1.0673	21.35%	68.29%
Share of dietary energy supply derived from cereals, roots and tubers	PC3	0.8169	16.34%	84.63%
Average protein supply	PC4	0.5217	10.43%	95.07%
Average supply of protein of animal origin	PC5	0.2465	4.93%	100%
Access				
Minimum dietary energy requirements	PC1	1.71652	57.22%	57.22%
Incidence of caloric losses at retail distribution	PC2	1.0113	33.71%	90.93%
GDP per capita (in purchasing power equivalent)	PC3	0.2721	9.07%	100%
Stability				
Cereal import dependency ratio	PC1	1.7298	28.83%	28.83%
Percent of arable land equipped for irrigation	PC2	1.1754	19.59%	48.42%
Value of food imports over total merchandise exports	PC3	1.0186	16.98%	65.40%
Political stability and absence of violence/terrorism	PC4	0.8263	13.77%	79.17%
Per capita food production variability	PC5	0.7869	13.12%	92.29%
Per capita food supply variability	PC6	0.4267	7.71%	100%
Utilization				
People using at least basic drinking water services	PC1	2.4928	49.86%	49.86%
People using at least basic Sanitation services	PC2	1.3908	27.82%	77.67%
Prevalence of obesity in the adult population (18 years and older)	PC3	0.5531	11.06%	88.74%
Prevalence of anemia among women of reproductive age (15–49 years)	PC4	0.3930	7.86%	96.60%
Prevalence of low birthweight	PC5	0.1700	3.40%	100%

supplied to other parts suffering from a lack of food. Secondly, economic access to food exists when people cannot afford to buy sufficient food because they lack the financial freedom to do so. Lastly, social access occurs when food may be physically available, and the potential consumer has the money to buy the food, but one is prevented from doing so for being a member of a particular social group or even gender. We apply PCA to three time series to create the index for 'food access', namely, (i) Minimum dietary energy requirements (ii) Incidence of caloric losses at retail distribution (iii) Gross domestic product per capita (in purchasing power equivalent). The PCA result in Table 1 for access shows the presence of 1 prevalent dimension which explains more than half of the variance and that is strongly represented by dietary energy requirements alone. Overall, the PCA result for access points out that all the indicators contribute in a balanced way to the access dimension and supports the use of all the analyzed indicators for this dimension.

3.1.3. Stability

According to García-Díez et al. (2021), food stability measures of the '*... availability and access to food must be present at all times...*' and a distinction is made between chronic food insecurity where food needs of a country cannot be met over a protracted period of time and transitory food insecurity, where the time period is more temporary. The PCA was applied to six time series variables to create an index for 'food stability' i.e. (i) Cereal import dependency ratio (ii) Percent of arable land equipped for irrigation (iii) Value of food imports over total merchandise exports (iv) Political stability and absence of violence/terrorism (v) Per capita food production variability (vi) Per capita food supply variability. From Table 1, the PCA analysis highlights the presence of 4 prevalent dimensions which altogether explains about 79% of the total variation. The first dimension accounted for 28% of the variance and described by cereal import dependency ratio. Percent of arable land used for irrigation contributes to the second component, which explains 19% of total variation and value of food imports over total merchandise exports represents the third component which explains 16% of total variation.

3.1.4. Utilization

Food utilization is defined as '*... safe and nutritious food provided to meet the dietary needs of a country...*' and this highlights the necessity that food consumed must contain sufficient energy to help the citizens carry out routine physical activities (Labadarios et al., 2011). We apply PCA to five time series variables to create an index for 'food utilization' i.e. (i) People using at least basic drinking water services (ii) People using at least basic Sanitation services (iii) Prevalence of obesity in the adult population (18 years and older) (iv) Prevalence of anemia among women of reproductive age (15–49 years) v) Prevalence of low birthweight. From Table 1, it can be observed that the first three PCA components explain more than 88% of the total variation. However, all the indicators contribute in a balanced way to the utilization dimension and support the use of all the analyzed indicators for this dimension.

3.2. Explanatory variables

The main explanatory variable of this study is CF flows to SSA, data was sourced from OECD-DAC climate-related development finance in constant 2018 USD. CF is defined by the UNFCCC as '*local, national or transnational financing—drawn from public, private and alternative sources of financing—that seeks to support mitigation and adaptation actions that will address climate change*' and based on this definition, our CF data combines funding from bi-lateral and multilateral sources.

The second explanatory variable is total foreign direct investment (FDI) inflows to SSA which is sourced from World Development Indicators (WDI). We note that whilst some previous studies have used agricultural FDI as a more appropriate determinant of food security (Santangelo, 2018; Wardhani & Haryanto, 2020; Yao et al., 2020) we opt for the use of total FDI due to insufficient time series data on agricultural FDI for African countries recorded by FAOSTAT. Besides, the previous studies of Mihalache-O'keef and Li (2011), Slimane et al. (2016) and Adom et al. (2019), generally find total FDI to be positively related to food security which further motivates the use of this variable as control variable in This study.

The third explanatory variable is Governance readiness (GR) which is sourced from ND-GAIN. Governance readiness is an index (From 0-1) computed using 4 main variables by ND-GAIN: Political stability and non-violence, control of corruption, regulatory quality and rule of law. Countries with high GR are more likely to use climate funds efficiently with less corruption which, in turn, could assist in security food security. For instance, Mohammadi et al. (2022) notes that good governance is key to successful stakeholder engagement, policy alignment and institutional capacity building all which are necessary for enhancing food security. Moreover, Arshad (2022) provides empirical support on the positive impact of governance on food security.

The fourth explanatory variable is the total government expenditure in agriculture sector as a percentage of governments total expenditure (AGR.GOV) which is sourced from the FAOSTAT online database and notable there exist some studies which have shown the importance of agricultural spending on food security. For instance, Cuesta et al. (2013) find that public agriculture spending, primarily through infrastructure and R&D, has a positive effect on high or very high food security vulnerability. Moreover, Aliyeva et al. (2019) find that reduction in government spending and intervention in agriculture markets adversely affected food security whilst Kovljenic and Reletic-Jotanovic (2021) find that public investment in agriculture improves agricultural GDP, reduces poverty and ultimately improves food security.

The fifth explanatory variable is agricultural land (AGR. LAND) AGL is the percentage of a country's land used for agricultural activities and is computed as agricultural land over total land area and compiled from World Development Indicators (WDI). We chose agriculture land as control variable since it is responsible for largest share of food supplies globally and is therefore crucial for sustainable food systems (Viana et al., 2022).

The sixth explanatory variable is agricultural capacity (AGR.CAP) which measures the food production capabilities from agricultural activities and capacity existing in a particular country and this data is sourced from ND-GAIN. ND-GAIN computed it as an index (From 0-1) using 4 main indicators; capacity to equip agriculture areas with irrigation, N + P205 total fertilizer use on arable and permanent crop area use, pesticide use, and tractor use. This indicator is used to detect the adaptive capacity of a country's agriculture sector to produce food in the face of climate change (Rosegrant et al., 2014).

The last explanatory variable is rural population (RURAL.POP) which is the number of rural people as a percentage of total population, compiled from Word Development Indicators (WDI). Rurpop is included because most of the world's poor and food insecure ones live in rural areas (Adjognon et al., 2021; Piaskoski et al., 2020) and are more at risk to face food shortages due to poor food value chain development in these areas (Davis et al., 2022).

4. Empirical findings

4.1. Summary statistics and correlation matrix

The summary statistics of the time series used in This study are presented in Table 2 and they reveal some interesting stylized facts on food security and climate finance. For instance, among the food security indexes generated, food access is the only component with negative averages which implies that

Table 2. Summary statistics.

Variable	Obs	Mean	Std. Dev	Min	Max
Availability	359	8.41e-10	1.000003	−1.340236	3.047371
Access	407	−8.00e-10	1.000011	−.785265	3.894056
Stability	367	5.42e-11	1.000001	−1.935471	2.064715
Utilisation	262	2.36e-10	1.000001	−1.984648	1.675469
FSI	247	−6.71e-09	1	−1.342723	2.804812
AGR.LAND	406	48.09356	18.21883	8.154355	80.92054
GOV.READ	407	0.39783	0.114726	0.1724241	0.6685993
FDI	407	8.69e + 08	1.66e + 09	−7.12e + 09	1.00e + 10
AGR.GOV	393	6.054247	4.866872	0.4988956	28.88279
CF	344	355.6343	383.9299	2.186	2656.563
AGR.CAP	407	0.981361	0.030887	0.83717	0.999976
RURAL.POP	396	60.6413	16.3774	11.441	90.383

food access is the most problematic dimension of food security in Africa. This shows that in as much as there is enough food in the sub-region, physical and economic access to food is greatly lacking. Moreover, it can be observed that on average each country in SSA received on average USD 335 million of annual donor funding although the high standard deviation shows that distribution of the climate funds is far from its average and the skewness values show that climate finance is biased towards the minimum values. This shows that only a few African countries are receiving most of climate finance whilst a majority of these countries are deprived of the funding.

Table 3 presents the correlation matrix between the time series variables, which provides preliminary evidence on whether the variables are positively (i.e. beneficial for) or negatively (i.e. adversely affecting) correlated. The observed correlations can be summarized in four points. Firstly, there exists positive (negative) correlations between climate finance and food availability (food access, food stability, food utilization, overall food security index). Secondly, we observe negative (positive) correlations between agricultural land and food availability, food access, food stability, (food utilization, overall food security index). Thirdly, FDI has positive correlations with all measures of food security except food access whilst government spending agriculture has a negative impact on all dimensions of food security except food utilization. Lastly, agricultural capacity and rural population are found to be negatively correlated with all measures of food security.

4.2. GMM estimates

In this section of the paper we present our main empirical analysis with Table 4 reporting the results of the GMM estimation of the empirical regression specified in Section 2. From the onset, it is important to note that most regression co-variables produce different effects on the different dimensions of food security and we compactly summarize our findings in the following five points.

Firstly, for food availability, we observe positive (negative) and statistically significant coefficient estimates on climate finance, FDI and government readiness (agricultural land, agricultural technology and rural population) variables whereas the public agricultural spending variable produces insignificant estimate. Secondly, for food access, positive (negative) and significant estimates are found for FDI, government readiness and public agricultural spending (agricultural land, agriculture technology and rural population) whilst climate finance produces an insignificant estimate. Thirdly, for food stability, positive (negative) and significant coefficients exist for government readiness and FDI (climate finance, agricultural land, agricultural technology, public agricultural spending and rural population). Fourthly, for food utilization, positive (negative) and statistically significant estimates found for FDI, agricultural land, agriculture technology and public agricultural spending (climate finance and rural population). Lastly, for the composite food security index, we find positive (negative) and significant estimates on climate finance, agricultural land, FDI, government readiness (public agricultural spending, agricultural technology and rural population).

All-in-all, our empirical results imply that (i) only FDI and government readiness mutually improve food security across all its dimensions (ii) rural population and agricultural capacity are factors which adversely affect food security across all its dimensions (iii) climate finance only improves availability and overall security but adversely affects stability and utilization (iii) Agricultural land adversely affects food

Table 3. Pairwise correlation.

	Avail	Access	Stabil	Util	FSI	AGL	GR	FDI	GASE	CF	ACAP	Rurpop
Avail.	1.0000											
Access	0.3790	1.0000										
Stabil.	0.7367	0.5100	1.000									
Utilisat.	-0.3109	0.4545	0.2697	1.000								
FSI	0.6588	0.7655	0.4698	0.153	1.000							
AGR.LAND	-0.1190	-0.264	-0.362	0.094	0.350	1.000						
GOV.READ	0.3363	0.5102	0.3586	-0.342	0.708	0.1893	1.000					
FDI	0.0274	-0.270	0.1123	0.1686	0.223	0.2433	0.140	1.000				
AGR.GOV	-0.1062	-0.285	-0.307	0.144	-0.416	-0.029	0.033	0.010	1.000			
CF	0.0527	-0.376	-0.273	-0.178	-0.016	0.1297	0.017	0.221	0.366	1.000		
AGR.CAP	-0.4566	-0.541	-0.196	-0.113	-0.622	-0.070	-0.347	-0.418	0.030	0.013	1.000	
RURAL.POP	-0.1287	-0.384	-0.345	-0.321	-0.081	0.261	-0.105	-0.174	0.435	0.304	0.088	1.000

Table 4. SYS-GMM panel regression.

Variables	(1) Availability	(2) Access	(3) Stability	(4) Utilisation	(5) Foodsecurity
Lag of dependent variable	0.479*** (0.115)	0.538 (0.399)	0.191*** (0.043)	1.538*** (0.166)	0.405 (0.253)
logAGL	−1.402*** (0.124)	−2.518*** (0.454)	−0.0287* (0.399)	0.1883*** (0.054)	0.115** (0.123)
logGR	1.131*** (0.221)	1.021*** (0.285)	0.505* (0.302)	1.513*** (0.123)	2.897*** (0.169)
logFDI	0.075** (0.036)	0.315*** (0.795)	0.132** (0.063)	0.042*** (0.016)	0.182*** (0.035)
logGASE	−0.079 (0.111)	0.288*** (0.097)	−0.003* (0.096)	0.055* (0.030)	−0.269** (0.064)
logCF	0.211*** (0.037)	0.034 (0.064)	−0.144** (0.066)	−0.115*** (0.027)	0.135*** (0.033)
LogACAP	−12.388*** (1.287)	−13.775*** (1.398)	−4.960*** (1.721)	10.241*** (3.594)	−5.669*** (0.961)
logRuralpop	−0.961*** (0.231)	−3.212*** (0.397)	−0.612* (0.368)	−0.297*** (0.105)	0.825*** (0.217)
Constant	6.501*** (1.114)	15.498*** (1.995)	0.489 (2.540)	2.914*** (0.589)	−5.033** (1.146)
AR(1)	0.100	0.335	0.323	0.603	0.710
AR(2)	0.243	0.681	0.922	0.234	0.165
Sargan Test	1.000	1.000	1.000	1.000	1.000

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

availability, access and security and yet positively contributes to food utilization and overall food stability (iv) public expenditure on agriculture adversely affects stability and overall food security yet positively contributes to food access and utilization.

Interestingly, our empirical findings are comparable to existing studies and in some instances provide additional knowledge to the literature. For instance, our finding of FDI and government readiness being positively related to food security can be compared with the previous works of Mihalache-O'keef and Li (2011), Slimane et al. (2016) and Adom et al. (2019) who similarly find a positive effect of FDI and readiness on food intake. Through the inclusion of climate finance in our regressions, our analysis additionally informs us that FDI and government readiness are currently more prominent in ensuring food security in comparison to climate finance. Furthermore, our finding of a negative impact of rural population on food security are comparable to the findings of Adjognon et al. (2021), Piaskoski et al. (2020) and Davis et al. (2022) albeit This study employs different dimensions of food security. Altogether, these mutual findings of larger rural populations decreasing food security are particularly concerning when thought of in context of the ongoing COVID-19 pandemic which has lowered household income in rural populations in African countries and aggravated food security concerns in the continent which is over 70 percent rural (Adjognon et al., 2021; Dasgupta & Robinson, 2021). Another cause for concern relates to the agricultural based variables such as public agricultural spending, agricultural land and agricultural capacity which do not show their expected positive on all dimensions of food security as previously found in the studies of Aliyeva et al. (2019), Mulwa and Visser (2020), Kovljenic and Reletic-Jotanovic (2021), Arshad, (2022) and Viana et al. (2022) who find agricultural funding, land and innovation to be conducive for food intake. Since This study employs different dimensions of food security, our findings provide additional knowledge on which aspects of food security are positively or adversely impacted by different agricultural activities. In this regard, we find agricultural activities to be more conducive for food utilization and not for other dimensions of food security such as availability, access and stability.

4.3. Quantile regression estimates

To test the sensitivity of the SYS-GMM estimates, we carry out a PQR analysis to control for the distributional heterogeneity of our empirical model and as a byproduct, accounts for nonlinearities. The coefficients estimation for the 25th, 50th, 75th and 90th quantiles of the conditional food security distribution on its covariates are reported in Table 5. To sum up, the empirical findings show that the impacts of various factors on various food security dimensions are clearly heterogeneous. Most of the PQR estimates are consistent with that of the SYS-GMM, apart from a few quantiles that indicated heterogeneity.

Table 5. Panel Quantile Regression .

	Availability				Access				Stability			
	25th	50th	75th	90th	25th	50th	75th	90th	25th	50th	75th	90th
LogAGL	−1.876*** (0.208)	0.768*** (0.246)	−0.588 (0.432)	0.644 (0.542)	−2.459** (1.101)	−1.919* (1.092)	−1.841* (1.022)	−1.354* (0.759)	−0.725 (0.806)	−0.55* (0.302)	−0.6** (0.248)	−0.42 (0.323)
LogGR	2.655*** (0.375)	0.734 (0.494)	0.994** (0.477)	0.007 (0.590)	0.797 (1.163)	0.837 (0.758)	1.81*** (0.388)	1.43*** (0.310)	0.614 (0.516)	0.544* (0.308)	0.7*** (0.203)	0.37* (0.192)
LogFDI	0.190 (0.140)	0.080 (0.083)	0.102 (0.089)	−0.115 (0.101)	0.349* (0.209)	0.262 (0.171)	0.306* (0.177)	0.062 (0.193)	0.122 (0.168)	0.006 (0.107)	−0.05 (0.039)	−0.054 (0.053)
logGASE	−0.526* (0.306)	0.166 (0.421)	−0.119 (0.334)	−0.263 (0.265)	0.345 (0.225)	0.626*** (0.221)	0.407 (0.369)	0.191 (0.365)	−0.151 (0.251)	−0.3** (0.161)	−0.4*** (0.096)	−0.4*** (0.125)
LogCF	0.237*** (0.050)	0.237*** (0.050)	0.146* (0.077)	−0.017* (0.132)	−0.063* (0.225)	0.005* (0.124)	−0.032* (0.171)	0.030* (0.181)	−0.054 (0.109)	0.026 (0.094)	−0.011 (0.055)	−0.09** (0.046)
LogACAP	−8.937*** (1.238)	−12.2*** (2.296)	−6.01** (2.204)	−3.112 (2.288)	−17.2*** (4.409)	−15.1*** (3.907)	−7.44*** (2.201)	−6.38*** (1.582)	−7.5** (3.238)	−3.8** (1.558)	−0.658 (0.671)	−2.06*** (0.781)
logRuralpop	−1.012** (0.462)	−1.012** (0.462)	−0.235 (0.687)	0.368 (0.656)	−4.05*** (0.957)	−3.54*** (1.089)	−2.301** (0.958)	−1.966** (0.963)	−1.234 (0.995)	−0.851 (0.602)	−0.021 (0.259)	−0.251 (0.244)
Constant	3.752** (1.509)	3.752*8 (1.509)	1.246 (2.665)	−0.856 (2.509)	17.28*** (4.187)	14.882 (5.201)	10.81*** (3.648)	12.41*** (2.896)	5.278 (6.357)	6.037 (2.917)	4.777 (1.430)	5.16*** (1.792)
	Utilisation				Foodsecurity							
	25th	50th	75th	90th	25th	50th	75th	90th				
LogAGL	−0.073 (0.305)	−0.104 (0.124)	−0.026 (0.124)	0.085 (0.140)	0.278 (0.601)	0.729* (0.426)	0.985** (0.396)	1.038*** (0.379)				
LogGR	1.227*** (0.312)	0.89** (0.362)	0.48* (0.275)	0.59** (0.270)	3.24*** (0.785)	2.4*** (0.483)	1.87*** (0.406)	1.53*** (0.517)				
LogFDI	0.075 (0.073)	0.061 (0.040)	0.009 (0.034)	0.004 (0.042)	0.15* (0.079)	0.069 (0.057)	0.021 (0.044)	0.023 (0.542)				
logGASE	0.241** (0.104)	0.276*** (0.085)	0.03** (0.119)	0.23** (0.111)	−0.314 (0.227)	−0.209 (0.179)	−8.25*** (1.651)	0.101 (0.187)				
LogCF	−0.275*** (0.068)	−0.23*** (0.049)	−0.1*** (0.039)	−0.058 (0.060)	0.073 (0.057)	0.084* (0.048)	0.051 (0.056)	0.051 (0.058)				
LogACAP	−15.068 (13.323)	−13.665 (8.554)	−5.830 (8.279)	13.109 (10.592)	−6.524* (3.629)	−7.91*** (1.817)	−8.25*** (1.651)	−7.481** (0.058)				
logRuralpop	−0.224 (0.915)	−0.508* (0.262)	−0.9*** (0.250)	−1.02*** (0.188)	−0.027** (0.649)	−0.024 (0.462)	−0.018 (0.468)	0.081 (0.518)				
Constant	1.296 (3.564)	2.393* (1.336)	4.322 (0.976)	4.415 (0.879)	−2.698 (1.979)	−3.43** (1.445)	−3.63*** (1.307)	−4.48*** (1.619)				

Standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

For instance, CF showed a significant positive impact on food availability to the 75th percentile apart from the 90th percentile. For access, CF showed a significant negative impact at the 25th and 75th percentile, but a significant positive impact at the 50th and 90th percentile. On the other hand, CF showed a homogenous negative and positive effects on food utilization and food security respectively. Since most of the quantile regression results mirror that of the SYS-GMM estimates, we can conclude that it complements our main findings.

5. Conclusions

Our paper sought to determine the effect of climate finance on food security for an unbalanced panel of 35 SSA countries over the period 2006–2016 using GMM estimators and PQR analysis. This study used PCA to create 5 indices which capture the different dimensions of food security (i.e. availability, access, stability utilization and overall security) and these indices are used as dependent variables in our regression models. These models also include food security, as a main independent variable, along with other covariates related to food security such FDI, government readiness, agricultural expenditure, agricultural land, agricultural activity and rural population, all which have been found to be significant factors of food security in previous studies. Therefore, our empirical analysis allows us to compare the effect of climate finance on food security against a host of other related factors affecting food security.

Our main empirical finding is that climate finance has not assisted in enhancing the different dimensions of food security in the SSA region. Infact, we find that climate finance has been more useful for food availability but not for food access, stability and utilization. Another important finding from This study is that FDI and government readiness are factors which have contributed more to securing food security in comparison to climate finance whilst we further find that rural population adversely affects

all dimensions of food security. Lastly, agricultural land and other agricultural related activities such as agricultural expenditure and agricultural capacity do not produce their expected positive effect on all dimensions of food security.

All-in-all, the policy implications of our findings can be summarized as follows. Firstly, this study support the arguments put forward for increasing the amount of climate finance allocated towards developing countries as This study finds that the current funds are insufficient for addressing Africa's food security concerns. Secondly, This study advises local policymakers to put efforts in creating an investor-friendly environment, strengthening public institutions, rule of law and corruption levels, and eradicating poverty in rural areas as a foundation for improving food security in the continent. Lastly, our findings encourage local government, international donors and researchers to work together to find ways to adopt environmentally-friendly innovations which can improve the efficiency of agricultural land and capacity used in food production.

In moving forward, we propose at least three avenues for future research endeavors. Firstly, future studies could use more advanced econometric methods to estimate 'optimal points' at which climate finance is most useful for improving food security and this can be used to inform policymakers on specific amounts of climate finance that should be negotiated at future COP meetings. Secondly, future studies could also investigate the impact of climate finance on food security at household level which would be useful in informing policymakers which demographic groups of rural and/or urban dwellers benefit or do not benefit from climate funding. Finally, randomized experimental trials can be carried out to see whether funding directly allocated to farmers could improve food security by encouraging innovate, environmental-friendly farming practices and this can be used to induce behavioural change at household level.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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