Master’s Thesis of Science in Agriculture

The Impact of Climate Change on Food Production and Undernourishment in Developing Countries

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The Impact of Climate Change on Food Production and Undernourishment in Developing Countries

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Abstract

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This thesis estimates the impact of climate change on food security in developing countries using panel data from 90 developing countries from 1990 to 2020. Employing the system-GMM method, the study analyzes food security, focusing on food availability (Food Production Index, FPI) and food access (Prevalence of Undernourishment, PoU). The findings highlight the influence of lagged values, with the previous year's food production and undernourishment affecting current outcomes. Temperature changes significantly impact food production, with lower temperatures positively affecting production and higher temperatures negatively affecting vice versa. However, Asia exhibits a positive response, possibly due to climate-induced changes in food production patterns. Climate-related disasters exacerbate undernourishment, emphasizing the adverse effects of climate change on food security. Furthermore, GDP growth and population growth rate negatively associate with undernourishment, while food imports and inflation show a positive correlation. Meanwhile, the impact of food aid varied across regions and income groups. These research findings provide valuable foundational resources to inform the formulation of policies and strategies aimed at improving food security in these nations. In conclusion, this thesis emphasizes the significance of region and income-specific proactive measures for climate crisis response and sustainable food production. In this process, it is essential to develop systematic strategies that consider the level of national development and climate vulnerability.

Keywords: Food Security, Food Production, Undernourishment, Climate Change, Developing Countries, Dynamic Panel Model, System-GMM

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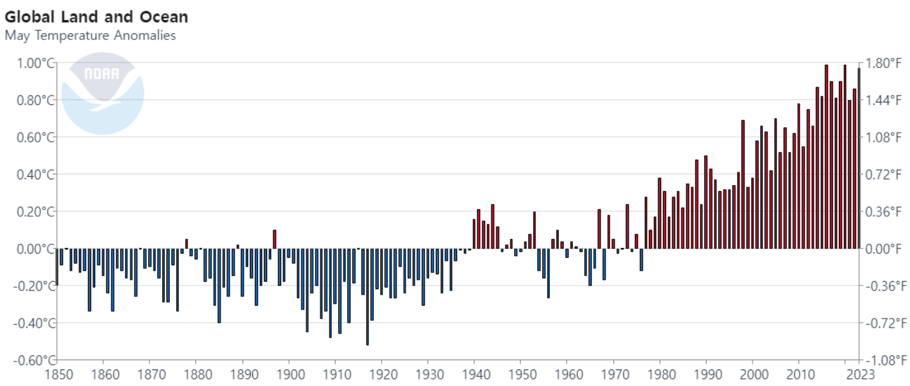
1. Introduction

1.1 Research Background

Global climate change significantly negatively impacts food security and poverty reduction (Uitto & Shaw, 2015). It leads to natural disasters and affects human health, food production capacity, housing, and safety. Extreme weather events have long been recognized as significant contributors to food insecurity (Burgess & Donaldson, 2010). Since 1880, the Earth's temperature has experienced an average increase of 0.14°F (0.08°C) per decade, resulting in a cumulative rise of approximately 2°F (1.1°C) over the period. The ten warmest years in the historical record have all occurred since 2010, indicating a clear pattern of increasing global temperatures in recent times (NOAA, 2023) (**Figure 1**). This temperature rise has resulted in various adverse effects, such as extreme droughts, water scarcity, sea-level rise, floods, polar ice melting, and biodiversity loss (UN, 2023).

Figure 1. Global average surface temperature change.



Source: NOAA (2023).

Agriculture, among various industries, is particularly vulnerable to the effects of climate change. Food production environments are strongly influenced by climate, which not only reduces food crop production but also impacts the economy, food systems, and consumer choices (Abbade, 2017). Moreover, agriculture remains the largest industry in many developing countries, exacerbating inequalities in responding to and preventing natural disasters. Countries with weaker societies and economies have limited capacity to deal with extreme climate events (Campbell et al., 2016; Schmidhuber & Tubiello, 2007). Additionally, more frequent, severe climates disrupt food supply chains in low-income countries (FAO, 2022). Consequently, reduced food production due to climate change poses a long-term threat to achieving food security in developing countries.

Climate change threatens food security in two major aspects: extreme weather events and long-term changes in average temperature and precipitation due to greenhouse gas accumulation in the atmosphere. Heatwaves, droughts, and floods caused by extreme climates are predicted to cause severe crop damage in the future (Schlenker & Lobell, 2010; Schlenker & Roberts, 2009), likely leading to increased food price volatility (Diffenbaugh et al., 2012).

Furthermore, though climate change is a global phenomenon, its impacts vary across regions (Fellmann, 2012; Fisher et al., 2015; Gachene et al., 2015; Kotir, 2011). It is crucial to prepare appropriate long-term responses as the threat of climate change escalates (Hertel & Lobell, 2014).

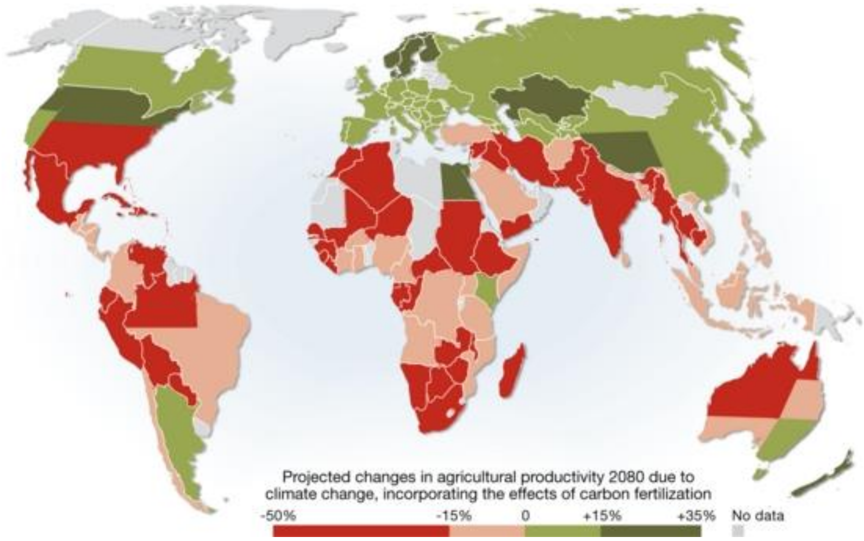
1.2. Purpose of study

This study's main objective is to measure the influence of climate change on food security, with a specific focus on two dimensions: food availability, measured by the food production index, and food access, indicated by the prevalence of undernourishment. Moreover, the findings of this study can be utilized to design policies for climate adaptation and mitigation strategies in the agricultural sectors for developing countries.

Climate change reduces agricultural productivity in developing countries, resulting in inadequate food supply and nutrition. Food production is particularly vulnerable to climate change, as rapid climate change increases the frequency of natural disasters such as droughts, floods, and heat waves.

In developing countries, particularly, agriculture is experiencing a continuous decline in productivity due to climate change. For instance, in the African region, it is projected that agricultural potential may decrease by an average of 16–27% by 2080 (UNEP, 2009). Additionally, the adverse effects of climate change—such as water scarcity due to melting glaciers, altered rainfall patterns, and excessive use of fertilizers—can significantly exacerbate the challenges faced by the agricultural sector. Notably, the impact of climate change is not uniform across all developing countries. Therefore, climate change risks should be measured based on regional and income segments in developing countries.

Figure 2. Projected agricultural productivity in 2080 due to climate change.

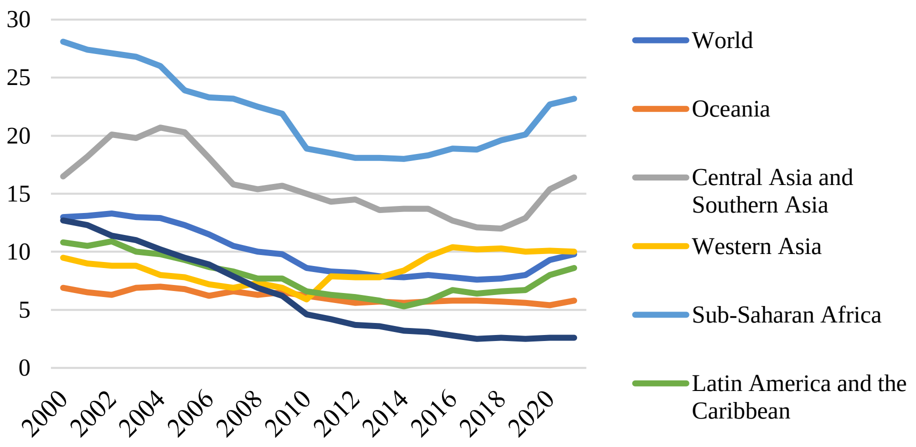


Source: UNEP (2009).

Furthermore, the population affected by undernourishment has rapidly increased in the past two years, reaching a staggering 820 million people worldwide in 2021. The intersection of factors such as COVID-19, climate change, wars, and conflicts, has led to a sustained level of undernourished population for five years, followed by an estimated global prevalence of undernourishment of approximately 8% in 2019, which rose to approximately 9.3% in 2020, and further to 9.8% in 2021, indicating the highest number of people facing hunger globally in 2021 (**Figure 3**).

The prevalence of undernourishment continues to exhibit significant disparities across regions worldwide, with worsening conditions observed everywhere, compared to 2015. In addition to Africa, Asia (with an increase of 1.1 percentage points) and Latin America and the Caribbean (with an increase of 2.8 percentage points) have also experienced a similar trend.

Figure 3. Percentage of undernourished people by region in 2000–2020.



Source: FAO (2023).

Therefore, this study employs an empirical analysis using a dynamic panel model. This approach considers the previous period's (*t*-1) food production index and prevalence of undernourishment, which are proxy variables for food security. Since past conditions influence the current food security status, autocorrelation will likely occur. Ignoring this autocorrelation in a static model can introduce analysis bias. This study broadened the scope and target based on regional and income differences to analyze the impact of climate change on food security in developing countries, unlike previous studies that focused solely on specific regions severely affected by climate change, such as the Horn of Africa (Bedasa & Bedemo, 2022) and Middle East and North Africa (Alboghdady & El-Hendawy, 2016).

The remainder of this paper is structured as follows: Chapter 2 provides a literature review, Chapter 3 presents the conceptual framework, Chapter 4 explains the model and method, Chapter 5 describes the data and procedures used, Chapter 6 presents the results and discussion, and the conclusions of the study are presented in Chapter 7.

2. Literature Review

Definition of Food Security

Food security is a complex and multifaceted concept that has been the subject of extensive discussions and diverse definitions. Over 200 definitions of food security have been proposed thus far (Maxwell & Frankenberger, 1992). The concept gained prominence in the 1970s when global attention shifted toward hunger, famine, and food crises.

During the 1970s and 1980s, the discussion on food security primarily revolved around production and distribution and chronic and acute food insecurity (UN, 1974; FAO, 1983; World Bank, 1986). Chronic food insecurity was associated with structural poverty and low-income issues, while acute (temporary) food insecurity stemmed from natural disasters, economic collapses, and conflicts (World Bank, 1986). Sen (1981) emphasized that food shortage and starvation are not necessarily caused by insufficient food supply but rather by uneven distribution, stating that "*starvation is a matter of some people not having enough food to eat and not a matter of there being not enough food to eat*."

In the mid-1990s, the scope of food security expanded from the individual level to a global level. While access to food was deemed sufficient, the focus shifted to discussing nutrition. Consequently, food security began to encompass the concepts of food safety and nutritional balance, ensuring that individuals have access to adequate and nutritious food for an active and healthy life (UNDP, 1994; FAO, 1996; FAO, 2001).

As the understanding of food security evolved, it became clear that addressing it requires considering the availability and distribution of food and the nutritional quality and safety of the food consumed. This broader perspective acknowledges the interplay of various factors in achieving food security. It highlights the importance of addressing structural issues, poverty, and access to a nutritious diet for individuals and communities (**Table 1**).

Table 1. Definition of food security.

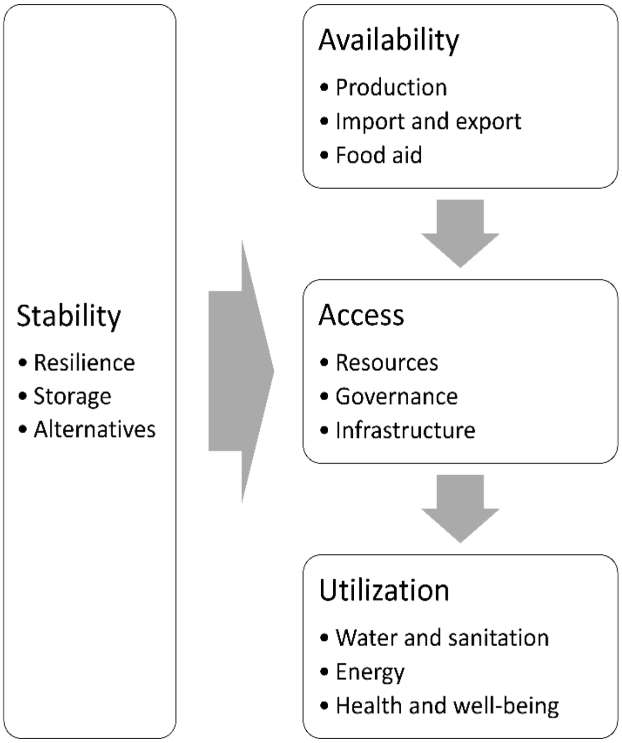
Organization	Definition
UN (1975)	Availability at all times of adequate world food supplies of basic foodstuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices.
Sen (1981)	Focused on the entitlements of individuals and households.
FAO (1983)	Ensuring that all people at all times have both physical and economic access to the basic food that they need.
World Bank (1986)	Access of all people at all times to enough food for an active, healthy life.
FAO (1996)	Exists when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food to meet their dietary needs and food preferences for an active and healthy life.
FAO (2001)	A situation that exists when all people, at all times, have physical, social, and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life.

Food security is a comprehensive concept encompassing four key pillars: availability, access, utilization, and stability (FAO, 2002) (**Figure 4** and refer to **Appendix 1**).

Availability refers to the presence of an adequate and sufficient supply of food in terms of quantity and quality, which can be achieved through domestic production, imports, aid, and other means. Access pertains to the ability of individuals to obtain food resources, ensuring that they can essentially acquire nutritious food through various channels such as home production, market purchases, and exchanges. Utilization focuses on the efficient and proper use of food, considering factors such as nutrition, hygiene, and overall health. This pillar addresses stunting in children, anemia in women, and being overweight in adults. Stability refers to the level of ease in accessing food and the absence of food insecurity, indicating a reliable and consistent availability of food resources (FAO, 2002).

Initially, the concept of food security primarily addressed issues related to food supply and stability. However, as poverty and hunger persisted, the understanding of food security expanded to encompass various challenges related to food access, consumption, and demand. Food security not only involves individual food intake but also encompasses the nutritional status of household members and the overall food security situation at the national level. Moreover, with the increasing prevalence of uncertain factors such as climate change, the COVID-19 pandemic, and conflicts, it has become imperative to consider population growth and strengthen food security in the face of environmental impacts.

Figure 4. Dimensions of food security.



Source: FAO (2002).

Studies on Food Security and Climate Change

Climate change significantly negatively impacts food security, exhibiting periodicity and seasonality over extended periods (Pangaribowo et al., 2013). As a result, numerous studies have been conducted to analyze the effects of climate change on food security, often focusing on regions particularly vulnerable to the climate crisis, such as developing countries. The definition of food security varies among these studies, and many of them employ regression analysis using proxy variables like per capita calorie intake, the prevalence of undernourishment, and food production index to represent food security (**Table 2**).

Badolo and Kinda (2014) analyzed the impact of climatic variability on food security across 71 developing countries from 1960 to 2008. The findings of their study revealed that the adverse effects of climate variability on food supply and undernourished populations are more pronounced in Sub-Saharan Africa (SSA) compared to other developing regions. Moreover, they observed that the negative impact of climate variability is exacerbated in countries experiencing civil war, making them even more vulnerable to food price shocks.

In a study by Adesete et al. (2022), the impact of climate change on food security was analyzed using the Generalized Method of Moments (GMM) model for SSA between 2000 and 2019. They employed the prevalence of malnourishment and greenhouse gas emissions as proxy variables for food security and climate change, respectively. The findings indicated that increased greenhouse gas emissions were associated with higher rates of undernourishment, thereby reducing food security in SSA. Climate change and food prices were found to have a significant negative impact on food security, while income and food supply had a significant positive effect. Consequently, the study suggested that reducing carbon emissions can enhance agricultural supply and productivity, improving regional food security.

Bedasa and Bedemo (2022) conducted a study on the impact of climate change on food insecurity using the GMM estimator in four countries within the Horn of Africa. The results revealed that high temperatures harmed food insecurity, with a 1% increase in average temperature and carbon dioxide emissions leading to an increase of 0.357% and 0.026%. Conversely, a 1% increase in precipitation was associated with decreased food insecurity by 0.023%. The study emphasized the importance of developing crop varieties resistant to high temperatures and drought to mitigate the impact of climate change on food availability and security.

In contrast to conventional regression analysis, Molotok et al. (2020) proposed a modeling framework called Food Estimation and Export for Diet and Malnutrition Evaluation (FEEDME) to assess the relationship between climate variability and food security using the prevalence of malnutrition as a proxy variable. The study introduced three Socio-economic Pathways (SSPs) to explore different future scenarios. It was observed that countries with anticipated population decline exhibited higher levels of food security compared to those without such projections. Additionally, the study predicted that future crop yields would vary depending on different climate change scenarios.

Alboghdady and El-Hendawy (2016) studied climate variability and economic impacts in 20 countries in the Middle East and North Africa (MENA) region from 1961 to 2009. They used the agriculture production index as a proxy variable for food security and employed a fixed effect model and marginal effect analysis. The findings revealed that a 1% increase in winter temperature led to a 1.12% decrease in agricultural production. Moreover, a 1% increase in temperature variability during winter and spring decreased agricultural production by 0.009% and 0.14%, respectively. These results indicated the significant impact of temperature variables on food security in the context of climate change.

Mahrous (2019) examined the impact of climate change on food security using panel data from five East African Community (EAC) countries between 2000 and 2014. The study employed the food production index as a proxy variable for food security and considered independent variables such as precipitation, temperature, population growth, and land under cereal production. The fixed effect analysis revealed that temperature harmed food security in the EAC region. Additionally, an increase in arable land area and precipitation had a significant positive effect on strengthening food security.

Fusco (2022) analyzed the impact of climate change on food security in Northeast Africa from 2000 to 2012. The study employed a panel analysis and considered climate change variables such as precipitation and temperature. The findings indicated that rainfall increase had a positive relationship with enhancing food security, while temperature change had a negative relationship. Moreover, the study found that countries with high food security resilience were those with high per capita income, and the size of arable land had a relationship with the level of food security.

Kinda (2016) analyzed the impact of climate shocks on food security in developing countries using fixed- and random-effects models. The study focused on the role of foreign aid in mitigating food security deterioration in response to climate shocks. The findings showed that foreign aid was crucial in buffering the adverse effects of climate shocks on food security, particularly for countries vulnerable to food price shocks. The study emphasized the importance of increasing foreign aid for developing countries vulnerable to climate and food price shocks.

Pickson and Boateng (2022) conducted a panel data analysis for 15 African countries from 1970 to 2016. The study highlighted the significance of precipitation for food security in Africa, although the importance of rainfall varied across countries. While temperature had an insignificant long-term impact on food security, short-term temperature extremes worsened food security.

Wheeler and von Braun (2013) conducted a comprehensive study on the four dimensions of food security: availability, accessibility, utilization, and stability. Their literature analysis revealed that food availability accounted for approximately 70% of the discussions on food security, followed by accessibility (13%), utilization (11.9%), and stability (4.2%).

Nonetheless, Firdaus (2019) noted the importance of further research focusing on other dimensions of food security. The findings highlighted the existing discussions on food availability in the context of climate change and food security but identified a need for more discussions on stability.

This study aims to analyze the impact of climate change on food security by employing proxy variables, including annual average temperature, precipitation, climate-related disaster frequency, and socio-economic and agricultural factors, used in previous studies. This study is differentiated from previous research as it uses the World Bank's income classification and categorized regions, such as Africa, Asia, and Latin America, with a focus on developing countries, considering their income levels and continents .

Table 2. List of related studies

Author	Title	Scope	Methodology	Dependent Variables	Independent Variables	Findings
Wheeler and von Braun (2013)	Climate change impacts on global food security	None	Classifying study	None	None	Climate change-related food security literature research, followed by availability (70%)>utilization (13%)>access(11.9%)>stability(4.2%).
Balado and Kinda (2014)	Climatic Variability and Food Security in Developing Countries	71 developing countries from 1960 to 2008	Panel regression and Robustness check	Food security (Proportion of undernourished people) and food supply	Population growth, arable land, cereal production land, income per capita, food price shocks vulnerability	As a net food importer, Africa is vulnerable to food price volatility and climate change volatility.
Alboghdady and El-Hendawy (2016)	Economic impacts of climate change and variability on agricultural production in the Middle East and North Africa region	20 countries in MENA region from 1961 to 2009	Fixed Effect Model and Marginal impact analysis	Agriculture Production Index	Fertilizers consumption, livestock, labor, land, temperature, precipitation	Rising temperatures 1%, reducing agricultural yields by 1.12%. Increased temperature variability in winter and spring 1%, reduced agricultural yields by 0.09% and 0.14%, respectively.
Kinda (2016)	Climatic Shocks and Food Security: The Role of Foreign Aid	71 developing countries from 1960 to 2008(compiled 5-year averages)	Fixed Effect Model and Random Effect Model	Food security (Food supply per capita)	Rainfall, arable land, income per capita, population growth, democratic institutions	Foreign aid mitigates food security climate shocks in developing countries. Countries more vulnerable to food price shocks have higher marginal effects.

Mahrous (2019)	Climate change and food security in EAC region: a panel data analysis	5 countries EAC, from 2000 to 2014	Fixed effect estimates	Food security (Food Production Index)	Precipitation, temperature, population growth, land under cereal production	Food security in the EAC is negatively affected by temperature. Increased rainfall needed to grow crops helps to ensure food security.
Firdaus (2019)	Does climate change only affect food availability? What else matters?	None	Narrative review	None	None	Climate change negatively impacts all aspects of food security. Developing countries are more vulnerable to climate shocks and food insecurity than developed countries.
Molotok et al (2020)	Impacts of land use, population, and climate change on global food security	Global impacts to 2050	FEEDME (Food Estimation and Export for Diet and Malnutrition Evaluation) and Scenario analysis	Food security (Undernourishment Prevalence)	Dietary energy provision-based methodology	Climate change will negatively affect crop yields in the future. Population growth could lead to an epidemic of malnutrition.
Fusco (2022)	Climate Change and Food Security in the Northern and Eastern African Regions: A Panel Data Analysis	the North and East African countries, from 2000-2012	Panel data (RE, FE)	Food Production Index (FPI) and Average protein supply	Precipitation, temperature, population growth, land under cereal production, GDP growth, GDP per capita, Quality of Government	Climate change variables (e.g., precipitation, temperature, etc.) have a statistically significant effect. Increased rainfall helps to enhance food production and food security, while temperature changes negatively affect food security. Higher per capita income refers to more arable land and better resilience.
Adesete et al (2022)	Climate change and food security in selected Sub-Saharan African Countries	SSA countries from 2000 to 2019	GMM Model	Food security (Prevalence of	Income, population growth, food supply, food price, food utility, climate	Climate change and food utility are negative (-) for food security, while income and food supply are positive (+) for food security.

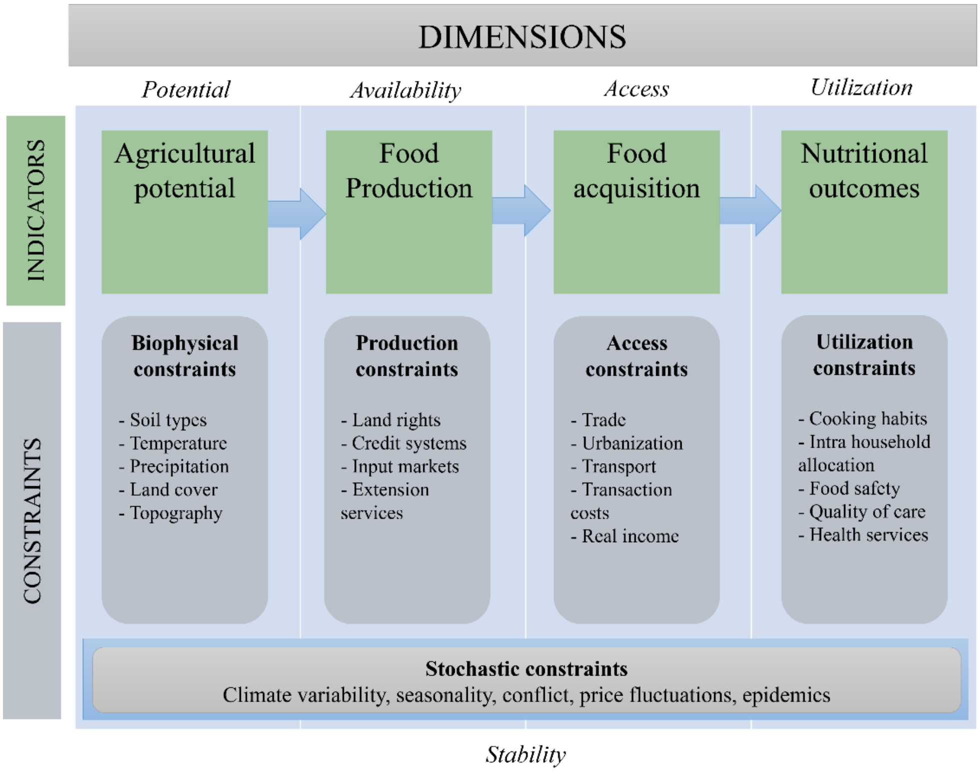
				malnourishment rate, PRM)	change	Reducing carbon emissions helps to improve agricultural supply and productivity, reduces rates of malnutrition, and enhances food security.
Bedasa and Bedemo (2022)	The effect of climate change on food insecurity in the Horn of Africa	4 Countries of horn of Africa from 2000 to 2018	GMM Model	Food insecurity (Prevalence of Undernourishment)	Total released carbon dioxide emissions, cereal yield, import value of food, food production index, annual mean precipitation	Food insecurity in the Horn of Africa is most affected by temperature.
Pickson and Boateng (2022)	Climate change: a friend or foe to food security in Africa?	15 African countries between 1970 and 2016	Mann–Kendall test, Sen's slope estimator, Dumitrescu–Hurlin panel causality test	Food security (cereal availability)	Climate variables (temperature and rainfall), GDP, population growth, cultivated land under cereal production	Rainfall is a critical factor for food security in Africa, but its impact varies from country to country. In the long run, temperature does not have a significant impact on food security, but in the short run, temperature has a negative impact (-).
Chandio et al (2023)	Climate change and food security of South Asia: fresh evidence from a policy perspective using novel empirical analysis	South Asian countries from 1991 to 2016	panel dynamic least squares (PD-LS) method	Crop production index (2004–2006 = 100)	the average annual level of temperature (°C), the average annual level of precipitation (mm), CO2 emissions (kt), the cultivated area under cereal production (hectares), income level is measured by per capita GDP	Temperature and CO_2 negatively affect (-) crop production. Precipitation has a positive effect (+) on it in the long run. Crop production increases as arable land, income levels, and financial development increase. Information on weather needs to be provided to prevent adverse effects of climate change on productivity.

3. Conceptual Framework

Conceptual framework

The conceptual framework of this thesis revolves around the multidimensional nature of food security and its relationship with climate change (Pangaribowo et al., 2013). The four interconnected dimensions of food security—availability, access, utilization, and stability—are crucial in ensuring a resilient and shock-free food system.

Figure 5. Conceptual pathway from agricultural potential to nutrition.



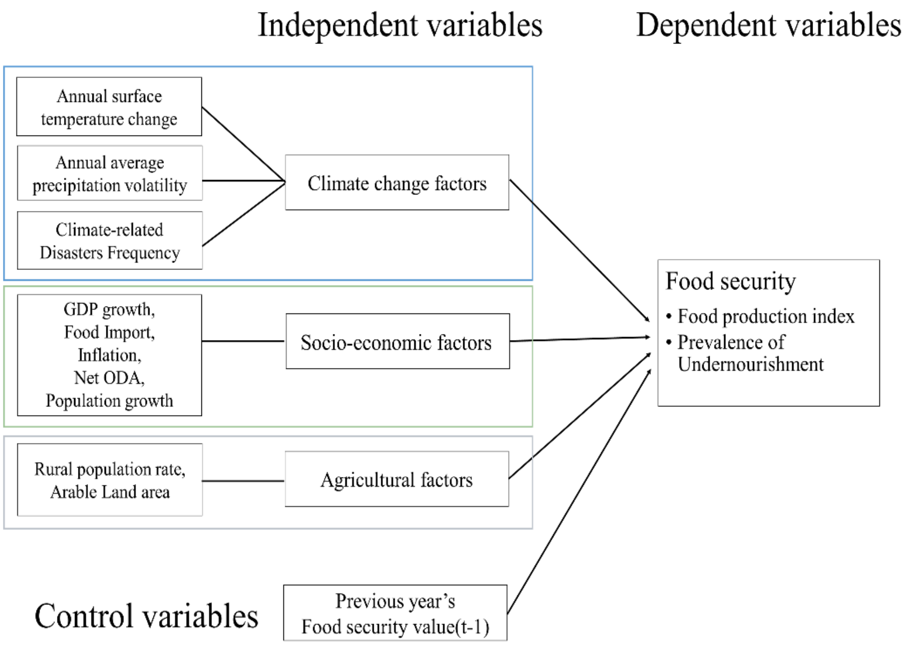
Source: Pangaribowo et al. (2013).

Constraints impacting the transition between these dimensions are classified into two categories: structural and stochastic. Structural constraints are long-term and arise from biophysical, production, access, and utilization factors, while stochastic constraints occur suddenly due to climate variability, conflicts, and epidemics. The sequential progression of potential, availability, access, and utilization influences food security, highlighting the interdependencies among these dimensions (Wim M. et al., 2019). Accordingly, this study presents a novel conceptual framework that reflects the characteristics of the food security dimension in the context of climate change.

Within this framework, the research emphasizes the dimensions of availability and access. Availability pertains to food production, while access focuses on food intake and nutritional status. To measure these dimensions, proxy variables are employed. The food production index and prevalence of undernourishment serve as proxies for availability and access, respectively. Climate change factors that affect food security, such as temperature, precipitation, and frequency of climate-related disasters, were selected through these proxy variables. In addition, this study consistently applied the principle that the four dimensions of food security hierarchically influence each other; for instance, availability affects access. By investigating the connections between climate change factors and the proxy variables for availability and access, the research aims to enhance our understanding of how climate change influences food security.

By considering the distinct characteristics of each food security dimension and establishing a clear link between climate change and food security, the conceptual framework contributes to informed decision-making and policy development. The study aims to develop strategies that address the evolving constraints faced by food systems and ensure food security in the face of climate change.

Figure 6. Conceptual framework.



Research Questions

This study uses panel data to investigate the relationship between climate change and food security. The research aims to address the following key questions:

1. Does annual surface temperature change affect food availability in developing countries?
2. Does the annual frequency of climate-related disasters affect food access in developing countries?
3. Are there regional or income-based disparities in food security among developing countries?
4. Do the economic or agricultural factors impact food security in developing countries?

By exploring these research questions, the study seeks to provide insights into the connections between climate change and food security, considering regional dynamics and income disparities. The panel data analysis will allow for a comprehensive examination of these relationships over time, leading to a better understanding of the implications for food security in the context of climate change.

4. Model

4.1. Cobb-Douglas function of food security

The Cobb-Douglas production function, introduced by Cobb in 1928 (Cobb & Douglas, 1928), establishes the relationship between climate change and food security, considering a single commodity with two factors of production. Referring to the model by Alagidede et al (2016), the function is as follows:

$$Y = AK^{\beta}L^{\alpha} \tag{1}$$

where Y is production output, A is total productivity, K is capital input, and L is labor. Moreover, Adesete et al. (2022) and other previous studies (Alboghady et al, 2016; Mahrous, 2019; Fusco, 2022) argued that climate change factor has come to stay as a factor of production, given that it affects food security. Transforming Eq. (2) to a food security Cobb-Douglas function,

$$FS = A(CL)^{\alpha}(OF)^{\beta} \tag{2}$$

FS denotes food security, CL references climate change related factors, and OF represents other factors such as economic and agricultural variables. Considering the natural logarithm of both sides of Eq. (2),

$$\ln(FS) = lm[A(CL)^{\alpha}(OF)^{\beta}] \tag{3}$$

$$\ln(FS) = \ln[A] + \ln[(CL)^{\alpha}] + \ln[(OF)^{\beta} \tag{4}$$

$$\ln(FS) = \ln[A] + \alpha\ln[CL] + \beta\ln[OF] \tag{5}$$

$$\text{Let } \ln[A]\ is\ constant(\rho)$$

$$\ln(FS) = \rho + \alpha \ln[CL] + \beta \ln[OF] \tag{6}$$

Therefore, using Eq. (6) as a mathematical model,

$$\begin{aligned} \ln(FS) = \rho + \alpha \ln[CL] + \beta_1 \ln[GDPG] + \beta_2 \ln[IMP] \\ + \beta_3 \ln[INFL] + \beta_4 \ln[ODA] \\ + \beta_5 \ln[POPG] + \beta_6 \ln[RUR] + \beta_7 \ln\,[AL] \end{aligned} \tag{7}$$

Transforming Eq. (7) to econometric model,

$$\begin{aligned} \ln(FS) = \rho + \alpha \ln[CL] + \beta_1 \ln[GDPG] + \beta_2 \ln[IMP] \\ + \beta_3 \ln[INFL] + \beta_4 \ln[ODA] \\ + \beta_5 \ln[POPG] + \beta_6 \ln[RUR] + \beta_7 \ln[AL] \\ + \varepsilon \end{aligned} \tag{8}$$

4.2. Dynamic Panel Regression: sys-GMM Model

This study conducts dynamic panel data analysis to examine the relationship between climate change and food security. Static panel data analysis typically includes pooled OLS and fixed- and random-effects models. In this analysis, a fixed-effects model is utilized when there is a correlation between the individual effect and the explanatory variable, while a random-effects model is used otherwise (Brüderl, 2005). Fixed-effects models are suitable when individual variables impact forecasts or outcomes and are particularly helpful in addressing cross-country differences (Clarke et al., 2010).

However, static panel models, even with fixed effects, suffer from several issues—serial correlation and heteroscedasticity (known as endogeneity)— that can lead to biased and inconsistent estimates(Arellano & Bond, 1991). This occurs due to the correlation between the individual effect term and the error term. Ignoring the unobserved effects in model estimation leads to inconsistent estimators. The unobserved effect persists over time; thus, a series correlation emerges between the individual effect and the error term (Caselli et al., 1996).

This study employs a dynamic panel model to address these endogeneity problems and account for unobserved country-specific effects. Additionally, for food security variables, the value of food security in a specific country at time *t* is likely influenced by the lagged value in year *t*-1, which can significantly impact short-term results.

There are two dynamic panel models: difference Generalized Method of Moments (diff-GMM) and system Generalized Method of Moments (sys-GMM). In this study, sys-GMM is used. When the sample size is finite, GMM estimation can be inefficient

(Arellano & Bond, 1991; Blundell & Bond, 1998). Considering the relatively short time series period from 2001 to 2020, sys-GMM estimation is employed to mitigate the bias issue.

Sys-GMM is designed to address the limitations of GMM (Blundell & Bond, 1998). Monte Carlo simulations have shown that sys-GMM estimation performs best in this context. The sys-GMM estimation method involves two steps. First, an additional restriction is introduced in the initial condition process, allowing for a linear GMM estimator in a system of first-difference and level equations, thereby exploiting all available moment conditions. Second, the initial values obtained by the system can be consistently estimated through Generalized Least Squares (GLS) error components under certain conditions.

The following formula is the relationship between food security, climate change, and other factors, as defined in **Section 4.1**.

$$FS = f(CL, GDPG, Import, INFL, ODA, POPG, RUR, AL) \qquad (11)$$

Rewriting Eq. (11) as a dynamic model,

(1) Food Production Index:

$$\begin{gathered} FPI_{it} = \beta_0 + \beta_1 FPI_{it-1} + \beta_2 TEM_{it} + \beta_3 PRE_{it} + \\ \beta_4 GDPG_{it} + \beta_5 Import_{it} + \beta_6 INFL_{it} + \beta_7 ODA_{it} + \\ \beta_8 POPG_{it} + \beta_9 RUR_{it} + \beta_{10} AL_{it} + \alpha_t + \eta_i + \varepsilon_{it} \end{gathered} \qquad (12)$$

$$FPI_{it} = \beta_0 + \beta_1 FPI_{it-1} + \beta_2 TEM_{it} + \beta_3 PRE_{it} + \beta_4 GDPG_{it} + \beta_5 Import_{it} + \beta_6 INFL_{it} + \beta_7 ODA_{it} + \beta_8 POPG_{it} + \beta_9 RUR_{it} + \beta_{10} AL_{it} + \alpha_t - U_{it} \tag{13}$$

where, U_{it} is the random term and $U_{it} = \eta_i + \varepsilon_{it}$,

$$\Delta FPI_{it} = \beta_0 + \beta_1 \Delta FPI_{it-1} + \beta_2 \Delta TEM_{it} + \beta_3 \Delta PRE_{it} + \beta_4 \Delta GDPG_{it} + \beta_5 \Delta Import_{it} + \beta_6 \Delta INFL_{it} + \beta_7 \Delta ODA_{it} + \beta_8 \Delta POPG_{it} + \beta_9 \Delta RUR_{it} + \beta_{10} \Delta AL_{it} + \Delta U_{it} \tag{14}$$

(2) Prevalence of Undernourishment

$$PoU_{it} = \beta_0 + \beta_1 PoU_{it-1} + \beta_2 FPI_{it} + \beta_3 Disaster_{it} + \beta_4 GDPG_{it} + \beta_5 Import_{it} + \beta_6 INFL_{it} + \beta_7 ODA_{it} + \beta_8 POPG_{it} + \beta_9 RUR_{it} + \beta_{10} AL_{it} + \alpha_t + \eta_i + \varepsilon_{it} \tag{15}$$

$$PoU_{it} = \beta_0 + \beta_1 PoU_{it-1} + \beta_2 FPI_{it} + \beta_3 Disaster_{it} + \beta_4 GDPG_{it} + \beta_5 Import_{it} + \beta_6 INFL_{it} + \beta_7 ODA_{it} + \beta_8 POPG_{it} + \beta_9 RUR_{it} + \beta_{10} AL_{it} + \alpha_t - U_{it} \tag{16}$$

where, U_{it} is the random term and $U_{it} = \eta_i + \varepsilon_{it}$

$$\begin{aligned} \Delta PoU_{it} = \ & \beta_0 + \beta_1 \Delta PoU_{it-1} + \beta_2 \Delta FPI_{it} + \beta_3 \Delta Disaster_{it} \\ & + \beta_4 \Delta GDPG_{it} + \beta_5 \Delta Import_{it} \\ & + \beta_6 \Delta INFL_{it} + \beta_7 \Delta ODA_{it} + \beta_8 \Delta POPG_{it} \\ & + \beta_9 \Delta RUR_{it} + \beta_{10} \Delta AL_{it} + \Delta U_{it} \end{aligned} \tag{17}$$

where β_1 is the coefficient for the lagged dependent variable given biased upward since it is positively correlated with η_i, α_t is the time-specific Food Security (FS) fixed effect, η_i is the country-specific effect, and ε_{it} is error term. Furthermore, sys-GMM estimator was used in this thesis, it can be defined as follow equations:

To estimate the above two Eqs. (13) and (14), two sets of instruments $Z_i = Z_D + Z_L$ were used, as sys-GMM estimation, where Z_D is the instrument variable for the model at the first difference and Z_L is the instrument variable for the model at the level L.

5. Materials and Methods

5.1. Data and Variables

In this study, the data spanned the period from 1990 to 2020 in 90 developing countries (refer to **Appendix 2**). The countries were categorized into three regions: Africa, Asia, and Latin America and the Caribbean. Additionally, they were classified into income groups: low-developed, low-middle, and upper-middle countries by the OECD DAC ODA List of countries (refer to **Appendix 3 and 4**).

Secondary data for the analysis were obtained from various sources, including the World Bank (World Development Indicators and Climate Change Knowledge Portal), FAO (FAO STAT), Emergency Events Database (EM-DAT), and Centre for Research on the Epidemiology of Disasters (CRED).

This study considered two dependent variables: food security, measured by the Food Production Index (FPI) and the Prevalence of Undernourishment (PoU). The independent variables consisted of ten factors: climate change indicators (annual surface temperature change, annual average precipitation volatility as a coefficient variable, and climate-related disaster frequency), socio-economic factors (% annual GDP growth, % of food import, % annual inflation, % annual net ODA, and population growth), and agricultural factors (% rural population and % arable land of land area). Following the conceptual framework, FPI represented food availability, while PoU represented food access. Considering the hierarchy of food security, when PoU was the dependent variable, FPI was included as an independent variable in the analysis. **Table 3** provides the sources of the variables used in the study.

Table 3. Variables description and source from 1990 to 2020.

Variable	Abb.	Description	Unit	Source
Food security	**FPI**	Food production index (2014–2016 = 100)	Index	FAO
	PoU	Prevalence of undernourishment	%	FAO
Climate change	**TEM**	Annual surface temperature change	%	FAO
	PRE	Annual average precipitation, Country and Sub National, a coefficient variable	%	CCKP
	Disaster	Climate-related Disaster Frequency (annual)	Number of	EM-DAT, CRED
Socio-economy	**GDPG**	GDP Growth	%	WDI
	Import	Food import (of merchandise)	%	WDI
	INFL	Inflation, GDP deflator	%	WDI
	ODA	GNI per Net ODA	%	WDI
	POPG	Population growth	%	WDI
Agriculture	**RUR**	Rural Population	%	WDI
	AL	Arable land (of land area)	%	FAO

Note (1): TEM presents the mean surface temperature change during the period 1961–2021, using temperatures during 1951–1980 as a baseline.
Note (2): PRE represents variability as a coefficient for variation of annual average precipitation ($PRE = \frac{\sigma}{\mu}$).
Note (3): Disaster means trend in number of climate related natural disasters (e.g., drought, extreme temperature, flood, landslide, storm, and wildfire).

5.2. Descriptive Statistics

Table 4 presents the descriptive statistics for the series on Prevalence of Undernourishment (PoU), Food Production Index (FPI), annual surface temperature change (TEM), annual average precipitation volatility (PRE), Climate-related Disaster Frequency (Disaster), % GDP growth (GDPG), % of food import (Import), % inflation of GDP deflator (INFL), % Net ODA of GNI (ODA), population growth (POPG), rural population (RUR), and % arable land (AL).

The Prevalence of Undernourishment (PoU) has an average of 12.2% with a standard deviation of 9.1%, ranging from a minimum of 2.5% in Azerbaijan to a maximum of 52.2% in the Central African Republic, based on 1,511 observations. The Food Production Index (FPI) has an average value of 84.1, with a standard deviation of 22.0. The minimum FPI is 17.1 (Malawi), while the maximum FPI is 182 (Senegal), based on 1,989 observations. The average annual surface temperature change (TEM) is 0.328, with a standard deviation of 1.00. The values for TEM range from 0.007 (Indonesia) to 15.1 (Mongolia) across the observations. The mean value of the annual average precipitation volatility (PRE) is 0.754, with a standard deviation of 0.312. The minimum PRE value is 0.106 (Indonesia), and the maximum value is 2.28 (Cabo Verde), based on 1,989 observations. The average frequency of climate-related disasters (Disasters) is 4.18, with a standard deviation of 6.07. The minimum frequency is 0 (Kyrgyzstan), and the maximum frequency is 60 (Philippines), based on 1,989 observations.

Table 4. Descriptive statistics.

	Means	**Std. Dev**	**Min**	**Max**	**Obs.**
POU	12.2	9.1	2.5	52.2	1511
FPI	84.1	22.0	17.1	182	1989
TEM	0.328	1.00	0.007	15.1	1989
PRE	0.754	0.312	0.106	2.28	1989
Disaster	4.18	6.07	0	60	1989
GDPG	3.84	4.41	-36.4	43.5	1989
INFL	12.8	95.1	-26.3	2737	1989
Import	14.8	7.26	0.474	52.3	1989
ODA	4.22	5.86	-0.643	59.8	1989
POPG	1.61	1.18	-3.63	11.8	1989
RUR	49.6	18.9	7.89	89.6	1989
AL	14.8	13.6	0.288	72.6	1989

5.3. Empirical Model

As derived in **Chapter 4**, the following Eq. (18) estimates the statistical relationship between food security (FS) and the dependent variables.

$$FS = f\begin{pmatrix} TEM, PRE, Disaster, GDPG, \\ Import, ODA, INFL, POPG, RUR, AL \end{pmatrix} \tag{18}$$

The above Eq. (18) can be re-written as a dynamic panel regression model:

(1) Food Production Index (FPI)

$$\begin{gathered} FPI_{i,t} = \beta_0 + \beta_1 FPI_{i,t-1} + \beta_2 TEM_{i,t} + \beta_3 PRE_{i,t} + \\ \beta_4 GDPG_{i,t} + \beta_5 Import_{i,t} + \beta_6 INFL_{i,t} + \beta_7 ODA_{i,t} + \\ \beta_8 POPG_{i,t} + \beta_9 RUR_{i,t} + \beta_{10} AL_{i,t} + \alpha_t + \eta_i + \varepsilon_{i,t} \end{gathered} \tag{19}$$

where $\boldsymbol{FPI_{i,t}}$ represents the Food Production Index in country i and time t (from 1990 to 2020), $\boldsymbol{FPI_{i,t-1}}$ indicates the lagged dependent variable, $\boldsymbol{TEM_{i,t}}$ is the annual surface temperature change, $\boldsymbol{PRE_{i,t}}$ is annual average precipitation volatility as coefficient variable, $\boldsymbol{GDPG_{i,t}}$ means annual GDP Growth rate, $\boldsymbol{Import_{i,t}}$ is food import of merchandise, $\boldsymbol{ODA_{i,t}}$ represents the Net ODA, $\boldsymbol{INFL_{i,t}}$ is annual inflation rate, $\boldsymbol{RUR_{i,t}}$ indicates rural population rate, $\boldsymbol{AL_{i,t}}$ is arable land area, $\boldsymbol{\alpha_t}$ is the time-specific FPI fixed effect, $\boldsymbol{\eta_i}$ is the country-specific effect, and $\boldsymbol{\varepsilon_{i,t}}$ is the error term.

(2) Prevalence of Undernourishment (PoU)

$$
\begin{aligned}
PoU_{i,t} = \; & \beta_0 + \beta_1 PoU_{i,t-1} + \beta_2 FPI_{i,t} + \beta_3 Disaster_{i,t} \\
& + \beta_4 GDPG_{i,t} + \beta_5 iMPORT_{i,t} + \beta_6 INFL_{i,t} \\
& + \beta_7 ODA_{i,t} + \beta_8 POPG_{i,t} + \beta_9 RUR_{i,t} \\
& + \beta_{10} AL_{i,t} + \alpha_t + \eta_i + \varepsilon_{i,t}
\end{aligned}
\tag{20}
$$

In the second estimation, where $\boldsymbol{PoU_{i,t}}$ represents the Prevalence of Undernourishment in country i and time t (from 2001 to 2020), $\boldsymbol{PoU_{i,t-1}}$ indicates the lagged dependent variable, $\boldsymbol{FPI_{i,t}}$ is the Food Production Index, $\boldsymbol{Disaster_{i,t}}$ is the annual climate-related disaster frequency, $\boldsymbol{GDPG_{i,t}}$ means annual GDP growth rate, $\boldsymbol{Import_{i,t}}$ represents food import of merchandise, $\boldsymbol{ODA_{i,t}}$ means the net ODA, $\boldsymbol{INFL_{i,t}}$ is annual inflation rate, $\boldsymbol{RUR_{i,t}}$ is rural population rate, $\boldsymbol{AL_{i,t}}$ is arable land area, $\boldsymbol{\alpha_t}$ is the time-specific FPI fixed effect, $\boldsymbol{\eta_i}$ is the country-specific effect, and $\boldsymbol{\varepsilon_{i,t}}$ is the error term.

6. Results and Discussion

6.1. Pre-regression Analysis

Pairwise Correlation Matrix

A correlation analysis was conducted among the variables examined in this study to estimate the impact of climate change factors on food security, specifically FPI and PoU. The correlation matrix of the main variables is presented in **Tables 5 and 6**, and the detailed results can be found in the Appendix.

The correlation analysis reveals the following relationships among the variables: FPI shows a positive correlation with TEM (0.34), Import (0.08), and GDPG (0.43). It indicates that the food production index also tends to increase as these factors increase. Conversely, there is a negative correlation between FPI and ODA (-0.14). It suggests that an increase in net ODA is associated with a decrease in the food production index.

PoU exhibits a positive correlation with ODA (0.45) and Import (0.08). It implies that higher levels of ODA and food import are associated with an increase in the prevalence of undernourishment. However, there is a negative correlation between PoU and the FPI (-0.23). It suggests that as the food production index decreases, the prevalence of undernourishment tends to increase.

These correlation findings provide insights into the relationships between climate change factors and food security indicators. The positive correlations between FPI and certain variables (TEM, Import, GDPG) indicate their potential influence on food production. By contrast, the negative correlation with ODA suggests that ODA might limit food production. Similarly, the positive correlations between PoU and ODA, as well as PoU and food import, suggest the adverse impact of these factors on undernourishment levels. The negative correlation between PoU and FPI further highlights the importance of food production for reducing undernourishment (refer to **Appendix 5 and 6**).

Table 5. Correlation Matrix of FPI.

	FPI	TEM	PRE	GDPG	ODA	Import
FPI	-					
TEM	**0.346***** (<.001)	-				
PRE	0.012 (0.590)	**0.112***** (<.001)	-			
GDPG	**0.430***** (<.001)	**0.187***** (<.001)	**-0.295***** (<.001)	-		
ODA	**-0.145***** (<.001)	0.014 (0.541)	**0.281***** (<.001)	**0.087***** (<.001)	-	-
Import	**0.089***** (<.001)	**0.154***** (<.001)	**0.361***** (<.001)	**-0.102***** (<.001)	**0.351***** (<.001)	-

Table 6. Correlation Matrix of PoU.

	PoU	Disaster	FPI	GDPG	ODA	Import
PoU	-					
Disaster	0.048 (0.064)	-				
FPI	**-0.233***** (<.001)	-0.039 (0.129)	-			
GDPG	0.048 (0.063)	0.037 (0.152)	**-0.195***** (<.001)	-		
ODA	**0.450***** (<.001)	**-0.168***** (<.001)	**-0.095***** (<.001)	**0.096***** (<.001)	-	
Import	**0.086***** (<.001)	**-0.323***** (<.001)	**0.115***** (<.001)	**-0.124***** (<.001)	**0.393***** (<.001)	-

6.2. Results

6.2.1. Food Production Index (FPI)

Table 7 provides the results for the FPI from (1) to (7). Result (1) represents the total for countries, (2) to (4) indicate the results by region, and (5) to (7) present the results by income group. Across all the results, an increase in FPI(*t*-1) raised the FPI by 0.675 (Total), 0.809 (AF), 0.771 (AS), 0.735 (LAC), 0.482 (LDC), 0.778 (LMC), and 0.851 (UMC), at the 1% significant level.

For the Total, several variables showed significant associations with the dependent variable. FPI(t-1), GDPG, Imports, INFL, and AL demonstrated positive relationships. A 1% increase in these variables would increase FPI by 0.675, 0.203, 0.085, 0.014, and 0.312, respectively. However, TEM, ODA, and RUR exhibited negative associations with FPI. A 1% increase in these variables would decrease FPI by -2.139, -0.302, and -1.550, respectively. The coefficients for the other independent variables were not statistically significant.

For African countries (AF), only GDPG positively influenced FPI, with a coefficient of 2.144 at the 10% significance level. However, a 1% increase in TEM and RUR would decrease FPI by -1.566 and -1.024, respectively, at the 1% significance level.

In the Asian countries (AS), TEM and AL had positive effects on FPI, with coefficients of 2.144 and 1.014, respectively, at the 5% significance level. However, INFL and ODA negatively impacted FPI, with coefficients of -0.185 and -0.106, respectively, at the 1% significance level.

For Latin American and Caribbean countries (LAC), TEM, PRE, and RUR had significant negative effects on FPI, with coefficients of -3.804, -18.756, and -1.628, respectively. Only AL positively affected FPI, with a coefficient of 2.217 at the 5% significance level.

In the analysis by low-developed countries (LDC), GDPG, Imports, and AL had positive and statistically significant relationships with food production. A 1% increase in GDPG, Imports, and AL would increase FPI by 0.668, 0.267, and 2.017, respectively. However, RUR had a negative effect on FPI, with a coefficient of -1.500 at the 1% significance level.

For low-middle income countries (LMC), PRE and INFL had negative effects on FPI at 1% and 10% significance levels, respectively. Conversely, GDPG and ODA positively affected FPI. A 1% increase in GDPG and ODA would increase FPI by 6.139 and 0.359, respectively, at 5% and 10% significance levels.

Finally, according to Model (UMC), GDPG and INFL had adverse and significant effects on FPI in upper-middle income countries at 5% and 1% significance levels, respectively. Nevertheless, TEM and RUR negatively impacted FPI, with coefficients of -0.983 and -0.611 at 1% and 5% significance levels, respectively.

In summary, the FPI analysis reveals that arable land has the most significant positive impact on food security across all models, followed by GDP growth. Increasing the availability of arable land and promoting economic growth is crucial for enhancing food production. However, rising temperatures, the proportion of the rural population, and excessive precipitation negatively affect food security. Addressing climate change, managing urbanization, and mitigating the impacts of extreme rainfall is essential for safeguarding food security. Access to food imports and controlling inflation also support food security.

Understanding the relative importance of these variables and their statistical significance can guide policymakers and stakeholders in prioritizing interventions and implementing strategies to improve food security. Arable land, GDP growth, and addressing the impacts of temperature and rural population proportions should be key focus areas for promoting sustainable food production and enhance global food security.

Table 7. Regression results for Food Production Index (FPI) by region and income group.

	(1) Total	(2) AF	(3) AS	(4) LAC	(5) LDC	(6) LMC	(7) UMC
FPI(t-1)	**0.675***** (0.027)	**0.809***** (0.078)	**0.771***** (0.077)	**0.735***** (0.101)	**0.482***** (0.096)	**0.778***** (0.046)	**0.851***** (0.067)
TEM	**-2.139***** (0.310)	**-1.566*** (0.846)	**2.144**** (1.054)	**-3.084**** (1.346)	23.163 (36.515)	-0.431 (0.487)	**-0.983***** (0.308)
PRE	-0.935 (1.608)	0.457 (4.232)	5.585 (5.559)	**-18.756**** (6.805)	-1.748 (5.942)	**-7.693***** (3.369)	-5.176 (3.455)
GDPG	**0.203***** (0.022)	**0.401*** (0.208)	0.200 (0.137)	0.063 (0.119)	**0.668***** (0.207)	**6.139**** (1.982)	**0.108**** (0.047)
Import	**0.085**** (0.033)	0.059 (0.125)	-0.037 (0.173)	-0.862 (0.537)	**0.267***** (0.082)	**-0.256*** (0.146)	0.125 (0.133)
INFL	**0.014***** (0.004)	-0.008 (0.017)	**-0.185***** (0.068)	0.001 (0.001)	0.034 (0.032)	-0.037 (0.031)	**0.022***** (0.005)
ODA	**-0.302***** (0.058)	0.204 (0.162)	**-1.016***** (0.366)	-0.284 (0.366)	0.028 (0.068)	**0.359*** (0.196)	-0.107 (0.281)
POPG	0.344 (0.268)	1.806 (3.367)	1.545 (0.972)	2.762 (5.468)	-0.991 (2.692)	2.811 (2.544)	0.851 (1.170)
RUR	**-1.550***** (0.157)	**-1.024**** (0.431)	-0.475 (0.408)	**-1.628**** (0.778)	**-1.500***** (0.327)	-0.744 (0.479)	**-0.611**** (0.253)
AL	**0.312**** (0.116)	0.444 (0.632)	**1.014**** (0.397)	**2.217**** (1.056)	**2.017***** (0.467)	-0.792 (0.586)	-0.018 (0.628)
Hansen test	80.798 (0.422)	25.788 (0.363)	12.758 (0.621)	9.807 (0.547)	16.912 (0.391)	22.330 (0.172)	23.288 (0.561)
AR (1)	-4.127 [0.000]	-3.158 [0.001]	-2.114 [0.034]	-3.363 [0.000]	-2.362 [0.018]	-2.595 [0.009]	-2.678 [0.074]
AR (2)	1.910 [0.056]	1.302 [0.192]	1.205 [0.228]	0.286 [0.774]	1.824 [0.068]	0.821 [0.411]	1.390 [0.164]
Period	1990–2020	1990–2020	1990–2020	1990–2020	1990–2020	1990–2020	1990–2020
Cross-section	88	35	25	21	26	27	35
Observation	1810	699	482	505	339	608	776

*Note (1): *, **, and *** indicate significance at α=10%, 5%, and 1% levels*
Note (2): ( ) is Robust standard errors, [ ] is Prob.

6.2.2. Prevalence of Undernourishment (PoU)

The results presented in **Table 8** provide valuable insights into the PoU across the total for countries, regions, and income groups. Results (8) represents the findings for the total for countries, (9) to (11) indicates results at the regional level, and (12) to (14) present the PoU by income groups. Across all results, the lagged PoU variable significantly influenced the current PoU, with coefficients of 0.594 (total), 0.659 (AF), 0.332 (AS), 0.674 (LAC), 0.592 (LDC), 0.734 (LMC), and 0.690 (UMC) at the 1% significance level, holding other variables constant.

The findings for the total for countries (Total) indicate that several independent variables significantly influence PoU. Specifically, Disasters, INFL, ODA, RUR, and AL demonstrate positive associations with PoU, leading to increases of 0.045, 0.094, 0.009, 0.056, 0.041, and 0.074, respectively, at 1% or 5% significance levels. Conversely, FPI, GDPG, and POPG exhibit negative effects on the dependent variable, with coefficients of -0.015, -0.036, and -0.165 at the 1% significance level.

In Africa (AF), the analysis reveals that Imports, Inflation, and ODA positively affect PoU, with coefficients of 0.122, 0.013, and 0.182 at 1% and 10% significance levels. By contrast, RUR and AL negatively impact PoU, with coefficients of -0.268 and -0.479 at the 1% significance level.

For Asia (AS), FPI, GDPG, and ODA negatively influence PoU, with coefficients of -0.043, -0.122, and -0.049 at 1% and 10% significance levels. Importantly, imports (0.102) and the proportion of the rural population (RUR) (0.626) exhibit a positive relationship with PoU at the 1% significance level. In Latin America and the Caribbean (LAC), imports (0.079), INFL (0.020), ODA (0.199), and AL (0.161) positively impact PoU at 1% and 10% significance levels.

The results for income groups highlight distinct patterns. In low-developed income countries (LDC), the variables FPI (-0.062), GDPG (-0.135), and RUR (-0.407) negatively impact PoU at the 1% significance level. Conversely, Imports and ODA positively correlate with the dependent variable. A 1% increase in imports and ODA would result in a rise of 0.087 and 0.178, respectively, at the 1% significance level.

For low-middle income countries (LMC), the analysis reveals that Disasters, Imports, ODA, and RUR positively impact PoU, with coefficients of 0.009, 0.035, 0.200, and 0.179 at 5% or 1% significance levels. However, GDPG and AL exhibit a negative relationship with the dependent variable, with coefficients of -0.073 and -0.555 at 1% and 5% significance levels, respectively.

In the case of upper-middle income countries (UMC), FPI (-0.012) and GDPG (-0.033) negatively impact PoU at 5% and 1% significance levels. Conversely, INFL, ODA, and RUR exhibit a positive relationship with the dependent variable, with coefficients of 0.161, 0.010, and 0.149 at 1% and 5% significance levels. The results, listed in order of the greatest impact on PoU, are as follows. The lagged PoU variable consistently has the most significant impact on current PoU in all models, indicating the persistence of undernourishment. The proportion of the rural population is consistently influential across various models, with a higher proportion associated with increased undernourishment. ODA has a significant positive impact on PoU in multiple regions and income groups. AL and Imports also demonstrate significant associations with PoU in various regions and income groups. GDPG, INFL, and FPI have notable impacts on PoU in specific contexts. Additionally, POPG and Disaster have relatively lower but still significant impacts on PoU.

Understanding the significance levels and relative importance of these variables can guide in formulating targeted interventions and policies to address undernourishment and improve global food security. Factors such as the proportion of the rural population, official development assistance, arable land, and imports play critical roles in reducing undernourishment and promoting food security.

Table 8. Regression results for Prevalence of Undernourishment (PoU) by region and income group

	(8) Total	(9) AF	(10) AS	(11) LAC	(12) LDC	(13) LMC	(14) UMC
PoU(t-1)	**0.594***** (0.001)	**0.659***** (0.020)	**0.332***** (0.051)	**0.674***** (0.045)	**0.592***** (0.039)	**0.734***** (0.035)	**0.690***** (0.012)
FPI	**-0.015***** (0.000)	-0.021 (0.013)	**-0.043***** (0.007)	-0.020 (0.033)	**-0.062***** (0.021)	-0.003 (0.005)	**-0.012**** (0.003)
Disaster	**0.045***** (0.002)	0.019 (0.016)	0.003 (0.006)	-0.015 (0.018)	-0.023 (0.083)	**0.009**** (0.008)	-0.023 (0.011)
GDPG	**-0.036***** (0.001)	-0.036 (0.021)	**-0.122***** (0.013)	-0.022 (0.034)	**-0.135***** (0.045)	**-0.073***** (0.011)	**-0.033***** (0.005)
Import	**0.094***** (0.001)	**0.122***** (0.013)	**0.102***** (0.020)	**0.079**** (0.036)	**0.087***** (0.025)	**0.035**** (0.016)	**0.161***** (0.016)
INFL	**0.009***** (0.000)	**0.013*** (0.007)	-0.002 (0.006)	**0.020***** (0.005)	0.007 (0.015)	0.002 (0.003)	**0.010**** (0.004)
ODA	**0.056***** (0.002)	**0.182***** (0.020)	**-0.049*** (0.029)	**0.199***** (0.031)	**0.178***** (0.033)	**0.200***** (0.030)	-0.004 (0.050)
POPG	**-0.165***** (0.024)	-0.248 (0.483)	-0.140 (0.160)	0.149 (1.146)	2.114 (2.056)	0.121 (0.557)	-0.000 (0.176)
RUR	**0.041***** (0.010)	**-0.268***** (0.043)	**0.626***** (0.072)	0.077 (0.101)	**-0.407***** (0.125)	**0.179**** (0.070)	**0.149***** (0.039)
AL	**0.074**** (0.002)	**-0.479***** (0.070)	0.002 (0.196)	**0.161*** (0.094)	-0216 (0.162)	**-0.555**** (0.260)	-0.056 (0.090)
Hansen test	75.916 (0.577)	28.871 (0.316)	12.295 (0.656)	12.678 (0.314)	18.406 (0.300)	22.267 (0.220)	27.369 (0.337)
AR (1)	0.179 [0.749]	-1.114 [0.264]	-0.213 [0.821]	-1.081 [0.279]	-0.806 [0.420]	-1.152 [0.249]	-0.985 [0.324]
AR (2)	1.110 [0.266]	0.042 [0.966]	2.135 [0.032]	0.273 [0.784]	0.008 [0.993]	-0.383 [0.701]	0.445 [0.655]
Period	2001–2020	2001–2020	2001–2020	2001–2020	2001–2020	2001–2020	2001–2020
Cross-section	90	35	25	21	26	27	35
Observation	1333	527	351	344	339	433	561

*Note (1): *, **, and *** indicate significance at α=10%, 5%, and 1% levels*
Note (2): ( ) is Robust standard errors, [ ] is Prob

6.3. Discussion

6.3.1. Determinant Factors of Food Production Index (FPI)

The results consistently demonstrate that the current FPI is significantly influenced by the FPI(t-1), highlighting the considerable impact of past food production on present-year production. However, it is essential to note that this impact is not deterministic and can be influenced by various other factors, including weather conditions, pest outbreaks, policy changes, and global market dynamics.

The study found that a decrease in TEM is associated with an increase in FPI across all countries, including AF, LAC, and UMC. Higher temperatures have been linked to a shorter crop maturation period and reduced food production, mainly when high temperatures occur during blooming (Moriondo et al., 2011; Malhi et al., 2021). Additionally, high temperatures after premature blooming accelerate the biological aging of grains and increase water stress (Lobell et al., 2012). Therefore, temperature increases have a negative impact on crop yields and food production (Ray et al., 2019; Waaswa et al., 2022). These findings suggest that smaller temperature increases are more likely to affect food production positively.

Interestingly, only AS shows a positive effect of TEM on the FPI. It could be attributed to the widening of the climatic zone due to climate change, leading to modifications in the crop production period and cultivation areas. Additionally, certain Asian regions, such as East Asia and East-south Asia, may experience increased productivity at lower levels of temperature rise due to climate change (Kim et al., 2009).

In addition, the findings indicate that PRE has a negative effect only on LAC and LMC. Exposure of low- and middle-income countries to climate extremes is at risk, rising from 83% in 1996–2000 to 96% in 2011–2016 (FAO, 2020). This result for LMC's PRE supports that trend. Nevertheless, it is essential to note that precipitation alone does not accurately predict food production due to spatial and seasonal variations (Zachariah et al., 2021). Therefore, it is crucial to consider not only precipitation but also water resources and drought variables, as water scarcity due to extreme drought is a significant cause of food insecurity and a crucial variable affecting food security. Further analysis should incorporate these additional variables to gain a comprehensive understanding of the impact of climate change on food security.

Regarding socio-economic variables, GDPG shows a positive relationship with the FPI in Total, AF, LDC, LMC, and UMC. Generally, economic growth and agricultural productivity enhance food security (Dithmer & Abdulai, 2017; Nugroho et al., 2022). Paradoxically, many developing countries heavily rely on agriculture as their primary industry but are also net food importers. Consequently, in this study, Import have a positive effect on the FPI, reflecting the characteristics of developing countries that are both agricultural-oriented and reliant on food imports. However, in LMCs, food imports and the FPI have a negative relationship, indicating a decreasing dependence on food imports as the economy grows (van Berkum, 2021). INFL positively affects the FPI in Total and UMC, but has a negative relationship with Asia. This variable is more closely related to food access than to food production and is addressed in terms of the supply chain (Zurayk, 2020). Therefore, the results demonstrate varying effects of inflation across regions and income groups.

Drawing on Schultz's (1960) theory, food aid can have conflicting effects on food production in recipient countries. On the one hand, it may increase household income and depress the price effect in the market (Ferrière & Suwa-Eisenmann, 2015). On the other hand, the short- and long-term effects of food aid differ, emphasizing the importance of considering the timing of the analysis (Maxwell, 1991; Barrett & Maxwell, 2007). In this study, food aid was analyzed as ODA and was found to have a negative effect on food production in Total and Asia. However, in LMCs, ODA shows a positive effect on the FPI, indicating that food aid does not uniformly have a negative impact on agricultural productivity and investment across all countries.

Regarding agricultural variables, RUR has a negative effect on the FPI, while arable land shows a positive relationship with the FPI. AL is a crucial factor in increasing food production. Approximately 3.4 billion people in developing countries reside in rural areas, with the majority relying on small family farms for their income and livelihoods. Moreover, approximately 80% of individuals living in extreme poverty are in rural areas (IFAD, 2023). However, due to the dominance of small-scale agriculture and poverty in rural populations, the positive impact of the rural population on food production is limited.

Consistent with previous studies (Osabohien et al., 2020; Olsson et al., 2016), the analysis confirms the positive effect of arable land on the increase in the FPI. Despite the challenges posed by climate change, having and preserving an appropriate cultivated area for sustaining food production is imperative.

6.3.2. Determinant Factors of Prevalence of Undernourishment (PoU)

The results of PoU represent food access at the individual level, whereas the results of FPI reflect food availability at the national level. Similar to the FPI, the previous year's PoU significantly influences the PoU in countries, regions, and income groups. Nugroho et al (2022) expressed concerns about the significant impact of PoU(*t*-1) on developing countries, which varies across different regions. Developing countries employ policies to reduce PoU, although sometimes focusing on short-term goals may worsen the situation (Smith et al., 2017). Additionally, factors such as population growth, poverty, lack of agricultural investment, climate and weather, political stability, conflict, and migration affect the PoU (Prosekov & Ivanova, 2016).

The FPI, which represents food security at the regional level, exhibits a negative relationship with the PoU in Total, AS, LDC, and UMC. Insufficient food production leads to a decline in nutritional quality and can contribute to chronic poverty and hunger (Mughal & Fontan Sers, 2020). Consequently, increasing food production at the national level is necessary to enhance food security at the individual level.

On an annual basis, Disaster positively impacts PoU in Total and LMC. This suggests that a higher occurrence of disasters resulting from climate change exacerbates food insecurity. Therefore, strengthening food security by establishing a resilient and stable food system to respond to disasters and effectively mitigating their impact on nutrition is vital (Sinha et al., 2022).

Regarding socioeconomic variables, GDPG and POPG significantly negatively affect the PoU. Conversely, the overall findings indicate that Import and INFL positively affect PoU, implying that malnutrition is more closely linked to economic stagnation or sudden economic shocks than economic growth. Therefore, GDPG, typically associated with economic progress, negatively influences the PoU.

According to Malthus (1798), population growth implies that the available food supply is insufficient to meet the needs of a growing population. As a result, countries with high levels of PoU may struggle to provide an adequate food supply for their expanding populations. Furthermore, inflation and the reliance on food imports indicate inadequate domestic food production and supply, along with unstable national and household economies. Therefore, it can be inferred that the factors contributing to the increase in PoU are associated with economic and social instability within a country.

In contrast to the results of FPI, ODA exhibits a positive relationship with PoU when excluding Asia. This suggests that countries receiving food aid are more susceptible to widespread undernourishment, and short-term support is being provided to address food insecurity and poverty eradication.

The results regarding RUR and AL in agricultural-related variables varied across different models. Specifically, the proportion of rural residents in Africa and low-developed countries showed a negative relationship with PoU. However, in the overall analysis, as well as in Asia, LMC, and UMC, the proportion of rural residents had a positive relationship with PoU. This suggests that in these contexts, a higher proportion of rural residents is linked to a higher PoU.

In further analyses, additional variables should be considered to better understand the relationship between the proportion of the rural population and nutritional deficiency. Specifically, incorporating the urbanization rate would provide valuable insights into the dynamics of urban and rural populations and their impact on food security.

Furthermore, the traditional use of cultivated areas as a variable may no longer capture the full picture due to the influence of agricultural mechanization and industrial development. Exploring variables related to industrialization within the agricultural sector is necessary to account for these changes. This could involve examining factors such as agricultural technology adoption or agricultural value-added to better understand the evolving relationship between food production and nutritional deficiencies.

7. Conclusion

This study examined the impact of climate change on food security in 90 developing countries using panel data from 1990 to 2020. Through the utilization of the system-GMM method and analysis of food availability and access dimensions, several key findings emerged.

Firstly, in the results of FPI, lagged values were found to significantly influence current value, highlighting the importance of the previous year's food production on present outcomes. Temperature changes significantly affected food production, with lower temperatures positively influencing yields while higher temperatures were negatively impacting food productivity. Additionally, precipitation volatility emerged as a significant cause of food insecurity, indicating the need for effective water management strategies. Socioeconomic factors such as GDP growth and food imports positively correlated with food production. The impact of ODA on food production varied across regions and income groups, suggesting the need for tailored approaches.

Concerning the PoU, the previous year's value affects the present value, and a negative relationship between the food production and undernourishment was identified. The frequency of climate-related disasters was found to positively impact undernourishment, underscoring the adverse effects of climate change on food security. Moreover, GDP growth and population growth rate were found to affect undernourishment significantly negatively, while food imports and inflation had a positive effect.

Meanwhile, this study has limitations. Firstly, it focused only on two dimensions of food security, namely food availability and access. Future studies should consider incorporating the remaining dimensions for a more comprehensive analysis. Second, to enhance the validity of the impact of climate change on food security, it is essential to include additional explanatory variables. These variables could encompass financial expenditures by governments for climate change response or green ODA. Lastly, the regional categorization in this study was limited to Asia, Africa, and Latin and the Caribbean, however, future research should reflect the unique regional characteristics of specific areas such as sub-Saharan Africa, Central Asia, and Southeast Asia.

The significant importance of this study lies in investigating the impact of climate change on food security in developing countries and comprehending it in a multi-layered manner. The study differentiated food security into two dimensions: food availability and access, and thoroughly estimated how climate change variables influence these aspects.

In particular, the study revealed that climate change has direct effects on food production, which subsequently affect undernutrition. It analyzed the changes in temperature and precipitation that directly impact crop production, as well as the effects of climate-related disasters on undernutrition.

These research findings provide valuable insights for better understanding the relationship between food security and climate change in developing countries and contribute to the formulation of policies and measures to strengthen food security. The study presents climate-resilient development approaches to address climate challenges and emphasizes the need for tailored strategies for vulnerable regions and income groups. It also offers guidance and direction for future research by incorporating diverse aspects of food security and explanatory variables.

Therefore, this study is meaningful research that provides essential information and insights for comprehending the complex interaction between food security and climate change and developing policies and strategies to enhance food security in response to climate change challenges.

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APPENDICES

Appendix 1. Food Security Indicators by FAO.

Pillars	Title	Unit
Availability	Average dietary energy supply adequacy	%
	Average value of food production	I$ per caput
	Share of dietary energy supply derived from cereals, roots, and tubers	%
	Average protein supply	gr/caput/day
	Average supply of protein of animal origin	gr/caput/day
Access	Rail lines density	Total route in km per 100 square km of land area
	Gross domestic product per capita (in purchasing power equivalent)	constant 2017 international $
	Prevalence of undernourishment, 3-year averages	%
	Prevalence of undernourishment, yearly estimates	%
	Prevalence of severe food insecurity in the total population, 3-year averages	%
	Prevalence of severe food insecurity in the total population, yearly estimates	%
	Prevalence of moderate or severe food insecurity in the total population, 3-year averages	%
	Prevalence of moderate or severe food insecurity in the total population, yearly estimates	%
Stability	Cereals imports dependency ratio	%
	Percent of arable land equipped for irrigation	%
	Value of food imports over total merchandise exports	%
	Political stability and absence of violence/terrorism	Index
	Per capita food production variability	$ per capita
	Per capita food supply variability	kcal/caput/day
Utilization	People using at least basic drinking water services	%
	People using safely managed drinking water services	%
	People using at least basic sanitation services	%
	People using safely managed sanitation services	%
	Percentage of children under 5 years of age affected by wasting	%
	Percentage of children under 5 years of age who are stunted	%
	Percentage of children under 5 years of age who are overweight	%
	Prevalence of obesity in the adult population (18 years and older)	%
	Prevalence of anemia among women of reproductive age (15–49 years)	%
	Prevalence of exclusive breastfeeding among infants 0–5 months of age	%
	Prevalence of low birthweight	%

Source: FAO (2022).

Appendix 2. DAC List of ODA Recipients: Effective for reporting in 2022 and 2023 flows.

Least Developed Countries	**Low Income Countries** (per capita GNI<=$1,045 in 2020)	**Lower Middle-Income Countries and Territories** (per capita GNI $1,046~$4,095 in 2020)	**Upper Middle-Income Countries and Territories** (per capita GNI $4,096~$12,695 in 2020)
Afghanistan (L)	Democratic People's Republic of Korea	Algeria	Albania
Angola (LM)	Syrian Arab Republic	Belize	Argentina
Bangladesh (LM)		Bolivia	Armenia
Benin (LM)		Cabo Verde	Azerbaijan
Bhutan (LM)		Cameroon	Belarus
Burkina Faso (L)		Congo	Bosnia and Herzegovina
Burundi (L)		Côte d'Ivoire	Botswana
Cambodia (LM)		Egypt	Brazil
Central African Republic (L)		El Salvador	China (People's Republic of)
Chad (L)		Eswatini	Colombia
Comoros (LM)		Ghana	Costa Rica
Democratic Republic of the Congo (L)		Honduras	Cuba
Djibouti (LM)		India	Dominica
Eritrea (L)		Indonesia	Dominican Republic
Ethiopia (L)		Iran	Ecuador
Gambia (L)		Kenya	Equatorial Guinea
Guinea (L)		Kyrgyzstan	Fiji
Guinea-Bissau (L)		Micronesia	Gabon
Haiti (LM)		Mongolia	Georgia
Kiribati (LM)		Morocco	Grenada
Lao People's Democratic Republic (LM)		Nicaragua	Guatemala
Lesotho (LM)		Nigeria	Guyana
Liberia (L)		Pakistan	Iraq
Madagascar (L)		Papua New Guinea	Jamaica
Malawi (L)		Philippines	Jordan
Mali (L)		Samoa	Kazakhstan
Mauritania (LM)		Sri Lanka	Kosovo
Mozambique (L)		Tajikistan	Lebanon
Myanmar (LM)		Tokelau	Libya
Nepal (LM)		Tunisia	Malaysia
Niger (L)		Ukraine	Maldives
Rwanda (L)		Uzbekistan	Marshall Islands
Sao Tome and Principe (LM)		Vanuatu	Mauritius
Senegal (LM)		Viet Nam	Mexico
Sierra Leone (L)		West Bank and Gaza Strip	Moldova
Solomon Islands (LM)		Zimbabwe	Montenegro
Somalia (L)			Montserrat
South Sudan (L)			Namibia
Sudan (L)			Nauru (H)
Tanzania (LM)			Niue
Timor-Leste (LM)			North Macedonia
Togo (L)			Palau
Tuvalu (UM)			Panama
Uganda (L)			Paraguay
Yemen (L)			Peru
Zambia (LM)			Saint Helena
			Saint Lucia
			Saint Vincent and the Grenadines
			Serbia
			South Africa
			Suriname
			Thailand
			Tonga
			Türkiye
			Turkmenistan
			Venezuela
			Wallis and Futuna

Note: L, LM, UM, and H shown after country names refer to the latest World Bank Income classifications of: LDCs and any high-income countries that have not yet met the criteria for graduation. For the World Bank's current 2021 fiscal year, low-income (L) economies are defined as those with a GNI per capita, calculated using the World Bank Atlas method of USD 1,045 or less in 2020; lower middle-income (LM) economies are those with a GNI per capita between USD 1,046 and USD 4,095; upper middle-income (UM) economies are those with a GNI per capita between USD 4,096 and USD 12,695; high-income (H) economies are those with a GNI per capita USD 12,696 or more. The countries and territories within the classification of "Low Income Countries," 'Lower Middle-Income Countries and Territories," and "Upper Middle-Income Countries and Territories" exclude those that are not LDCs.
Source: OECD DAC (2022).

Appendix 3. DAC List of ODA Recipients in thesis (n=90).

Least Developed Countries (n=27)		**Lower Middle-Income Countries and Territories (per capita GNI $1,046~$4,095 in 2020) (n=27)**		**Upper Middle-Income Countries and Territories (per capita GNI $4,096~$12,695 in 2020) (n=36)**	
AFG	SDN	BLZ	PAK	ARG	IRQ
AGO	SEN	BOL	PHL	ARM	JAM
BEN	SLE	CMR	SLV	AZE	JOR
BFA	STP	COG	SWZ	BIH	KAZ
BGD	TCD	CPV	TUN	BLR	LBN
CAF	TGO	DZA	UKR	BRA	MEX
COD	TLS	EGY	UZB	BWA	MNE
ETH	TZA	GHA	VNM	COL	MUS
GMB		HND		CRI	MYS
KHM		IDN		CUB	NAM
LAO		IND		DMA	PAN
LSO		IRN		DOM	PER
MDG		KEN		ECU	PRY
MLI		KGZ		FJI	SRB
MMR		LKA		GAB	SUR
MRT		MAR		ALB	THA
MWI		MNG		GEO	ZAF
NPL		NGA		GTM	
RWA		NIC		GUY	

Appendix 4. Total countries by regions (n=82).

Africa (36 countries)		**Asia (25 countries)**		**Latin and Caribbean (21 countries)**	
AGO	MLI	AZE	PAK	BLZ	SLV
BEN	MRT	BGD	PHL	BOL	SUR
BFA	MUS	FJI	THA	BRA	
BWA	MWI	IDN	TLS	COL	
CAF	NAM	IND	UZB	CRI	
CMR	NGA	IRN	VNM	CUB	
COD	RWA	IRQ		DMA	
COG	SDN	JOR		DOM	
CPV	SEN	KAZ		ECU	
DZA	SLE	KGZ		GTM	
EGY	STP	KHM		GUY	
ETH	SWZ	LAO		HND	
GAB	TCD	LBN		JAM	
GHA	TGO	LKA		MEX	
GMB	TUN	MMR		NIC	
KEN	TZA	MNG		PAN	
LSO	ZAF	MYS		PER	
MAR		AFG		ARG	
MDG		NPL		PRY	

Appendix 5. Correlation Matrix of Food Production Index (FPI).

	FPI	TEM	PRE	GDPG	ODA	Import	INFL	POPG	RUR	AL
FPI	-									
TEM	**0.346*** (<.001)	-								
PRE	0.012 (0.590)	**0.112***** (<.001)	-							
GDPG	**0.430***** (<.001)	**0.187***** (<.001)	**-0.295***** (<.001)	-						
ODA	**-0.145***** (<.001)	0.014 (0.541)	**0.281***** (<.001)	**0.087***** (<.001)	-	-				
Import	**0.089***** (<.001)	**0.154***** (<.001)	**0.361***** (<.001)	**-0.102***** (<.001)	**0.351***** (<.001)	-				
INFL	**-0.107***** (<.001)	-0.044 (0.051)	**-0.056*** (0.012)	-0.034 0.133)	-0.014 (0.534)	-0.036 (0.110)	-			
POPG	**-0.228***** (<.001)	**-0.138***** (<.001)	**0.307**** (<.001)	**0.085***** (<.001)	**0.235**** (<.001)	**0.096**** (<.001)	-0.001 (0.971)	-		
RUR	**-0.161***** (<.001)	**-0.151***** (<.001)	**0.246**** (<.001)	**0.174***** (<.001)	**0.356***** (<.001)	**0.071**** (0.001)	**-0.058**** (0.009)	**0.169***** (<.001)	-	
AL	-0.012 (0.589)	-0.023 (0.314)	**0.182***** (<.001)	**0.076***** (<.001)	**-0.051*** (0.024)	-0.015 (0.507)	-0.035 (0.114)	**-0.102***** (<.001)	**0.298**** (<.001)	-

*Note: *, **, and *** indicate significance at α=10%, 5%, and 1% levels*

Appendix 6. Correlation Matrix of Prevalence of Undernourishment (PoU).

	PoU	**Disaster**	**FPI**	**GDPG**	**ODA**	**Import**	**INFL**	**POPG**	**RUR**	**AL**
PoU	-									
Disaster	0.048 (0.064)	-								
FPI	**-0.233***** (<.001)	-0.039 (0.129)	-							
GDPG	0.048 (0.063)	0.037 (0.152)	**-0.195***** (<.001)	-						
ODA	**0.450***** (<.001)	**-0.168***** (<.001)	**-0.095***** (<.001)	**0.096***** (<.001)	-					
Import	**0.086***** (<.001)	**-0.323***** (<.001)	**0.115***** (<.001)	**-0.124***** (<.001)	**0.383**** (<.001)	-				
INFL	-0.004 (0.891)	-0.017 (0.510)	**-0.105***** (<.001)	-0.028 (0.272)	0.026 (0.320)	**-0.056*** (0.030)	-			
POPG	**0.389***** (<.001)	-0.000 (0.989)	**-0.118***** (<.001)	**0.096***** (<.001)	**0.287***** (<.001)	**0.132**** (<.001)	0.006 (0.808)	-		
RUR	**0.383***** (<.001)	**0.113***** (<.001)	**-0.126***** (<.001)	**0.191***** (<.001)	**0.349***** (<.001)	**0.089***** (<.001)	0.007 (0.797)	**0.159***** (<.001)	-	
AL	-0.045 (0.079)	**0.254***** (<.001)	-0.018 (0.487)	**0.055*** (0.032)	-0.024 (0.355)	0.005 (0.852)	0.033 (0.196)	**-0.177***** (<.001)	**0.264***** (<.001)	-

*Note: *, **, and *** indicate significance at α=10%, 5%, and 1% levels*

Abstract (Korean)

국 문 초 록

기후변화가 개발도상국의 식량생산과 영양결핍에 미치는 영향 분석

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국제농업개발협력 전공

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본 논문은 1990년부터 2020년까지 개발도상국 90개국의 패널데이터를 활용하여 기후변화가 식량안보에 미치는 영향을 분석하였다. 분석 대상은 전체 국가, 지역(아시아, 아프리카, 중남미) 및 소득그룹(최빈국, 중저소득국, 고중소득국)으로 분류하고 식량안보 변수의 동태적 특성과 내생성(endogeneity)을 통제하기 위해 system-GMM 모형을 이용하였다. 이때 종속변수인 식량안보는 가용성(availability) 차원인 식량생산지수(Food Production Index, FPI)와 접근성(access) 차원인 영양결핍 유병률(Prevalence of Undernourishment, PoU)로 구분하였으며, 주요 기후요인(온도 및 강수량)이 식량생산에 미치는 영향과 기후 관련 재난 발생 빈도가 영양결핍에 미치는 영향을 분석하였다.

분석 결과, 종속변수의 전기(t-1)값은 모든 결과에서 현재 결과에 유의한 영향을 미쳤다. 식량 가용성인 식량생산지수에서 연평균 표면온도 변화는 식량생산에 큰 영향을 미치며, 높은 온도변화는 음(-)의 영향을 미치는 것으로 나타났다. 그러나 아시아 지역에서는 오히려 온도 변화가 식량생산에 정(+)의 영향을 주었다. 식량 접근성인 영양결핍 유병률에서 기후 관련 재난 빈도, GDP 성장률, 인구 증가율이 음(-)의 영향을 미치는 반면 식품 수입과 인플레이션은 정(+)의 관계를 가지는 것으로 분석되었다.

ODA는 지역 및 소득 그룹에 따라 다양한 영향을 미치는 것으로 나타났다.

따라서 본 논문은 개발도상국의 기후변화가 식량 생산과 영양결핍에 미치는 직접적이고 연쇄적인 영향을 분석하였으며, 이러한 연구 결과를 토대로 개발도상국의 식량안보 강화를 위한 정책과 전략 개발에 기여하는 기초 자료로 활용할 수 있다. 특히 기후위기 대응과 지속가능한 식량생산을 위한 지역 및 소득 그룹별 사전 대응의 필요성을 강조하며, 이를 위해 국가 발전 수준과 기후 취약 정도에 따라 체계적인 전략 수립이 필요하다.

주요어: 식량안보, 식량생산, 영양결핍, 기후변화, 개발도상국, 동적패널모형, 시스템GMM

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