Food Insecurity dynamics in Ethiopia: A System dynamics approach

By

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This is to certify that the thesis prepared by Yabtsega Desalegn, entitled**:** Food insecurity dynamics in Ethiopia: A System dynamics approach and submitted in partial fulfillment of the requirements for the degree of Degree of Master of Applied Econometric Modeling Economics complies with the regulations of the University and meets the accepted standards with respect to originality and quality.

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I declare that "Food insecurity dynamics in Ethiopia: A System dynamics approach, Addis Ababa, Ethiopia 'is my own work and that all the sources that I have used or quoted have been indicated and acknowledged by means of reference and that the work has not been submitted before any other degree at any other institution.

Yabtsega Desalegn

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Acronyms

ENDF - Ethiopian National Defense Forces

GDP- Gross domestic product

GDP- Gross domestic product per capita, PPP (Purchasing power parity)

IPC- Integrated food security phase classification

SNNP- South nation nationality and peoples

USD/MT- US Dollar to My Token Converter

Pou- prevalence of undernourishment

GHG- Greenhouse gas

Abstract

Food security is a dynamic concept that has continuously integrated new dimensions and levels of analysis over the years; this reflects the wider recognition of its complexities in research and public policy issues. Food security is achieved when all people, at all times, have physical and economic access to sufficient, safe, and nutritious food that meets their dietary needs and food preferences for an active and healthy life. Food insecurity occurs at the individual, household, or nation level for those who have neither physical nor economic access to the nourishment they need. Food insecurity is an enduring and critical challenge in Ethiopia, which is Africa's second-most populous country after Nigeria. This study has assessed the trends and status of the complex issue of food insecurity at a national level, listed out the major influencing factors that form the causal relationship using the green economy framework, and identified policy-related issues using system dynamics that have assisted in addressing and investigating this problem as it has unfolded in the various causal relationships that will be used for further analysis in the definition of future policy options and testing of these policy options. The policy test was conducted on three aspects of the green economy: social, economic, and environmental. This study finds that food insecurity and malnutrition are more sensitive to the issue of increasing human capital through the social aspect, namely access to basic health care and the educational sector, which has a reinforcing effect, and also suggests the environmental aspect of decreasing the food waste emission rate to lower GHG emissions, which has a long-term effect on yield. Overall, this study suggests that food policies go beyond casualties and require long-term policy development in order to deal with Ethiopia's highest prevalence of Food insecurity.

1. CHAPTER ONE

1.1. Introduction

It is inexcusable that hundreds of millions of people are malnourished in a world with abundant wealth and resources where enough food is produced to feed everyone. This phenomenon gave rise to the idea and question of the uneven distribution globally, where the richest tenth owns 85 percent of the world's assets, just fewer than one billion people survive on less than one dollar per day, 2.8 billion on less than two dollars per day, and 850 million live in dehumanizing, abject poverty. This phenomenon, which in the 1980s was loosely referred to as hunger, is now a major global concern known as food insecurity (Campbell, 1991).

Food security is defined as the constant availability of sufficient, safe, and nutritious food for all people to meet their dietary needs and food preferences for an active and healthy life. The analysis focuses on three of the four pillars of food security (FAO, 2003, 2006): food availability, access, and stability. In contrast, "food insecurity exists whenever access to safe, nutrient-rich foods or the ability to obtain such foods in socially acceptable ways is limited or uncertain" (Anderson, 1990).

Food insecurity can be seen as both an effect and a cause. For instance, due to a lack of income and access, food insecurity prevails, and as a result, violence and instability occur in a country. Because of this behavior, food insecurity has different causal relationships with different aspects of the economy, which are mostly linked with poverty, a growing population, and drought, which later affect the macro- economic phenomena of one country. These causes of food insecurity impact the population through malnutrition, vulnerability, and stunted children. The result of this hunger and malnutrition, cause individuals to be less productive, more susceptible to disease, and unable to raise their earnings and standard of living, which will continue to impede sustainable development and trap people in a vicious cycle from which they cannot easily escape. (Ahmad & Shahnawaz, 2021)

Hunger kills more people annually than AIDS, malaria, and tuberculosis combined, and hunger kills more people than wars (Shaw, 2007). Food insecurity, the inability to obtain safe and nourishing food for a healthy, active life, is the core of this human tragedy. Global leaders and international organizations have pledged to solve hunger and poverty, but an unacceptable number of individuals still lack the food they require to live an active and healthy life. Between 2014 and 2016, 795 million individuals, or slightly more than one in nine, were undernourished globally. The prevalence of undernourishment has dropped from 18.6% in 1990-92 to 10.9 percent in 2014-16, representing fewer undernourished individuals in a growing worldwide population. Despite a decrease in food insecurity on a global scale, regional progress towards enhanced food security remained uneven from 2014 to 2016. Sub-Saharan Africa, specifically the Horn of Africa, has made minimal to no progress in eliminating hunger (FAO, 2015).

Following a period of relative stability since 2015, the prevalence of undernourishment increased from 8.0 to 9.3% during 2019 and 2020, before slowing to 9.9% in 2021. In 2021, between 702 and 828 million people went hungry. Since the start of the COVID-19 pandemic, the global population has grown by around 150 million people, 103 million between 2019 and 2020, and 46 million in 2021. According to projections, more than 670 million people would be hungry in 2030, the same number as in 2015, when the 2030 Agenda for Sustainable Development was launched. Despite a significant increase in 2020, the global prevalence of moderate or severe food insecurity remained nearly steady in 2021, while the prevalence of severe food insecurity grew, indicating a worsening of the situation for those who are already facing great challenges. Around 2.3 billion people would be moderately or severely food insecure in 2021, with 11.7% of the global population seriously food insecure (FAO, 2022).

A "greener," more sustainable, socially accountable, and more equitable economic system is needed as the world's population and prevalence of food insecurity rise and its natural resources become increasingly depleted. While different groups may have slightly different definitions of the term, most people would agree that the "green economy" is one that prioritizes growth while also fostering sustainable development through resource efficiency. Consistent with ideas of sustainability and food security, the goal of a green economy is to promote growth while decreasing our impact on the environment and boosting social well-being. (Fan et al., 2011) Food insecurity has been under constant threat throughout history. The poor management and growing scarcity of natural resources like water, arable land, and energy make it difficult to produce and access adequate, nutritious food for the world's 828 million undernourished people and the more than 2 billion people suffering from micronutrient deficiency in 2023. South Asia and Sub-Saharan Africa are particularly afflicted by food insecurity because of their lack of access to adequate sanitation and clean water, as well as their low food consumption (Fan et al., 2011).

This Food insecurity and a prolonged drought have created an unprecedented need for food aid in many countries across sub-Saharan Africa, including Ethiopia. There have been multiple famines in the country over the past few decades, with the worst occurring in 1983–1985. Eight million Ethiopians were impacted, and one million died as a direct result. Some 58 million people suffered because of the famine that occurred between 1973 and 1986 (Berhanu,et al., 2001). Estimates suggest that in 2023, despite the continuation and availability of food assistance since then, 20.4% of the population will still require assistance (FEWSNET, 2023).

Thus, food insecurity is a rapidly developing, multifaceted problem with varying impacts and points of view across a wide range of socioeconomic and ecological contexts. However, development practitioners and policymakers struggle to quantify the challenge and proactively plan to reduce the food gap that exists in accordance with the green economy framework and sustainability development. Therefore, this paper will try to look up the determinants of food insecurity by relating major causal effects using social, economic, and environmental factors using an aggregate and integrated system dynamics approach to show the inter-related causality within and its different impact on the development of Ethiopia.

1.2. Statement of the problem

The COVID-19 pandemic has significantly impacted food security, with the number of people unable to afford a healthy diet increasing by 112 million in 2018 to nearly 3.1 billion in 2021. The ongoing conflict in Ukraine disrupts supply chains, increasing food prices and increasing the cost of food, fertilizer, and energy. Extreme climate events also disrupt supply networks, particularly in low-income nations like the Horn of Africa (FAO, 2022).

The World Health Organization (WHO) classified the Horn of Africa's drought as a level three health emergency in June 2022, marking the first time since 2011 that a drought and food insecurity crisis reached the emergency level. The Hunger Hotspots report warns that acute food insecurity is likely to worsen in 19 countries, including Ethiopia and Somalia in the Horn of Africa.

Despite achieving its highest harvest record in 1992, Ethiopia's food gap reduction was only marginal, declining from 5 million metric tons in 1993/94 to 2.6 million metric tons in 1995/96. This reduction was not sufficient to eradicate chronic food insecurity, as indicated by the provision of 240,000 metric tons of food aid that year. This suggests that a significant proportion of the Ethiopian population endures persistent food insecurity in the absence of a temporary output shock (Befekadu & Berhanu, 2000). In recent years, Ethiopia has experienced an exacerbation of food insecurity, as an outcome of diverse external shocks and the influence of climate change. Commencing in the years 2019 and 2020, the ramifications of persistent drought conditions and persistent instability have led to an unparalleled necessity for provisions of food aid. In light of such circumstances, it is estimated that approximately 20.4 million individuals remain reliant upon such forms of assistance (FEWSNET, 2023).

The presence of attaining this severe poverty and food insecurity in Ethiopia, while possessing the essential resources and capability to surmount these degrading influences, represents a critical paradox of society. The aforementioned circumstance not only transgresses moral and ethical principles, but also carries political, economic, and social repercussions that lack justification and pose a potential hazard to global harmony. As we advance into the initial decade of the twenty-first century, the attainment of food security for all individuals will assume augmented significance for sustainable development and forthcoming generations (Delisle &Shaw, 1998; Fan et al., 2011).

The concept behind to attain sustainable development is plagued by a multitude of social, economic, and environmental obstacles on a global scale. These obstacles encompass unpredictable and adverse climatic patterns, the necessity to appropriately cater to an expanding populace, the persistence of impoverishment, and gradual degradation of the natural environment. The aforementioned challenges have prompted a necessity to reassess the prevailing approach towards development, culminating in the inception of the notion of a "green economy." The implementation of this notion leads to an enhancement of human welfare and the promotion of social parity, simultaneously mitigating substantial hazards to the ecological system. This approach is underpinned by principles that incorporate social, economic, and environmental facets. Ethiopia has embraced the principle of green economic development and ratified its National Adaptation Plan (NAP-ETH) in 2019, with a specific focus on implementing the Climate Resilient Green Economy (CRGE) strategy in the agriculture sector.

Food insecurity in Ethiopia is a pervasive issue that exerts significant pressure on the agricultural sector and is caused by a complex web of interrelated factors (ATA, 2010).Although previous research (Welderufael, 2014; Kidane et al., 2005; Endalew et al., 2015; Devereux & Sussex, 2000; Ayenew & Kopainsky, 2014; Ramakrishna & Demeke, 2002) (Ayenew, 2013; Sjaifuddin et al., 2009) has pointed out the reasons of food insecurity includes insufficient agricultural productivity due to irregular rainfall, land degradation, an imperfect market, rapid population expansion, and so on; little research has been done to integrate this and other linked causes of food insecurity. Additionally, the previous integrated papers also didn't give insight using a green framework by incorporating climate change.

In the discourse pertaining to sustainable development and the attainment of food security within the framework of a green economy, our methodology shall involve the application of a system dynamics approach. This is necessitated by the inadequacy of conventional fragmented and mechanistic scientific paradigms in the effective resolution of sustainability challenges, which often arise in the context of intricate, autonomous systems. In contemporary discourse, it has been contended that the comprehension of present-day predicaments necessitates a shift away from linear and mechanistic modes of thought and towards non-linear and organic thinking, otherwise referred to as systems thinking. The adoption of System Dynamics, a holistic approach that operates at the level of the entire system, is posited as an efficacious strategy for mitigating issues related to sustainability (Bagheri's, 2006).

With due consideration of the aforementioned, the current discourse aims to elucidate and scrutinize the causal nexus between divergent variables via the system dynamics approach deployed across three fundamental dimensions - social, economic, and environmental - in relation to food insecurity. This article places significant emphasis on the environmental factor and addresses it as the central premise. It aims to complete the missing piece of the puzzle concerning food insecurity and production policies in Ethiopia. To achieve this objective, a research methodology of system dynamics is employed to develop an integrated approach for model-based policy analysis and design. This comprehensive framework examines the intricate processes that determine food insecurity, while also assessing the effectiveness of various policies aimed at mitigating this issue.

This paper utilizes a system dynamics methodological approach in which to examine the attainment of food security within the framework of a green economy, in light of sustainable development. Conventional fragmented and mechanistic scientific methodologies are deemed inadequate in addressing sustainability concerns, which often pertain to intricate and autonomous systems. In the effort to apprehend the root causes and remedies of present-day dilemmas, it is posited that conventional linear and mechanistic reasoning must yield to a non-linear and organic conceptualization, commonly referred to as systems thinking. (Hjorth, 2006) The utilization of System Dynamics, a comprehensive approach that operates at the systemic level, is suggested as a compelling tactic for tackling sustainable development challenges. (Bagheri, 2006)

With this perspective as a guiding principle, the present study shall elucidate and scrutinize the causal connection linking multiple variables by employing a system dynamics-oriented approach in three dimensions: the social, economic, and environmental facets pertinent to the issue of food insecurity. The central premise of the present article is to underscore the environmental issue as a key factor in the context of food insecurity and production policies in Ethiopia. An appropriate research methodology based on system dynamics is employed to address a missing piece in the discourse on this topic. This paper presents an integrated approach for model-based policy analysis and design, aimed at scrutinizing the processes governing food insecurity and the effectiveness of various policies implemented to combat this issue.

1.3. Objectives

- General Objective

The general objective of this study is to develop and test a system dynamics model for evaluating the interaction between the various causes of food insecurity using green economy framework.

- Specific Objective

In addition to the main goal, the study will also intend;

1. To review trends and status of food insecurity in Ethiopia
2. To explore the factors that majorly influences the food insecurity dynamics.
3. To show their causal relationship in accordance with green economy framework.
4. To identify policy related issues that can alleviate the food insecurity dynamics in Ethiopia

1.4. Research question

1. How do systemic and dynamic interactions between economic, social, and Environmental factors affect food insecurity dynamics in Ethiopia?
2. What are potential factors that make the sector unsustainable?
3. What is the highest leverage point that majorly affects the food insecurity dynamics in Ethiopia?
4. Can the food insecurity dynamics can be sustained with the current system of production?

1.5. The significance of this study

Food insecurity research in developing nations like Ethiopia focuses on current status, lacking ex-ante information for policymakers. To improve food security and reduce susceptibility to insecurity, understanding national vulnerability and taking a holistic approach is crucial (Sileshi et al.). With this in mind, this study will contribute to demonstrating a holistic approach from the standpoint of social, economic, and environmental issues, as well as ongoing efforts to address climate change in the country's development policy framework, such as the Climate Resilient Green Economy (CRGE) strategy and the Second Growth and Transformation Plan (GTP II), by prioritizing the first adaptation method as increasing food security through sustainable agriculture. This study also provides a new way of analyzing the effect of environmental issues on food insecurity, demonstrating that food insecurity is more than just a food policy issue and that societal and environmental factors indirectly impact the sustainability of food security in Ethiopia. By analyzing this, the study also supports farmers, agricultural practitioners, and other stakeholders regarding the environmental effects and prospects of the sector. Furthermore, it informs mitigation and options for better management practices to create a production system that promotes output and socioeconomic growth while minimizing environmental effects.

1.6. Organization of the Study

The paper is divided into five chapters. The first chapter provides an introduction, problem statement, objective, research question, significance, and scope of the study. The second chapter discusses several conceptions and definitions of food insecurity as well as empirical study reviews. The dynamic problem, hypothesis, and thorough description of the model subdivided into three sectors are described in the third chapter. The fourth chapter provides model validation tests and a comparison of simulation findings to historical data, as well as an explanation of future policy alternatives and policy testing under various scenarios. The study's conclusion and limitations are addressed in the last chapter (Chapter 5).

2. Chapter Two

2.1. Definition of food insecurity

Food is not a 'normal' commodity because it is irreplaceable. If we are unable to obtain sufficient food, all human being will suffer and ultimately perish, regardless of our other possessions. Moreover, because our bodies lack the capacity to store large amounts of energy and other essential nutrients, we must consume adequate food almost continuously in order to have a healthy life style.

Dietary inadequacy can have a permanent impact on the development of children, whose growth may be permanently stunted by prolonged malnutrition. For large numbers of poor individuals, however, food security cannot be assumed. Even if the likelihood is low and the duration of food insufficiency is expected to be brief, the prospect of genuine food insufficiency is terrifying for anyone. For these reasons, it makes sense to speak of "food insecurity" but not "clothing insecurity" or "entertainment insecurity." We can survive for an extended period of time without these things, but not food. Consequently, food is distinct, as is the meaning of food insecurity (Warr, 2014).

When a person lacks regular access to sufficient safe and nutritious food for normal growth and development and a healthy, active life, they are considered food insecure. This could be due to a lack of nourishment or inability to procure food. Food insecurity has progressively included additional aspects and degrees of analysis over the years. This continual evolution of the food security idea reflects a larger acknowledgment of the term's intricacies in research and public policy, since the food insecurity issue dates back to the first half of the 1970s, when the worldwide food crisis occurred (Muhammad, 2017).

Food insecurity can be experienced at different levels of severity. According to FAO, in 2022 food insecurity will be measured using the Food Insecurity Experience Scale (FIES), as shown; **Food security to mild food insecurity**: In this category, the ability to obtain food is uncertain.

Moderate food insecurity: occurs when a person or group has insufficient money or resources or is uncertain about their ability to obtain food, and they may occasionally skip meals or run out of food.

Severe food insecurity: In this final stage, it is certain that the individual has run out of food, has sometimes gone an entire day without eating, or has had no food for at least a day.

According to the FAO, severe food insecurity is at one extreme, but even moderate food insecurity is grounds for alarm. Food access is questionable for persons with moderate food poverty. They may have to forego other fundamental requirements in order to feed. When they do eat, they may eat whatever is easiest or least expensive, which may not be the healthiest option. This tendency helps to explain why obesity and other kinds of malnutrition are on the rise. Energy-dense, high-saturated-fat, high-sugar, and high-salt processed meals are frequently less expensive and more readily available than fresh fruits and vegetables. You may be able to satisfy your daily caloric demands by eating these items, but you are missing out on critical nutrients that keep your body healthy and functioning properly. Furthermore, the stress of living in an unpredictable food environment and going without food for extended periods of time can cause physiological changes that contribute to overweight and obesity. Children who are hungry, food insecure, or malnourished today may be at a higher risk of being overweight, obese, or developing chronic diseases such as diabetes in the future. Obesity and malnutrition coexist in many countries, and both can be caused by food insecurity (FAO, 2022).

FAO's first aim is to ensure that no one goes hungry. However, even though many people are not "hungry" in the sense of suffering physical discomfort as a result of a significant lack of nutritional energy, they may still be food insecure. They may have enough food to meet their energy requirements, but they may not know how long it will last, or they may be compelled to limit the quality and/or quantity of food they consume in order to survive. This modest level of food insecurity can lead to a variety of malnutrition and have serious consequences for health and well-being.

The current food system structure and its difficulty in fighting food insecurity are at the heart of a network of global challenges spanning from poverty to environmental degradation. Extrapolating present production and consumption trends will not result in the increase in food production required to fulfill future demands ranging from moderate to severe food insecurity. Continued expansion and intensification tendencies will erode the resource foundation on which the food system and conflicting food insecurity rely (Fan et al., 2011).

2.2. Food insecurity around the world

Global food and agricultural production has expanded dramatically since World War II, owing to a mix of population and economic development, technological and cultural shifts in production practices. Global food demand has increased due to increases in population, affluence, and urbanization, while dietary tastes have evolved towards more resource-intensive foods (FAO, 2017).

Since 1974, when the FAO first began reporting on the extent of global hunger, both the impact of this global food trend and the level and quantity of individuals who are food insecure have changed considerably. The world's population is steadily expanding, as is urbanization. Constant technical improvement is accompanied by an increasing globalization of the economy. Despite the continuation of malnutrition, there are disturbing global trends in malnutrition, including a significant increase in overweight and obesity. Food production, distribution, and consumption have all altered substantially on a worldwide scale. This fundamentally transformed environment demands new perspectives on hunger and food insecurity (FAO, 2022).

Despite optimism that the globe would emerge from the crisis and food security would begin to improve in 2021, world hunger climbed even more in 2021, following a significant surge in 2020 during the COVID-19 epidemic. Inequalities worsened as a result of differences in pandemic impact and recovery, as well as inadequate coverage and duration of social protection measures, which contributed to significant setbacks in meeting the Zero Hunger objective by 2030 in 2021 (FEWSNET, 2021).

After being relatively stable since 2015, the prevalence of undernourishment (the SDG indicator of food insecurity) climbed from 8% in 2019 to 9.3% in 2020 and continued to rise, albeit at a reduced rate, to 9.3% in 2021. It is anticipated that between 702 and 828 million people (representing 8.9 and 10.5% of the global population, respectively) will go hungry in 2021. In 2021, 46 million more people were affected by hunger than in 2020, and 150 million more than in 2019, before the COVID-19 pandemic (FAO, 2022).

The results show that regional discrepancies remain, with Africa bearing the largest burden. In 2021, 20.2% of Africans would be in severe food insecurity, compared to 9.1% in Asia, 8.6% in Latin America and the Caribbean, 5.9% in Oceania, and fewer than 2.5% in North America and Europe (FAO, 2022).

According to current anticipates of the number of undernourished people, about 670 million people will still be undernourished in 2030, 78 million more than if the pandemic had never occurred. A fresh catastrophe is now expected to disrupt the global trajectory of food security. The conflict in Ukraine will have many implications on global agricultural markets through trade, production, and price channels, casting a shadow over the food security and nutrition of many nations in the near future (FAO, 2022).

According to agree-upon sustainable development goals; (UN, 2015)

SDG Goal 2.1 calls on the world to go beyond eradicating hunger by ensuring that everyone has access to enough food that is safe, nourishing, and available all year long.

The SDG Indicator 2.1.2—the prevalence of moderate or severe food insecurity in the population, as measured by the Food Insecurity Experience Scale—is used to track progress toward the ambitious goal of ensuring that everyone has access to sufficient food.

Globally, moderate to severe food insecurity has increased since FAO began collecting data in 2014 using the Food Insecurity Experience Scale. The rate of increase was similar to that of the previous five years combined in 2020, the year the COVID-19 virus swept the world. According to new estimates for 2021, the incidence of moderate or severe food insecurity has stayed basically stable from 2020, but the prevalence of extreme food insecurity has grown. This is evidence that the situation is deteriorating, especially for those who are already facing incredibly difficult circumstances. In 2021, 29.3 percent (2.3 billion) of the world's population is expected to be food insecure, with 11.7 percent (923.7 million) experiencing extreme food insecurity. (FEWSNET, 2021)

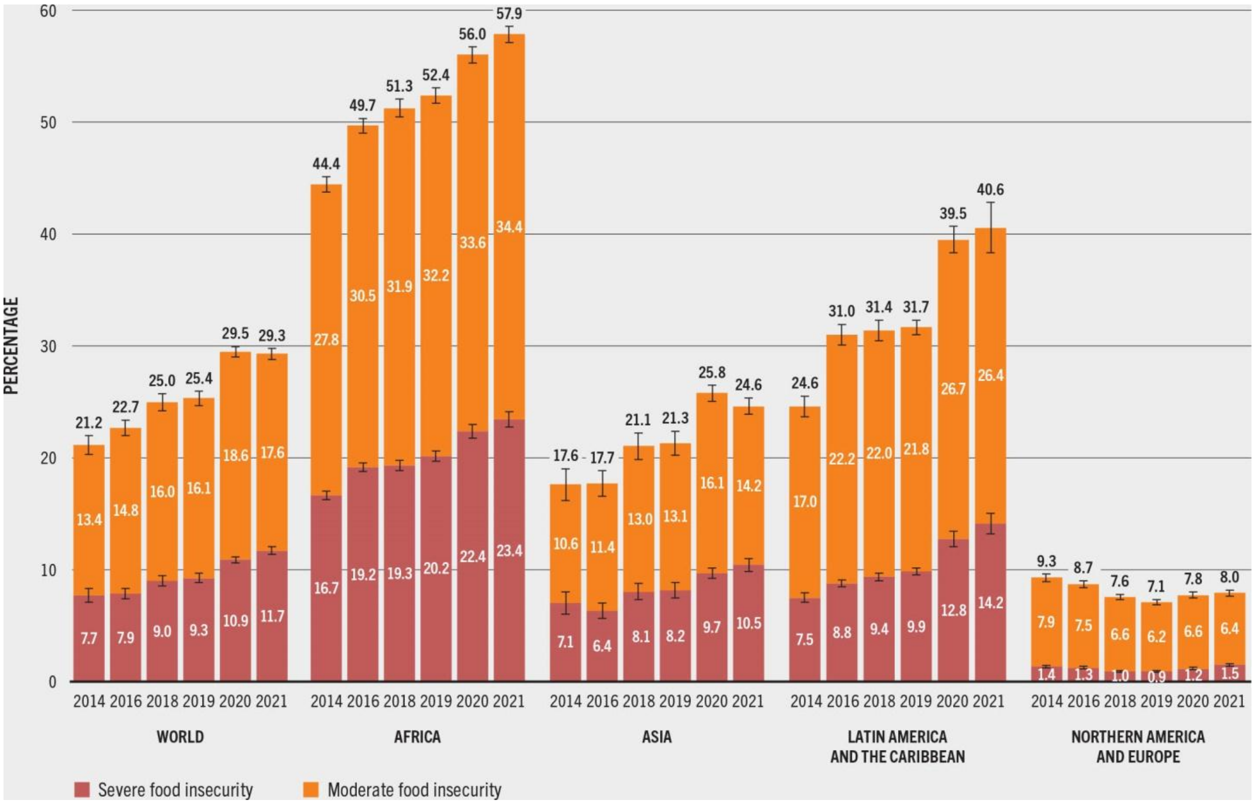


Figure 1FAO, 2022 data analysis on global food insecurity around the word

Globally, acute food insecurity is on the rise. According to the newly released Global Report on Food Crisis 2022 Mid-Year Update, up to 205 million people in 45 countries are expected to face severe food insecurity and require immediate assistance (IPC/CH Phase 3 or above or equivalent). If further information from the most recent 2021 study is integrated for 8 countries and territories, this estimate might climb to 222 million in the 53 GRFC (Global Report on Food Crisis nations)-covered countries and territories in 2022.

This is the highest figure reported in the seven-year history of the report. It is estimated that 45 million people in 37 countries will be severely malnourished, on the verge of death, or have already succumbed to famine and death (IPC/CH Phase 4 and above). This includes the 970,000 people who, if nothing is done, may suffer catastrophic conditions (IPC/CH Phase 5) by 2022.

According to the 2022 GRFC report, the populations of Afghanistan, Ethiopia, Nigeria, South Sudan, Somalia, and Yemen are still on high alert because they are either on the verge of starvation (catastrophe, IPC Phase 5), are already experiencing critical food insecurity (emergency, IPC Phase 4), or are at risk of deteriorating into catastrophic conditions due to severe aggravating factors. These countries must be handled with extreme caution.

2.3. Food insecurity in Ethiopia

Ethiopia is Africa's second-most populated country, with one of the region's fastest-growing economies. It has a population of about 115 million people (World Bank, 2021). From 2008/2009 to 2018/2019, Ethiopia's economy grew significantly and broadly, averaging 9.8% per year, while the fraction of people living in poverty declined from 38% to 24% (World Bank, 2020). Since 1990, the country's per capita income has more than doubled, life expectancy has improved by around ten years, and infant mortality has reduced by about half (International Monetary Fund [IMF], 2020). Ethiopia is undergoing domestic economic change. The government has devised a 10-point development strategy to achieve economic progress and prosperity while also ensuring food and nutrition security for its inhabitants.

Despite efforts, Ethiopia has been plagued by chronic food insecurity since at least 1980. Despite a record harvest, the food deficit expanded from 0.75 million tonnes in 1979-1980 to 5 million tonnes in 1993-1994 before dropping to 2.6 million tonnes in 1995-1996. Even that year, 240,000 tonnes of food aid were distributed, suggesting that millions of Ethiopians face persistent food insecurity in the absence of sudden output disruptions (Befekadu & Berhanu, 2000).

In Ethiopia, the issue of food insecurity has been chiefly centered on the growth of agricultural productivity. This has been given heightened importance through the implementation of the Agricultural Development Led Industrialization (ADLI) program, which was introduced in the early 1990s. From 2000 to 2010, the agricultural sector received a significant proportion of public expenditure, exceeding 10% of the total spending of the country (Fan, Babatunde, & Lambert, 2009; World Bank, 2010). In Ethiopia, there has been significant investment directed towards rural infrastructure and agricultural intensification, particularly with an emphasis on the expansion of extension services and the implementation of fertilization practices (IFPRI, 2013). As per the report by USAID in 2019, the agricultural industry has been of paramount importance to Ethiopia's economy, encompassing 40% of the gross domestic product, contributing 80% to the total exports, and providing employment to 75% of the workforce. Over the period of 1993 to 2018, Ethiopian agricultural output has exhibited an upward trend. However, it is important to note that despite this trend, the current food system is insufficient in terms of providing appropriate sustenance for the burgeoning and increasingly urbanized population, while also failing to produce the much-needed economic transformation. While agriculture remains a crucial component of the country's economy, subsistence farming carried out by smallholder farmers is heavily dependent on unstable rain-fed systems. The overwhelming majority of arable land, amounting to 96%, is held by smallholders. Ethiopia's agriculture is largely dependent on the amount of rainfall it receives, making it vulnerable to multiple uncertainties. Only a minute proportion of households, less than 3%, possess irrigation facilities, and the cereal acreages equipped with the same is less than 1% (Mann & Warner, 2015; Taffessee et al., 2011).

Ethiopia also loses approximately 16.5% of its GDP each year as a result of acute malnutrition and stunting. The yearly cost of child malnutrition is expected to be 55.5 billion birr (Ministry of Health, EPHI, and WFP, 2021). Despite recent progress in addressing chronic food insecurity and malnutrition in Ethiopia, food and nutrition security is gravely threatened by the combined effects of conflict, COVID-19, locust invasion, meteorological extremes, and climatic extremes (FAO & WFP, 2021). In 2021, Ethiopia experienced the biggest annual increase in the number of individuals facing a food crisis or worse (FEWS NET, 2021).

According to the Ethiopia Humanitarian Response Plan for 2021, humanitarian partners supplied food aid to 12.8 million individuals, with an additional 8 million getting other sorts of assistance. Other than food, 2 million individuals received aid. There were 2.26 million internally displaced people, 1.38 million returnees, and 11.19 million who were not displaced. Fighting in neighboring Amhara and Afar regions, on the other hand, impeded assistance delivery, with five times as many armed conflicts resulting in an increase in fatalities from June to September 2021 (FEWS NET, 2023).

Furthermore, Ethiopia's macroeconomic conditions have been difficult due of the COVID-19 epidemic, which has reduced GDP growth in 2019-2020 and 2020-21. Containment efforts have put an impact on livelihoods and earning potential. Rising prices for starchy and nutrient-rich foods, as well as decreased purchasing power, continue to limit access to food. Between June and September 2021, the national inflation rate rose from 24.5% to 34.8%, owing mostly to food price inflation (CSA, 2021).

In addition to food security, the nutritional content of people's food intake must be evaluated. Three out of every four households could not afford a diet rich in energy, protein, and micronutrients. As agricultural supply networks are interrupted and food prices rise globally, the conflict between Russia and Ukraine poses an additional threat to global and Ethiopian food security. Ukraine supplies 25% of Ethiopia's wheat imports, and the demand for humanitarian relief in 2022 is at an all-time high, outpacing both 2021 and 2016 by roughly 40% (FAO, 2022)

The El Nio drought has been one of the most severe in Ethiopian history. In 2016, more than 27 million people were food insecure, with 18.1 million need food assistance. Furthermore, there is evidence that the climate is already changing, causing a severe drought. Ethiopia's drought pattern has lasted ten years, but the cycle period is shrinking, resulting in major food security difficulties every three years (FAO, 2022).

According to Hunger Hotspots (2022), acute food insecurity is common in the majority of Ethiopia. Despite a five-month improvement in access during the truce, the flow of humanitarian goods remained sluggish due to insecurity, bureaucracy, a lack of vital services, and fuel shortages between the end of 2021 and June 2022. The resumption of hostilities in southern Tigray, as well as the Amhara and Afar regions, has hampered humanitarian access once more since the end of August.

Without a recent IPC analysis, there is no information on the current number of people in catastrophic conditions, which is estimated to be 401,000 between July and September 2021, and the level of concern remains extremely high. The Famine Review Committee issued a famine risk assessment for Tigray through December 2021 in July 2021, citing limited humanitarian assistance, rising conflict levels, and a lack of commercial goods and services (FAO, 2022).

Due to weak harvests and a lack of rainfall in neighboring farming regions, food insecurity has developed significantly in the southern, eastern, and pastoral regions. In the Somali, SNNP, Oromia, and Amhara regions, about 10 million people are experiencing acute food insecurity, with 2 million seriously insecure and in need of emergency help. Food assistance is anticipated to fall due to funding shortages and increased operational costs, with rations for refugees already reduced. It is projected that life-threatening conditions will be prevalent, with some people suffering famine and death (FEWSNET, 2023).

2.4. The Causes of Food Insecurity in Ethiopia

Food insecurity in Ethiopia has numerous causes, including drought risk, environmental degradation, demographic pressure, rural-to-urban migration, and conflict. In the absence of adaptation measures, climate variability and change act as risk multipliers, aggravating the conditions affecting food security trends.

2.4.1. Climate change

Overproduction has increased cereal supply by 2.2 billion metric tonnes in the last 50 years, owing to climate change. Environmental stresses, competition for land and nutrients, and ecosystem eutrophication all contribute to this. Climate change has a specific impact on agriculture, with natural catastrophes such as floods, tropical storms, and droughts being the primary causes of food poverty. Drought is a widespread cause of food scarcity, with catastrophic weather occurrences occurring in Eastern Africa, the Sahel region, Australia, Central Europe, Russia, and the United States. Future projections may contradict FAO projections, thus impeding future yield gains (IPCC, 2014).

Ethiopia's food security is highly vulnerable to climate risks, such as the 2008/2009 and 2011 food security crises in the Horn of Africa, which have highlighted the impact of droughts and floods on agricultural production, market access, and income. To better understand the relationship between these factors and food security outcomes, assessing the ways in which livelihoods and particular vulnerabilities are linked to climate is a challenging task. A dynamic analysis is needed to evaluate the effect of these events on food security (Mohamed, 2017).

Ethiopia's vulnerability to climate change stems from its reliance on precipitation, a significant driver of agricultural productivity and food accessibility in the region. As such, any adverse changes in rainfall patterns or other climatic factors may severely impact the country's food security and overall welfare. The primary driver of food insecurity and overall vulnerability, particularly in pastoral areas, is characterized by unpredictable precipitation patterns, known as erratic precipitation. Since 1980, there has been a noticeable decrease in rainfall data during the period spanning from March to September, with a significant impact on regions that rely on belg rainfall. This decline has resulted in a more frequent occurrence of severe droughts. According to the FAO, 2022 report, precipitation patterns have become increasingly erratic and unpredictable, in part due to a discernible alteration in the temporal distribution of rainfall.

In accordance with Ayal and Leal's (2017) research, the outcomes indicate that farmers' perspectives regarding the occurrences and repercussions of climate variability on the growth and rearing of crops and livestock are influenced by their sex, age, income, and education level. Furthermore, the study acknowledges that climate change factors contribute constructively to the efficacy of households, but the degree of influence is contingent on the distinctive geo-climatic attributes of different regions across the country.

Between June and October, Ethiopia has long rains, with the Kiremt rains being the most important agricultural season. These rains boost cropping areas and help to extend the agricultural season. Between February-March and May, the Belg rains supply water to Ethiopia's southern, north-eastern, eastern, and north-central regions. Rainfall in Belgium is critical for long-cycle crops such as sorghum and maize. Other rainfall patterns, such as sapia rains for sweet potato agriculture in SNNPR, gu and deyr for pastoral areas in the south/south-eastern sections, and two shorter seasons in Afar, are localised to certain places (WFP, 2012).

Since the 1980s, this annual precipitation across the nation has fluctuated significantly (NMA, 2012). According to empirical result (Yesuf et al., 2008) the result shown that the coefficient of determination (rainfall regressed over time) is relatively low, R2 = -0.039, indicating high inter-annual variability with a slight but statistically significant negative trend for this variability; this variability is a major contributor to food insecurity. Particularly concerning is the high variability of winter precipitation. Typically, Belg-dependent regions are the most food-insecure cropping regions and are also the most impacted by food security crises. Consequently, a failure of the Belg rains could exacerbate degraded livelihoods and food insecurity in these areas.

The approaching deyr (October-December) rains are expected to be below average in the south and east, resulting in a fifth consecutive unsuccessful rainy season. Precipitation totals in northern, eastern, and southern Ethiopia have been among the lowest since the mid-1980s in southern Tigray, eastern Amhara, eastern Oromia, and the northeastern Southern Nations, Nationalities, and Peoples' Region (SNNPR) (FAO-WFP, 2023).

In northern pastoral regions, the sugum rains from March to May were among the worst on record, while in Bermuda, they were the driest on record. In the South and southeast, drought conditions have been present since late 2020, with an average to above-average precipitation of 45 percent of the average. The Hagaa dry season continues with abnormally high temperatures in June, while the June to September rainy season began on schedule in the majority of the nation. In regions experiencing early-season rainfall deficits, kiremt rains typically begin in July. The beginning of the season is being closely monitored due to the failure of the belg season in these areas (FEWS NET, 2021).

2.4.2. Drought

Droughts and floods, for example, have a severe influence on households' ability to meet their food demands, resulting to food insecurity. Drought conditions prevail in Ethiopia, the SNNPR, southern Oromia, and southeastern Somalia, wreaking havoc on livelihoods. Total seasonal rainfall is up to 60% below average, reducing pasture and water availability and negatively impacting crop productivity, livestock conditions, and animal fatalities. Droughts and floods have a negative influence on food production, market access, and agricultural revenue, as demonstrated by historical and recent climate-related catastrophes such as the food security crisis in the Horn of Africa in 2009 and 2011 (CCAF and WFP, 2016).

Similarly, Ethiopia's history of food insecurity demonstrates that the danger of drought remains one of its fundamental drivers. Droughts have triggered twelve significant food security emergencies since 1950. Drought is especially prevalent in Afar (which has a climate similar to that of the Sahel), Somalia, and south and eastern Oromia (which has a climatological pattern similar to that of the Greater Horn and equatorial Eastern Africa). Additionally, recent trends indicate that drought risk has been increasing in highland regions (Riche et al., 2009). This aligns with community perceptions of drought risk changes. For instance, communities in Borana have reported that "there was a drought every eight years. Now, six of the next eight years will be dry. In the past 16 years, changes have become very apparent (ACF et al., 2009).

Ethiopia is perpetually affected by persistent and enduring food insecurity that is characterized by its chronicity and extended duration, as evidenced by reports from the World Food Programme (WFP) and the Central Statistical Agency (CSA) in 2014. The nation is also additionally vulnerable to recurring and severe food insecurity crises, which in many cases are only attributed to drought-related phenomena, as asserted by Guha-Sapir, 2013. According to Gleixner et al. (2015), it has been observed that during El Niño years, certain regions of the country experience reduced summer precipitation. The year 2008 and subsequent years have been closely linked to the occurrence of food security crises, as expounded by Glantz in 1994. The altered climatic conditions are inciting apprehension regarding variations in precipitation patterns, as well as heightened frequency and severity of droughts, which might culminate in Ethiopia experiencing heightened levels of food insecurity (WFP, 2014). The confidence level associated with the climate model projections for rainfall alterations in the Greater Horn of Africa is relatively low as reported by Otieno and Anyah (2013). As it stands, there isn't a distinctly discernible signal for climate change. As a result, efforts to adapt to climate change have been focused on fostering resilience to climatic variability. Examples of such endeavors include those undertaken by BRACED (2015) and CADAPT (2015). The definition of drought in Ethiopia is frequently delineated from a socio-economic vantage point, thereby indicating that it may be influenced by the structure of the food system, alongside climatic factors (Devereux and Sussex 2000). The contention that drought, in a wider scope, constitutes a significant and fundamental influence on the occurrence of food insecurity in Ethiopia not only impacts the interpretation of climate model projections and the perception of climate change challenges but also the prioritization of agricultural development initiatives presently.

This study focuses on the relationship between climate change and variability in rainfall in the food production system. Specifically, the investigation will highlight the prevalence of droughts (in relation to precipitation) in areas where climatic conditions are more significant, as opposed to attributing food insecurity solely to socioeconomic factors.

2.4.3. Food system

Extremely poor belg rains and high levels of social factors like conflict and displacement have resulted in massive displacement and failure of the crop production season in many areas, including Oromia and Amhara, as well as minimal planting of high-yielding long-cycle meher crops, primarily maize and sorghum (IOM, 2022). With this concept, even though the food system is comprehensive and difficult to capture in its entirety, this study attempt to identify the most significant determinants in relation to the food insecurity and green economy framework.

The food system is a collection of activities that ensures food production reaches consumers (Burrows and Kuyper, 2018), with food production serving as the primary purpose. Globally, there is increased interest in food and nutrition security as a means of combating malnutrition through high-intensity production. Much of this emphasis is on sustainable agriculture in order to feed the world's growing population (FAO, 2017).

Population and economic expansion, as well as technological and cultural shifts in production practices, have all contributed to a significant increase in worldwide food and agricultural production since World War II. Global food consumption has increased as a result of increases in population, affluence, and urbanization, while dietary tastes have evolved towards more resource-intensive foods (MEKURIA, 2019).

In Ethiopia Between 1961 and 2021, the production of teff, wheat, barley, and maize in Ethiopia has nearly quadrupled. Overall, during this time period, cereal production has increased steadily, with some declines between 1973 and 1975, and again in 1984/85 – this trend is attributable to the effects of major droughts in Ethiopia during these years. Yields have also increased consistently during this time period, with a relatively stable yield between 1975 and 1993 followed by a rapid increase afterward. In addition to population pressures on existing land, the frequency and severity of droughts during this time period may have had an impact on the viability of agriculture, as indicated by the steady decline in the area under cultivation from 1973 to 1993 (FAO,2021). Ethiopia's cereal production (metric tonnes) in 2021 was 30108985, according to the World Bank's collection of development indicators derived from officially recognized sources.

Climate variables, seed variety, water and soil nutrient availability, and farmer expertise all influence crop production in Ethiopia. While there has been some yield growth, it is insufficient due to the country's enormous population living in poverty and a substantial proportion being hungry. Pasturelands and natural vegetation are being converted to croplands in certain areas, while Khat and eucalyptus plantations are being developed in others. Except for productive safety net programmes in drought-prone areas, there is no policy edict on social protection for consumption insurance (FAO, 2018).

2.4.4. Food wastage

Globally Food that is produced but not consumed annually wastes enough water to equal the annual flow of Russia's Volga River and contributes 3.3 billion tons of greenhouse emissions to the environment. According to the FAO report, in addition to its environmental costs, food waste (excluding fish and shellfish) has direct economic consequences for producers of $750 billion per year (FAO & Food Wastage Footprint [FWF], 2013).

The UN 2030 Agenda recognizes the links between reducing food loss and waste (FLW) in the food supply chain and achieving the Sustainable Development Goals (SDGs), particularly SDG 12, which sets a target of halving per capita global food waste at the retail and consumer levels by 2030, as well as reducing losses along production and supply chains. It is estimated that approximately 800 million people are chronically undernourished, and that close to 40% of food produced is lost or wasted. Ivanova et al. (2020) and Sheahan and Barrett (2017) both discovered that significant food wastage could reduce pressures on food systems and contribute to improved food and nutrition security. In terms of environmental change, multiple studies have found that greater food waste management has the potential to significantly cut GHG emissions and the environmental footprint of food systems.

FAO published its first assessment on global food losses and waste in 2011 (FAO 2011). According to this report, one-third of all food produced for human use is lost or squandered each year. Unconsumed food has major environmental and economic consequences. Clearly, food waste is a squandered opportunity to improve global food security and reduce agricultural environmental consequences. Furthermore, to meet the expanding population's need, food production will need to be 60% greater by 2050 than it was in 2005/2007 (Alexandratos & Bruinsma, 2012). Using the food that is now available at the current level of production more efficiently would help fulfil future demand while increasing agricultural output less (FAO & Food Wastage Footprint [FWF], 2013).

Agricultural production generates the highest food waste, accounting for the majority of total loss volumes in the supply chain. The volume of upstream waste, which includes production, post-harvest handling, and storage, is 54%, and the volume of downstream waste, which includes processing, distribution, and consumption, is 46%. Food waste is distributed evenly between the supply network's upstream and downstream segments. Significant post-harvest losses occur in developing nations in the early stages of the supply chain, owing to financial and structural constraints in harvest practices, storage and transportation facilities, and weather conditions that favor food rotting.

The majority of food loss and waste in Ethiopia occurs between harvest and delivery to the processor or manufacturer. This inefficiency wastes millions of dollars each year, lowers farmer incomes, and worsens food and nutrition shortages. Despite the fact that it is expected to become increasingly relevant as rural-urban populations, diets, and consumption patterns evolve, there are currently no good national data on this topic (FAO, 2015).

2.4.5. Environmental degradation

Ethiopia is experiencing a cycle of natural resource depletion and food insecurity due to the country's extreme poverty and population growth. Degradation of the soil is a major hindrance to agricultural productivity, leading to soil erosion and a decrease in household and national food security. This Soil fertility is also a major issue in Ethiopia, affecting crop productivity and contributing to food insecurity. The main factors contributing to poor soil fertility are over-use on specified arable land, lack of awareness/education, and competing use of animal dung and fertilizer.

The global population is projected to increase from 7.8 billion in 2020 to nearly 10 billion in 2050, with food demand increasing by 60%, meat production by 70%, aquaculture production by 90%, and dairy product production by 55%. The global demand for crops has boosted the agrochemical industry, with the sales revenue for inorganic fertilizers expected to increase by 3.8% between 2020 and 2025 (Ilinova et al., 2021).

Pesticides and fertilizers provide several benefits, including reduced crop loss, reduced occurrence of human vector-borne diseases, and increased shelf life of agricultural products. There are still knowledge gaps to fill, and Jacqueline Alvarez, UNEP's Chief of the Chemicals and Health Branch, has focused on methodologies, tools, approaches, and policies that directly strengthen pesticide and fertilizer management with the goal of minimizing adverse effects on our health and the environment. Climate change is a serious hindrance to agricultural output in Ethiopia, leaving many Ethiopians food insecure and reliant on food aid (Prüss-Üstün et al., 2022).

2.4.6 Fertilizer availability

In order to maximize crop productivity, application of fertilizer is imperative for cereals, pulses, and oilseed crops. Alternatively, organic matter content may be maintained through the utilization of excreta from cattle and poultry. The self-sufficiency of food production in Ethiopia during the late 1950s has undergone a discernible decline, attributable to unbridled population growth, with the annual output dropping to a level of 160 kg. In contemporary times, the utilization of fertilizers and subsequent food production has demonstrated an uptick to address the burgeoning populace growth (World Bank, 2006).

The utilization of fertilizers in Ethiopia has significantly increased by nearly fivefold since the official cessation of input subsidy programs. Despite agricultural experts recommending higher application rates, current levels remain significantly below the recommended standard. This is further compounded by the limited capacity for expansion in cultivated areas, which has created a need for a concerted effort to promote fertilizer usage as a primary avenue to improve agricultural productivity. Contrary to several other developing nations, Ethiopia underwent a transition from a state of limited liberalization during the 1990s to complete government control over imports. Commencing in the year 2008, the country's imports have remained exclusive to farmers' organizations through stringent marketing regulations.

The Ministry of Agriculture (MoA) has reported that over fifteen million quintals of fertilizers have been made available for distribution at the onset of the kiremt season in June, catering to about eighty-three percent of the anticipated demand. Ever since the onset of the Ukraine crisis, the cost of retail fertilizers has exhibited a twofold increase, escalating up to $1,400 per metric ton as a result of the crisis-induced surge in global fertilizer prices. Such escalation can be attributed to the indirect consequences of the crisis. Despite the allocation of a substantial amount of approximately 15 billion ETB by the government towards subsidy of fertilizer costs, the exorbitant prices of fertilizers remain a significant financial impediment for the majority of smallholder farmers with limited household incomes. The employment of fertilizers is currently on the decline and can potentially yield repercussions on crop productivity.

2.4.6. Macro-economy

According to the FAO (2015), economic growth is critical for reducing undernourishment and improving the livelihoods of the poor. Improving smallholder family farmers' productivity and incomes, as well as investment and social protection, are critical to growth. Because of globalization, increased commerce, technological breakthroughs, longer supply chains, and volatile commodity prices, food systems have undergone fast upheaval. Population increase, urbanization, and evolving consumption habits are all important factors in ensuring food security (UNCTAD, 2017).

WFP (2016) also claims that due to rising food prices, unemployment, and insufficient social security, urban Wellers will be unable to be at least partially self-sufficient in food production. Droughts are the primary drivers of food insecurity in many countries, according to the World Food Programme (WFP), but other socioeconomic variables also have a role. International trade is required to bring agro-food production and supply to a national level, but it can also exacerbate producers' conditions. The World Trade Organization (WTO) and related bilateral, regional, and plurilateral liberalization agreements (outside the WTO) are important for international trade regulations because they affect nonagricultural output, trade, and consumption.

In the case of Ethiopia, Due to persistently low foreign reserves and declining budgetary support, macroeconomic conditions continue to deteriorate, resulting in high inflation and continued depreciation of the ETB (F. May's annual inflation rate of 37.2%, as reported by the Central Statistical Agency (CSA), was the highest in the last decade (CSA,2020).

Macroeconomic concerns are projected to intensify as a result of the combined effects of rising borrowing costs and skyrocketing international commodity prices, which contribute to the national import bill. Fuel shortages and currency depreciation on the black market have already happened as a result of the depletion of foreign exchange reserves. Food inflation was 40% higher in the first half of 2022 than the previous year, with additional increases expected (FAO&WFP, 2023).

In May, the annual food inflation rate stood at 44.2 percent, continuing to be the primary driver of the high inflation rate. The non-food inflation rate is roughly 28%. The high food inflation is a result of high transportation costs, below-average national production, and a lack of wheat and cooking oil imports.

According to the National Bank of Ethiopia, the ETB/USD exchange rate in June was 51.79 ETB/USD, which is approximately 19.3 percent higher than the same month last year; the official market price of the ETB declined by an average of 2% every month in 2021. However, between March and June of 2022, the rate of depreciation slowed to less than one percent per month. This is largely due to government controls over currency devaluation.

According to anecdotal evidence, the parallel market exchange rate in May was over 80 ETB/USD, which was approximately 55 percent higher than the official exchange rate. The value disparity between the official and parallel market rates is unprecedented and a reflection of the country's limited availability of hard currency in circulation and in banks. The rising cost of transportation due to the price of fuel has a ripple effect on food prices. Although the Ethiopian government subsidizes fuel prices, its ability to intervene in the market has diminished as a result of high global fuel prices and low government revenue. Four times between 2021 and 2022, the government had to increase fuel prices at the pump. In recent months, fuel prices have risen significantly in certain markets due to conflict. Further restrictions on fuel availability in Tigray impede humanitarian and economic endeavors. Fuel continues to arrive via humanitarian convoys; however, the supply is significantly below demand.

2.4.7. Land Use

Land use changes have occurred for thousands of years, but the current rate and extent are unprecedented due to the growing global population's food demands(de Sherbinin, 2002).Over the past 50 years, humans have modified 83% of global terrestrial ecosystems, threatening natural ecosystems, causing biodiversity loss, reducing ecosystem services, and increasing CO2 emissions (Nkonya et al., 2012; FAO, 2016). Agriculture expansion causes land changes & biodiversity loss. Deforestation for subsistence agriculture leads to land degradation in sub-

Saharan nations. Ethiopia has heavily modified landscapes for food production, especially in its highlands where sedentary agriculture has been practiced for a long time. Isolated primary forests remain in Ethiopia.

Enkossa (2022) investigated the farming system and land usage in western Oromia, identifying five land types: cropland, forestland, grassland, built-up areas, and water bodies. A large land use shift occurred over 45 years between forestland, agriculture, and grassland. The rates of forestland conversion were higher in simplified and moderate landscapes, implying that current land use dynamics are linked to earlier land use conversion legacies. It is critical to consider the historical legacy of land conversions as well as contemporary landscape circumstances when designing efficient land management systems.

2.4.8. Population

Ethiopia is Africa's second most populous country after Nigeria, with an expected 117 million people in 2021, and the region's fastest expanding economy, with a 6.3% growth rate in FY2020/21. It is also one of the poorest countries, with a per capita GDP of $960 (World Bank, 2022).

The more people there are, especially in poor countries with limited land and water resources, the fewer resources are available to provide basic necessities. If basic requirements are not addressed, development comes to a halt, and economies begin to collapse. Attempts to improve food production and consumption in certain poor countries are impeded by rapid population growth, rural-to-urban migration, unequal land distribution, diminishing landholdings, and rising rural poverty (FAO, 2021).
FEWS stated that Ethiopia's soaring population was one of several underlying causes of the country's widespread food insecurity. Regardless of weather conditions, an estimated five million people require food aid annually in the drought-prone country (FEWSNET, 2023).

2.4.9. Total productivity

Food security is crucial for people's health and well-being, as the World Health Organization emphasizes that poor health is a result of poverty. Governments should prioritize preserving lives and reducing mortality and avoidable illnesses. Social determinants of health, such as poverty and food insecurity, are linked to severe and costly health problems.

Nutrition is a basic human right and an investment in human capital that pays off now and in the future. Reduced hunger has both humanitarian and economic implications, as malnutrition reduces physical capacity, cognitive development, and learning accomplishment, resulting in decreased production. To calculate energy requirements, the FAO's basal metabolic rate (BMR) is used. According to (Croppenstedt & Muller, 2015) research, a 10% increase in calorie consumption can boost output and salaries by roughly 23 and 27 percent, respectively.

Height, as an indicator of a person's previous dietary history, is an important wage factor. Poor nutritional status not only reduces productivity but may also hinder a person from doing specific duties. Indirectly, poor nutritional condition may decrease productivity through absenteeism and limited employment possibilities. Micronutrients influence people's nutritional status, with iron-deficient anemic children developing at a slower rate and iodine shortage during pregnancy influencing child growth and mental development.. Bearing this in mind, this study rather than having poverty will assess the relationship of the with the use of total factor productivity with the production of food system in relation to affecting the health index as shown in the simulation model.

2.4.10.Technology

Food security is crucial for undernourished populations in developing countries and rural areas. Technologies like genetic modification, soil fertility improvement, and irrigation can increase food availability, accessibility, bio fortification, and mitigate food instability. However, implementing these technologies requires investments in research, development, human capital, infrastructure, knowledge flows, gender-sensitive approaches, regional and international collaboration, and technology readiness for agricultural innovations (UNCTAD, 2017).

Food security is a major obstacle in reaching the SDGs and other worldwide attempts to achieve them. To close the 70% food gap between crop calories available in 2006 and expected calorie demand in 2050, food production must be increased through genetic improvements, reduced food loss and waste, shifting diets and increasing productivity, improving soil fertility, pastureland productivity, and restoring degraded land. Food navigation is required in this scenario, despite decreasing arable land, limited water supplies, and other environmental, ecological, and agronomic constraints. Science, technology, and innovation can help to increase food production by developing plants with enhanced qualities and optimizing the inputs required to make agriculture more productive. Soil management and irrigation innovations are also crucial for increasing agricultural productivity (UN, 2017).

Agriculture is expected to play a vital role in guaranteeing Ethiopia's food security and economic prosperity. Despite its dropping share of overall GDP, its contribution to GDP has increased over the last six years, rising from 19.6 billion USD to 27.5 billion USD. Improving food security via boosting agricultural yields and farm income is largely due to increased technological usage. Numerous studies have shown that improved agricultural technologies and practises increase smallholder households' food security (Bezu et al., 2014; Biru et al., 2019; Kassie et al., 2018; Magrini & Vigani, 2016; Marenya et al., 2018; Shiferaw et al., 2014; Solomon et al., 2012; Teklewold et al., 2019).

Adopting sophisticated agricultural technologies, such as enhanced seed types, chemical pesticides, and conservation practices, can reduce poverty and food insecurity, according to Biru et al. (2019). Row-planting techniques, artificial fertilizers, and improved teff types can help to spread income and reduce poverty. These technologies have the potential to reduce poverty both directly and indirectly by lowering food prices for non-adopters and customers. To realize their full potential, these technologies should be used in a variety of combinations with complimentary inputs.

2.5. Empirical Reviews

Ethiopia's economic policy aims to ensure rapid and sustainable development through a strategy centered on agriculture, known as the Agriculture Development Led Industrialization strategy (ADLI). This strategy focuses on increasing productivity, improving food security, and reducing vulnerability in drought-prone regions. J.V. Braun (1994) linked famine in Ethiopia to declining production and availability, military conflict, droughts and crop failures, the Marxist regime's agricultural policy, prices, and market restrictions. Kebede (1995) concluded that the marketing policy prior to 1990 had a negative impact on both the availability and accessibility of food.

According to the empirical review by Asrat and Anteneh (2020), which investigated the level of food insecurity in Ethiopia with a special focus on dry land areas, the majority of Ethiopian families were food insecure. Drought hazards, desert locus, the spread of corona viruses, the long-term effects of previous poor seasons, conflict, low household income, the expense of nutritious food, and understanding of nutritious food components are the key determinants of food insecurity.

As food insecurity is more than just a food policy issue, different researches have been conducted to investigate various aspects of social, economic, and environmental factors. Rural Ethiopia suffers from food insecurity due to a high reliance rate (110%) among the dependent and working-age population (ages 15-60), according to the World Food Programme (2009). This enormous population necessitates a large amount of food while contributing little to advancement. Household heads' educational attainment has a substantial impact on food security (Haile et al., 2005**).**

Many studies conducted in different parts of Ethiopia (Amsalu etal.(2012); Dagnew, 1993; Sewnet, 2015) showed that food security in rural households in Ethiopia is influenced by factors such as farmland, credit, livestock holding, and access to productive assets. Ownership of key factors like draught oxen, breeding cattle, family labour, farm implements, and small livestock determines seasonal or annual production and income. More land holdings lead to increased cultivation, which in turn increases farm income and improves food security. In the Shashemene district of the Oromia region, total cultivated land, total annual farm income per adult equivalent, total off-farm income, and livestock size have a positive and significant relationship with food security.

Food security in Ethiopia is also significantly impacted by drought and rainfall variability, which have led to high food shortages and famines. In areas like Ethiopia, where agricultural activity relies heavily on rainfall, the contribution of irrigated land to agriculture is minimal, resulting in massive food shortages and hunger. Poor infrastructure, including roads, schools, and health services, also contributes to food insecurity and dependence on food aid. Inadequate infrastructure and social service development, such as roads, transportation, communication, electrification, education, health services, and agricultural services, are major challenges to sustaining agricultural production and food security. Addressing these issues is crucial for ensuring food security and promoting sustainable agricultural practises in Ethiopia (Zerihun, 2005; Brehanu, 2001; McBriarty, 2011)

With regard to the various causes of food insecurity, total crop production and consumer price index (CPI; from CSA, 2010) values in the year following harvest are negatively correlated with a coefficient of -0.638, indicating that crop production may be a key factor influencing food prices. As a result, years with lower-than-average precipitation may result in lower crop yields and higher food prices. Given this, we can observe the three-dimensional relationship between food insecurity and poverty (WFP, 2017).

Food insecurity causes were identified in many regions of Ethiopia, beginning with the 1972-73 Wello famine; Devereux (1988) stated that there was an effective demand for food, but insufficient quantities were available. Food systems must become more robust, sustainable, and egalitarian in order to increase community resilience. Ethiopia's government has created a comprehensive Ethiopia food system road map and vowed to fund game-changing solutions to address chronic food insecurity and all types of malnutrition. The goal of the 2021 Global Hunger Index is to provide data, analysis, and policy suggestions to help the Ethiopian government meet its promises and pledges through 2022 and beyond. To solve the country's major issue, which involves social, economic, and environmental variables and causalities, a robust policy approach is required.

CHAPTER THREE

3. Methodology

3.1. Model approach

A system dynamics model approach will be used to integrate different factors like population, market, food production, and environmental issues related to sectors that will be used to analyze past and future developments.

We meant extremely abstract modeling technique when we said system dynamics. It generates a broad representation of a complicated system by neglecting tiny details such as particular attributes of individuals, products, or events. These abstract simulation models can be utilized for long-term strategy modeling and simulation. It is a method for studying the nonlinear behavior of complex systems over time that employs stocks, flows, internal feedback loops, table functions, and time delays. System dynamics is a methodology and modeling technique that is used to frame, grasp, and discuss complicated issues and situations (Jim et.,al, 2016).

According to reductionism, the only meaning of study is analysis, which is the process of breaking down a complicated subject into smaller bits in order to get a greater knowledge of it. According to the Definitions and Development of Systems Thinking, knowing the grand total requires the analyst to recognise the tiniest components in independence from one another. System thinking, in contrast to the reductionist approach, is a holistic worldview that maintains that the whole is not the sum of its parts but rather the outcome of their interactions. According to this systems-thinking viewpoint, the whole arises through the interactions that occur among its components, and once the entire has evolved, it is the whole itself that gives meaning to the parts (Bagheri, 2006).

This study primarily concerned with food security as a national policy objective. The focus is on the "macro" level of food security. At this level, policymakers have the chance to establish the general frameworks that will enable households at the "micro" level to acquire dependable access to food through independent interactions with neighborhood markets and household resources. Consequently, a primarily economic perspective is adopted (Timmer, 2004). Over the years, food insecurity has integrated new aspects and degrees of investigation. As the food insecurity issue stretches back to the first half of the 1970s, when the global food crisis occurred, this continual evolution of the term indicates a greater acknowledgment of the concept's intricacies in study and public policy.

The food insecurity mainly indicated by the number of prevalence of undernourishment which is wider indicator of the extent of food insecurity at a national level. This prevalence demonstrates that a large proportion of the population has been undernourished over the last one and a half decades. The proportion of population undernourished was 64 percent (approximately 34 million people) in 1995. Thereafter, there has been a progressive improvement (approximately a linear decline) to (14.4%) till 2016. Despite its decrease till 2016, the prevalence of undernourishment starts to rise from 2017-2020 reaching up to 24.9% (recent data available) in 2020 (FAO, 2021). Existing related literature is reviewed to develop the model that reproduces the causal and feedback interaction of the prevalence of undernourishment and environment in Ethiopia. To quantify and parameterize the model's variables, a range of data will be gathered from various surveys and reports from both national (CSA) and international organizations (FAO:world bank; IMF& IFPRI, 2022).

Thus, this paper will attempt to implement the system dynamics approach due to the fact that the event is occurring and getting worse, particularly in Ethiopia, has its own pattern, especially since the 1970s, and has a variety of complex causes with an impact on the environment and socioeconomic aspects.

3.2. Dynamics hypothesis

Over the past twenty years, the Ethiopian population has observed a noticeable increase. Due to the growing population, there is a greater demand for food and nourishment. The challenge of meeting the dietary needs of the growing population necessitates a concurrent increase in the supply of food, as well as improved accessibility on the part of individuals. The physical availability of food is essential, as is the purchasing power necessary to acquire it. These factors collectively pose a significant challenge to the overall goal of providing sustenance to the entire population. The foremost reasons for the notable proportion of undernourishment are attributed to the purchasing power and the tangible availability of food supplies. As the purchasing power increases, so does the quantity of food acquired for consumption. This statement suggests that there exists a relatively low prevalence of undernourishment among the population. The availability of a greater quantity of food in the market is positively correlated with the amount of food purchased, which may consequently result in a reduced prevalence of undernourishment among the population.

One crucial way to measure food insecurity is by assessing the prevalence of undernourishment, which refers to the portion of the population experiencing malnutrition as a result of consuming food that lacks the minimum required calories on a regular basis. Therefore, as the intensity of constraining factors, namely food scarcity, increases, the level of consumption will correspondingly decrease. Thus, this leads to a comparatively increased prevalence of inadequate nutrition. Prevalence of Undernourishment results in impaired bodily functioning, the onset of diseases, and premature death or reduced life expectancy. These outcomes have a lasting impact on the labor force participation rate, particularly in countries with a significant percentage of their population, such as Ethiopia, where approximately 82% are affected. Such issues affect the human development index by negatively impacting the health status of the population, which in turn lowers life expectancy (MH, 2003;Ali. et al,2011; Gebremariam ., et al, 2005)

The growth of the population requires an increase in locally sourced food supply, primarily from Meher farming in Ethiopia. Consequently, the augmentation of food supply necessitates either the intensification of farming land or an amplification in cereal yield. Consequently, the augmentation of both arable land and cereal yields has exhibited noteworthy growth since the commencement of the twenty-first century. However, the expansion of arable land in Ethiopia has been accompanied by the depletion of natural resources, namely forest land, as a result of poor land management practices. Emissions resulting from such characteristics will have a consequential impact on Ethiopia's environmental domain and hold significant influence over its diverse climatic regions, with varying perceptions affected accordingly. The unfavorable impact of this phenomenon will have significant ramifications on Ethiopia since a substantial proportion of its agricultural industry depends on precipitation-fed techniques, which may cause a dearth of rainfall and subsequent reduction in agricultural or food output. As the production of food constitutes a significant component of a country's gross domestic product, it has considerable implications for the economic status of the nation. This may lead to a reduction in the proportion of investments allotted to green economy initiatives. The outcome of this measurement is anticipated to exert a significant influence on the reforestation process, precipitating recurring and self-sustaining phenomena.

The domain of food production is an expansive concept that encompasses matters concerning livestock raising practices and crop cultivation challenges. The present investigation shall delimit the scope of food production to predominantly consumed staple crops in Ethiopia, in order to facilitate an in-depth analysis. The food consumption trends in Ethiopia exhibit a remarkable degree of diversification, deviating from the common practice observed in several other nations where a solitary crop holds sway over the national food basket, for instance, rice in a majority of East Asian countries, maize in Latin America, or cassava in Central Africa. The Ethiopian cuisine presents an extensive array of grains and fundamental food items in its food basket. The levels and compositions of grain consumption exhibit significant variations that are contingent upon agro-ecological disparities, divergent socioeconomic statuses, and distinctive livelihood strategies. Furthermore, owing to the reliance on indigenous agricultural activities, particularly prevalent within rural settings, the consumption levels of food grains are subject to fluctuations across diverse temporal periods. In traditional societies, cultural values and traditions play a large role in determining dietary habits and preferences, which may not always align with the nutritional value or availability of foods. With the intention of providing a thorough analysis, this study examines the food production system through the consumption of specific grains in various rural and urban settings, agro-ecological regions, and income brackets. This study centers on the six primary staples that prevail in Ethiopia namely teff, wheat, maize, sorghum, barley, and enset, which is frequently referred to as "False Banana”. According to expeditious survey of the data that has been drawn from a nationally representative sample points out that these principal staples constitute a preponderant portion of the Ethiopian diet, accounting for in excess of 70 percent of the caloric intake.

Overall, the issue of food insecurity can be traced to the multidimensional factors encompassing the social, economic, and environmental dimensions encapsulated within the Green Economy

Framework of the Sustainable Development Goals. Drawing from the available evidence, we posit that food insecurity exhibits a dynamic interplay of direct and indirect causal relationships with major social, economic, and environmental factors, thereby indicating the issue's multifaceted nature. As such, it necessitates a more comprehensive and coordinated policy framework to address its complexity.

3.2.1. Casual loop diagram

With the above hypotheses, we will attempt to establish the following causality tree:

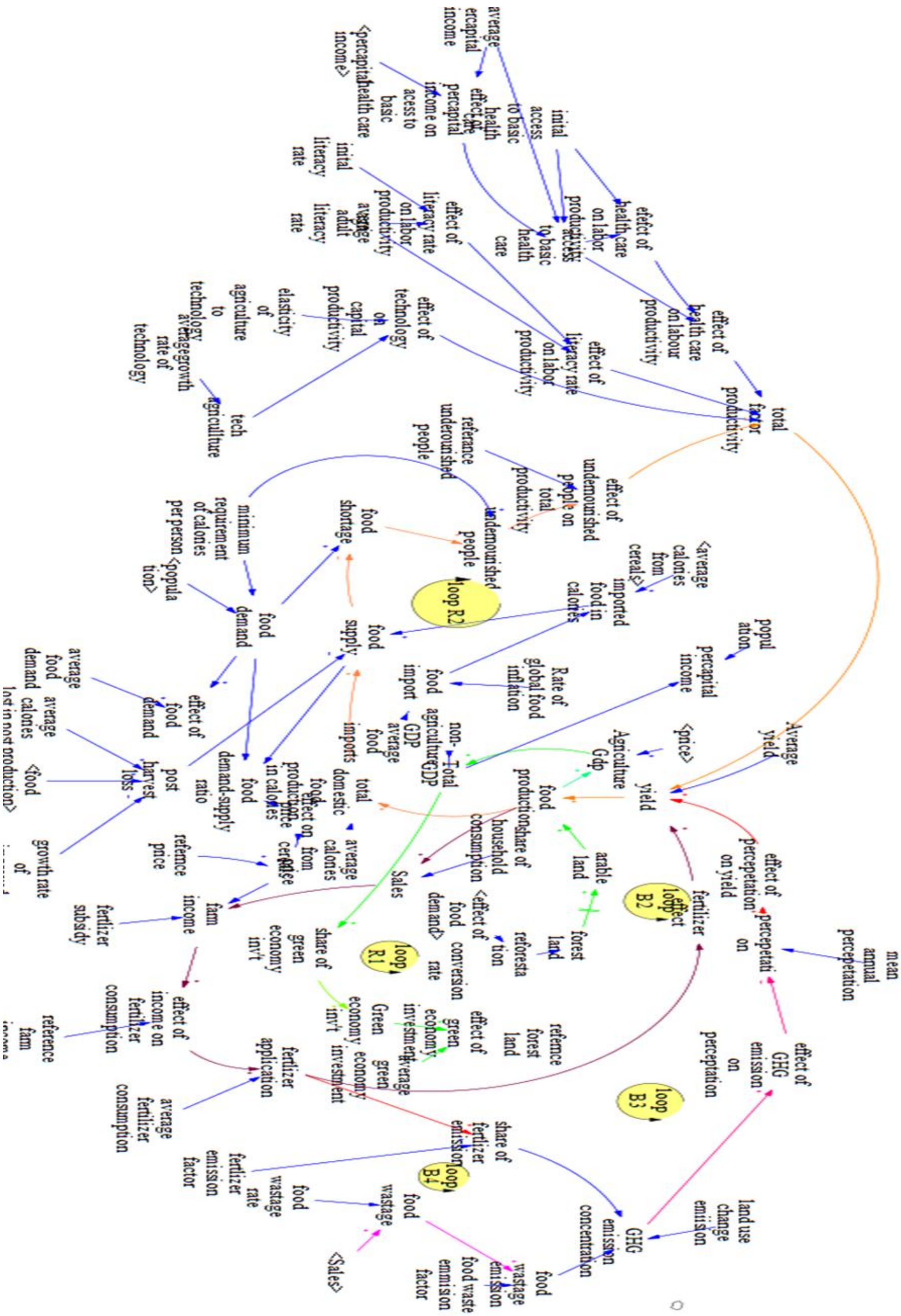

total factor productivity
effect of health care on labour productivity
effect of literacy rate on labor productivity
effect of technology on capital productivity
tech agriculture
average growth rate of technology
access to basic health care
inital literacy rate
average adult literacy rate
effect of undernourished people on total productivity
refrence undernourished people
undernourished people
food shortage
minimum requirement of calories per person
food demand
food supply
imported food in calories
food import
Rate of global food inflation
percapital income
Average yield
yield
food production
Agriculture Gdp
non agriculture GDP
Total GDP
arable land
forest land
reforestation
effect of percepetation on yield
mean annual percepetation
effect of GHG emission on perception
fertlizer application
average fertlizer consumption
effect of income on fertlizer consumption
farm income
fertlizer subsidy
refrence price
Sales
share of green economy inv't
Green economy invt
GHG emission concentration
land use change emission
share of fertlizer emission
fertlizer emission factor
food wastage
food wastage rate
food wastage emission
food waste emmision factor
post harvest loss
effect of food demand
loop R1
loop R2
loop B2
loop B3
loop B4

Figure 2: Authors Causal loop diagram representing the main feedbacks of the explanatory model.

In the causal loop depicted above, there are six main loops demonstrating the interdependence of socioeconomic and environmental factors. These include:

Loop B1: demonstrates the relationship between the prevalence of undernourishment and the simplified food production system. The loop started with yield affecting total food production, increasing total domestic food production in calories, and affecting the food supply. This food supply will help the undernourished by decreasing food shortages. This increase in nourishment will affect the labour participation force and health status, which will increase the level of the human development index in one country and positively affect the yield since Ethiopia's agriculture system is based on a labour-intensive structure. If the labour force isn’t sustained with the needed nutrition, then health issues will be a challenge for further food productivity, which will negatively impact the yield of an economy.

Loop R2: The other reinforcing loop indicates the economic effect of Total productivity in negative relation with undernourished people. In which an increase in prevalence of undernourishment will negatively affect the labour force through deficiency of nutrients amd more prone to disease that will decline the yield outcome.

Loop B2: The other impact in addressing the issue of prevalence undernourishment is the use of fertilizer, in which the final yield affects the agriculture production that will directly affect the sales; the more or less sold will highly impact the farmer's income. This income, incorporating the fertilizer subsidy and price, allows you to determine the fertilizer application that will affect the agricultural food production. The next loop shows the impact of fertilizer in another dimension, from an environmental point of view. With increasing agriculture production, this agriculture input also has a GHG emission level that will later affect the perception level and greatly impact the yield of agriculture production. (loopB3)

Loop B4: The other loop showing the environmental issue of food production is the impact of food waste, which has a greater impact on the growth rate of GHG emissions in Ethiopia. This alters the production sales as it happens after the product has reached the customer; this growth of

GHG emissions will directly impact climate change, which will alter the rainfall variation, which later highly affects the yield.

Loop R1: This reinforcing loop tried to depict the green economy investment project, in which increasing food production will increase the Gross domestic product (GDP) of a nation, which will impact the growth of the green investment. This increase will later encourage reforestation and decrease the conversion rate of forest land to arable land, which will again have an impact on the stock of arable land and affect the production system. However, this factor also has a balancing factor that will decrease the emission of GHG gases from land use change and impact the food production system through increased yields from sustainable precipitation.

3.3. Model specification and key equations

In contrast to other modeling methods, the identification of the optimal parameter value is a critical component. For instance, the proper determination of a parameter value in a given system may significantly affect the overall performance of the model. In the context of predictive modeling, the precise values of parameters hold limited significance when analyzed through an illustrative approach, such as the system dynamics method presented in this study. The estimation of feasible parameter values and subsequent testing to determine if any modifications result in alterations of the system's behavioral modes are of utmost importance. In accordance with the methodology proposed by Barlas (1996), an iterative model validation approach was employed, which incorporated parameter estimation and sensitivity analysis. Validation tests focused on both the structure and behavior of the model were administered in a comprehensive manner during the entire modeling process. The formalization of the framework presented in Figure 2 was achieved through the development of a rigorous mathematical simulation model. The current article presents an exposition of the stock and flow structure, which is graphically illustrated in Figure 3. Subsequently, Table 1 provides a detailed presentation of the fundamental equations pertaining to this structure.

3.3.1. Stock and Flow Structure

Stocks and flows are fundamental to the dynamics of complex systems. It is the crucial stage in which mental models are transformed into complete and communicable results. The stock and flow diagram is a system of feedback structures that depicts integral finite difference equations with a collection of feedback loop structure variables and simulates the dynamics of the behavior over time (Bala, Arshad, & Noh, 2017; Sterman, 2000). The food security problem has complicated characteristics such as time delays, non-linearity, feedback cycles, stocks, and flows, all of which alter understanding of the fundamental structure. In this section, we thoroughly present the model structure that has resulted in the dynamic problem.

The creation of the model involves the utilization of four significant stock variables. The population represents the first stock, and it undergoes transformation due to fluctuations in the rate of natural growth. The rise in population size will unavoidably induce a proportional increase in the demand for food, subsequently impacting the arable and forest land categories, the two significant stock variables of land usage.

The model focus only on the two land use because major land change in the past five decades have involved between forest and arable land (Lambin, & Meyfroidt, ,2011). The phenomenon of human alterations to landscapes has been traced back thousands of years, as documented by de Sherbinin (2002). The unprecedented demand for food by a rapidly growing global population has led to rates and extents of land use change that have not been observed previously (Lambin et al. , 2003; Gebreslassie, 2014). The practice of modifying the human landscape can be traced back several millennia, as noted by de Sherbinin (2002). The phenomenon of land use change occurring to address the exigencies stemming from an ever-increasing global population's food requirements is unprecedented in human history (Lambin et al. , 2003; Gebreslassie, 2014). Over the course of the last five decades, approximately 83% of the world's terrestrial ecosystems have undergone significant alteration at the hands of human activities (Nkonya et al. , 2012; FAO, 2016). The aforementioned alterations pose a clear and present danger to the integrity of natural ecosystems, as elucidated by El-Raey et al. (2000) and Lambin and Geist (2008). This phenomenon additionally leads to a depletion of biodiversity and a decrease in the caliber and magnitude of ecosystem services, as noted by Tolessa et al. (2017)Furthermore, the transformation of these environments contributes to an escalation in carbon dioxide emissions, as observed by Lambin and Geist (2008) and Pendrill et al. (2019). According to recent statistics from 2022, the majority (90%) of deforestation occurring on a global scale can be attributed to agricultural expansion. (FAO, 2023)

With the aforementioned consideration, the present investigation will center its attention on two significant alterations in land use, namely, forest and arable land. The model employed in this study depicts these land use patterns as stock variables, affecting the ultimate stock variable, that is, greenhouse gas (GHG) concentration. The proposed model delineates the interdependence between a specific stock variable and the conversion rate variable, which consequently impacts the level of greenhouse gas (GHG) emission resulting from land use change.

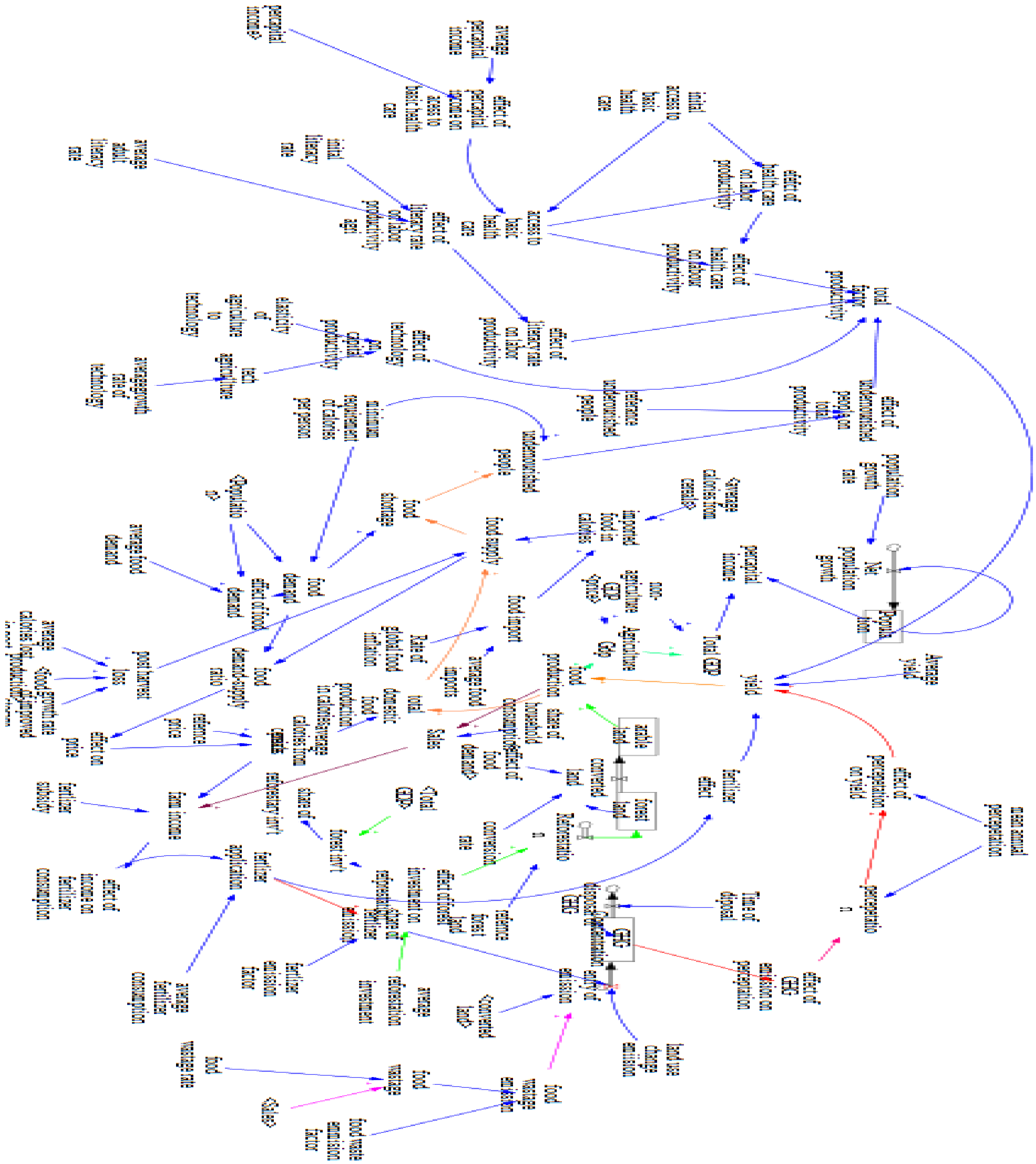


Figure 3: Stock and flow diagram of the simulation model. A rectangle around a variable name indicates a stock variable that represents an accumulation process. The value of stock variables changes through flow variables that are represented by double-lined arrows flowing into and out of the stock rectangle

Table 1: Key equations of the simulation model

Key equations of the simulation model

NO	Equation	Variables
1	S=Prod=y*AL	Y-yield, AL-arable land, prod- food production, S=Sales
2	dAL/dt=change in forest land to arable land-change in arable land to forest land	
3	dFL/dt= reforestion-conversion of arable land to forest land	
4	$P= ref_{p}*(S/D)^{e}$	p- price , ref_p- reference price, S-food supply, D-food demand, e- price elasticity
5	$y= (Y_{av}*TFP*fe* r)$	Y_{av}- yield average, TFP-total factor Productivity, r- precipitation effect
6	TFP= HE*Le*a/un	He- effect of health care,Le-effect of literacy rate, a- effect of technology, un- effect of undernourished people
7	PI=GDP/popn	PI= per capital income, GDP- Gross domestic product, popn- population
8	D=min req cal *popn	min req cal- minimum required calories per year
9	S=Tdfp+im-Psh	Tdfp- total domestic food product, im- imported good-psh- post harvest loss

10	FI=P*S+Fs	FI- farm income, S-sales, Fs- fertilizer subsidy

Table 2: Key parameters and initial conditions

: Key parameters and initial conditions

Key parameter	Value	Source
Minimum requirement in calories	2100kilocalories/day/person	FAO,2023
Average kilocalories/tons	347	(FSA,2018)
Conversion rate	0.206	(Othow etal,2017)
Average Yield	2 tons/hectare	(FAO,2023)
Rate of global inflation rate	0.035	(FAO, food index report)
Food wastage emission factor	700 $kgco_2$ /ton	(UNEP,2021)

4. CHAPTER FOUR

Model Validation and Behavioral Analysis

Models are helpful tools when they can make things happen correctly for the right causes. The aim of model validation is to make sure that the model can be used for what it was meant to do, and to feel sure about it. We should check that our model is correct and works well at every step of making it, from the beginning to the end when we use it to make decisions. (Barlas, Y.,1994).

4.1. Direct Structure test

In chapter three, we introduced both the causal-loop and stock-flow model structures, with which we characterize the systemic interaction between numerous parameters resulting in the problematic behavior utilizing the green economy framework. The model structure represents the causal hypothesis that describes the interaction of various agents throughout time. As a result, the model's validity is dependent on the validity of the model structure that represents the hypothesis. The conceptualization and specification of the model structure are purely based on the literature reviews many reports, papers, and journals. In the conception and estimation of some model parameters, we employed time serious survey data (from CSA, World Bank, and FAO) and possible look outs on diverse literature.

4.2. Unit consistency Test

Checking unit consistency is one of the model validation methods. It is critical to ensure that all of the units in the model are consistent and represent the desired variable. We checked the consistency of all the units in the model. Some of the variables and their corresponding units are listed below.

Table 3: Unit of Some Variables

Name of Variables	Type	Unit
Arable land	Stock	Hectare
Forest land	Stock	Hectare
GHG concentration	Stock	KgCO2/year
Food Production	Auxiliary variable	Tons
Yield	Auxiliary variable	Tons/hectare
Food demand	Auxiliary variable	KilloCalories/ year
Food supply	Auxiliary variable	Kilocalories/ year
GDP(Gross domestic product)	Auxiliary variable	Birr
Undernourished people	Auxiliary variable	Person
Food shortage	Auxiliary variable	Kilocalories/ year

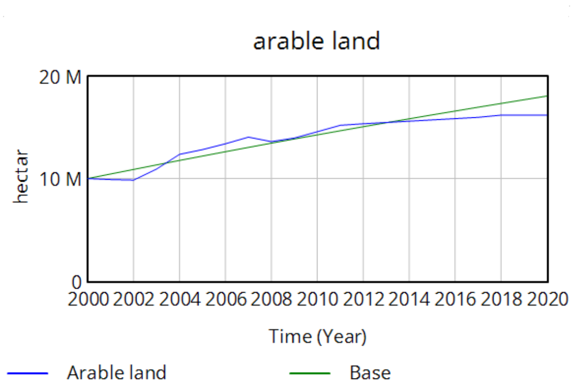
Price	Auxiliary variable	Birr/tons

4.3. Reference and Model Simulated Behavior Test

Model validation entails comparing the simulated model behavior to the historical behavior. In other words, it determines if the model's simulation outputs effectively reproduce the behaviour of the system modeled, capturing the major characteristics of the behavior.

To begin, we will examine the comparison of major data variables with historical data. This study will primarily examine the causality relationship of food insecurity; therefore we will look at undernourished people, GHG emissions, yield, and arable and forest land change. These major variables were chosen because they can provide information about the social and environmental dimensions of food insecurity. Yield is an economic phenomenon that has a direct impact on the food production system, followed by total domestic product and the food supply chain, in lessening the impact of food scarcity, which impacts the incidence of malnutrition. On the other hand, the change in land use of arable land over time, particularly from forest land stock, has an impact on food production; this conversion rate is also affected by the effect of demand, which has a direct social factor of population that will alter the agriculture GDP system, affecting the share of forest investment project. This conversion, along with other food production emissions such as fertilizer application and food waste, will have an impact on the model's environmental side by modifying the precipitation rate, which is the key factor controlling yield in the Ethiopian economy.

As illustrated in Figure 3a-e, the FAO and World Bank provided historical data dating back to 2000, which was used to validate the model and demonstrate the system's behavior.



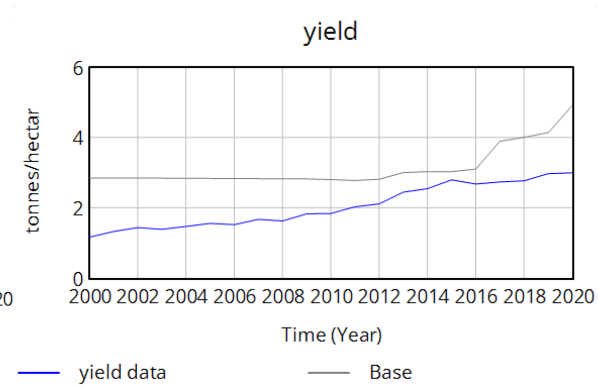
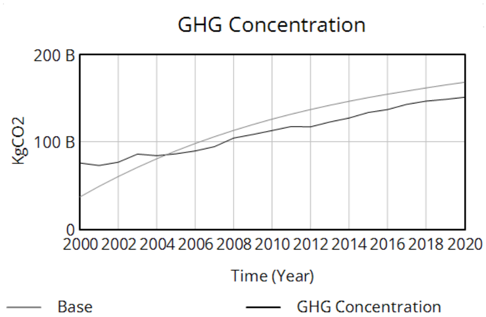


Fig 4a Arable land

Fig 4b yield



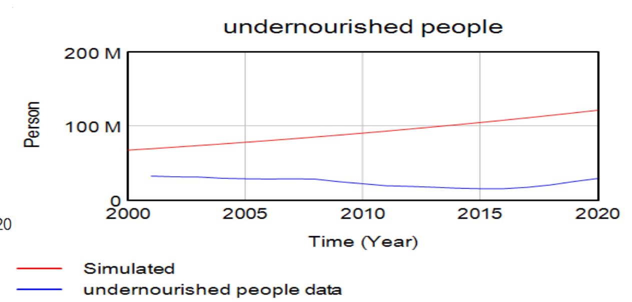


Fig 4c GHG Concentration

Fig 4d Undernourished people

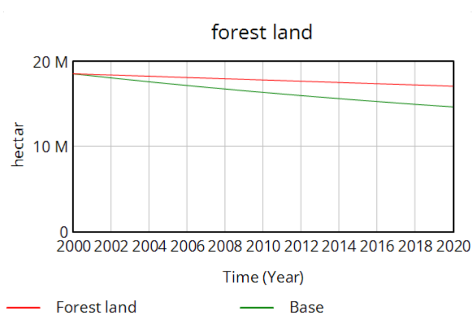


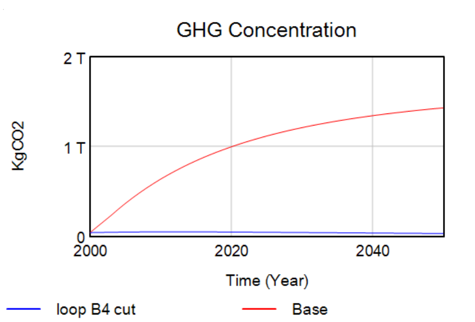
Fig 4e forest land

Figure 4: (a-e) the comparison of historical and model generated graphs

4.4. Structure-Behavior

Structure-behavior tests use behavioural tests to evaluate the structure's validity indirectly. This section analyses the relationship when particular loops are removed from the model. Structure-behavior tests use behavioural tests to indirectly assess the validity of the structure. In this section, we look at the connection between the model structure and its simulated behaviour when loop B4 is removed. We investigate whether cutting the B4 has the same effect on the model's simulation.

Loop B4 depicts the causality relationship and impact that one of the food production emissions (food waste emissions) has on environmental and economic phenomena by affecting GHG emissions and having a direct impact on precipitation, which has an impact on yield in the long run due to the seasonal functionality of environmental change. This study reveals how, by breaking the loop, circular activity has the same or expected impact on the three dimensions, as seen below.ehaviour between model structure and simulated behaviours.



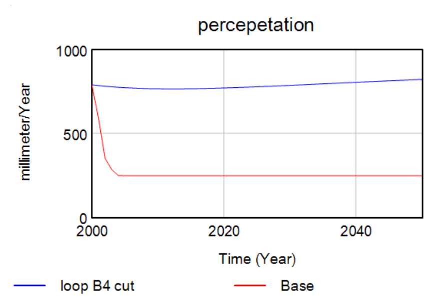
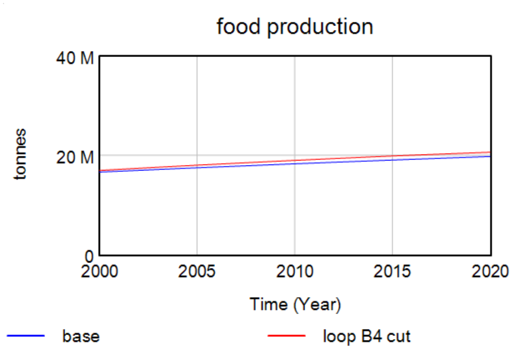


Fig 5a showing GHG concentration

Fig 5b showing perception



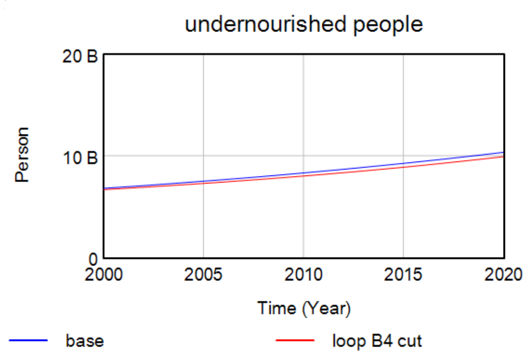


Fig5c showing the effect of on yield *Fig 5d showing the prevelance of undernourishmen*

Figure 5(a-d) showing structural behavior when food emission loop is cut

The four figures above show the structure and behavior of how one of the food emission loops (loop B4) is cut down, and the remaining loops reveal whether the main variables' behavior changes. According to the data presented above, the environmental aspect of GHG emissions will fail spectacularly and will continue to rise at a decreasing rate for the next 20 years. Following that, the perception will be positive due to the negative causal relationship that increased GHG emissions will have on one country's perception of the environmental scene. Because Ethiopia uses a rain-fed agriculture system, this will have an impact on the food production system in the long run by lowering yield and increasing the prevalence of undernourishment. Thus, the model replicate the expected behavior through the flow structure in which, reducing food wastage will have greater impact on the environment through affecting precipitation.

4.5. Extreme Condition Test

Another method of model validation in system dynamics is to determine whether the model is plausible in the face of extreme policies, shocks, and parameter values. The model must be robust in extreme settings, which implies it must generate realistic results even when the input values are extreme (Sterman, J., 2000). It is important to note that the extreme situation test does not always imply that the conditions occur in reality. The extreme levels of the average yield, one of the most important macroeconomic indicators, are examined in this section.

Assume that the extreme minimum criterion for average Yield is zero; this condition means that the country's productivity has collapsed and there is nothing to produce. In this situation, we anticipate that food production will be zero and that no one will have access to food. That is, we anticipate that business as usual (base run) and the extreme circumstance (average yield=0) will produce different results. As a result, everyone will be malnourished, and there will be a food scarcity proportional to the population's size because no one will have access to food. The figures depict the simulation findings for this difficult instance.

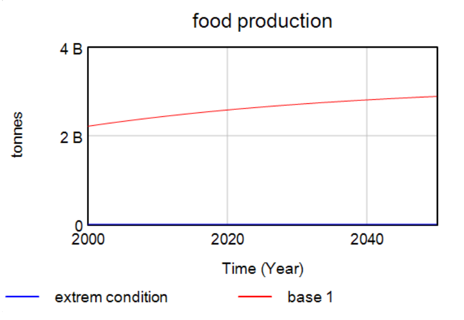


Fig 6a effect on food production

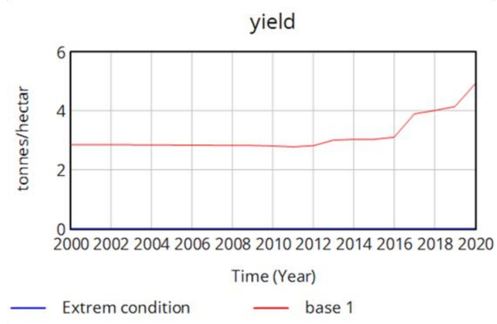


Fig 6b effect on yield

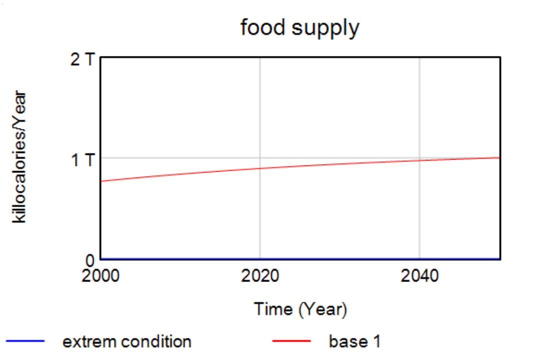


Fig 6c effect on food supply

Figure 6 a-c: extreme condition behavior

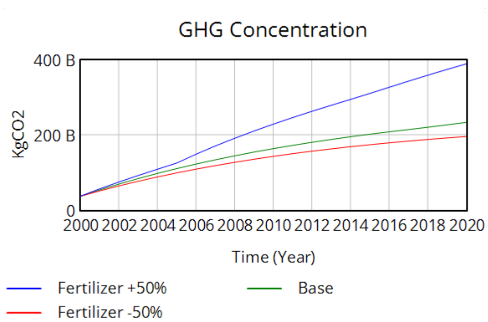
The simulation result, with the extreme minimum of average yield is zero shows the desired effect on yield, food production and food supply as they are all zero. The three figures above depicts the ultimate case when yield will be zero, resulting in total food production and food supply being zero as well since the nation is not generating anything.

4.6. Sensitivity Analysis

In system dynamics, sensitivity analysis is used to identify whether or not the model is sensitive to particular factors. Sensitivity analysis is performed on parameter values calculated using statistical data and expert knowledge, as well as parameter values derived from other research. The goal of sensitivity analysis is to determine whether the real system would be sensitive to the same parameter, as well as how sensitive the model is to the parameter (Barlas, 1994)

Scenario one

Fertilizer consumption is the amount of plant nutrients consumed per unit of arable land. Nitrogenous, potash, and phosphate fertilizers (including ground rock phosphate) are all examples of fertilizer products. Traditional nutrients, such as animal and plant manures, are excluded. According to the model description, average fertilizer consumption has two effects on yield and GHG emissions. The causality of fertilizer application has offsetting relationships in the two main variables. Fertilizer consumption increases yield per hectare, but as a country adopting a green economy approach, we must also consider the effect of fertilizer on the level of GHG emissions. When fertilizer consumption rises, it has a negative impact on one of the most important environmental factors, precipitation. We used the 50% threshold above and below to explain the effect of fertilizer on yield of the national economy.



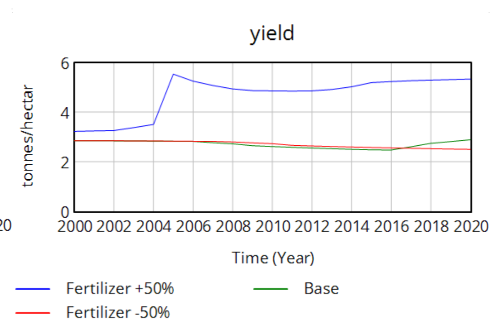


Fig 7a GHG concentration *Fig 7b yield change*

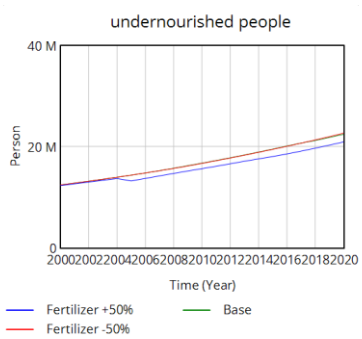


Fig 7c change in undernourished people

Figure 7:a-c showing sensitivity of fertilizer

Based on the four figures shown above, we can conclude that increasing fertilizer use will have a greater economic influence on the country's total output. This is justified because increases in fertilizer consumption have an incremental effect on total yield because it is one of the main agricultural inputs, but this effect also increases greenhouse gas emissions; however, fertilizer application reduced this offsetting relationship because as yield increased, farm income increased, which increased fertilizer use, resulting a reinforcing loop. Overall, we may conclude that fertilizer use affects both the environmental and economic sides, with the economic gain outweighing the environmental benefit.

Scenario two

The other sensitivity analysis will concentrate on one of the most important components of total food productivity: access to health care. In this analysis, we use both the 50% above and 50% below thresholds to determine whether it is necessary to increase the initial access to health from the constant 0.05 to above 50% (0.075) or down to 0.025. The main reason for using this variable is to see if there is an incremental increase or decrease in the main variables and which one will be more responsive or have an a sensitivity factor to change if our economy's access to health improves. The following are the sensitivity analysis results for some of the main variables: The results of some of the main variables in response to their sensitivity analysis are shown below:

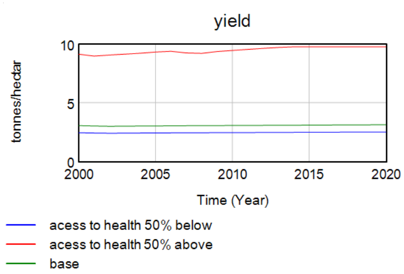


Fig 8a effect on yield

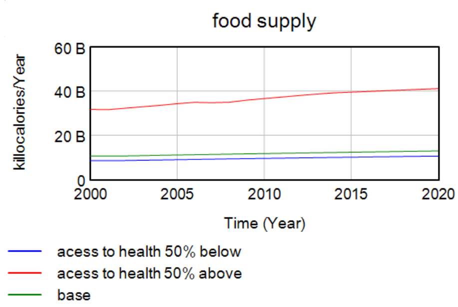


Fig 8b effect on food supply

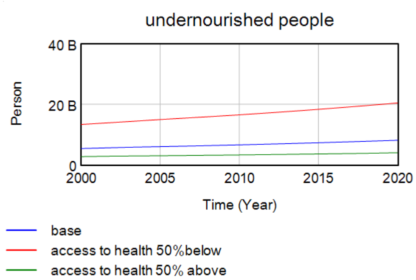


Fig 8c effect on undernorished people

Figure 8: a-c showing sensitivity of access to health

As we can see from the figures above, we can test the sensitivity of the variables due to one of the social factor phenomena of access to basic health care; that is, if we increase initial access to the health sector by 50%, we will see a consistent positive effect on total productivity increment, which will have a direct positive impact on yield. This scenario also helps to represent the case of Ethiopia, where the labour force accounts for 82% of the total population and an increase in access to health care will have a bigger influence on total output because Ethiopia use a labor-intensive production system. This increase in yield will then increase the food supply chain due to an increase in total domestic production. This will have a stronger impact on closing the gap between food scarcity and the incidence of under nutrition in the country by around 2 million individuals. This reduction in undernourishment will also have an impact on the work force, as a nutritious diet and regular health care will boost yield, illustrating loop R2 in the casual loop diagram.

If we reduce our initial access by 50%, this will have a decreasing turn-over effect on total productivity and yield (averagely 1-2% tonne per hectare), which will later decrease total domestic production and the food supply chain by around 2 trillion kilocalories per year, deteriorating the food shortage to a larger gap and increasing the prevalence of undernourished people.

Scenario three

When we say total factor productivity, we can’t ignore the influence of the educational sector, which has a greater advantage in showing both the human development index as well as economic development in one country. Given below, the figures show the sensitivity of yield, food production, and undernourished people when we increase the average adult literacy rate (0.5177 or 51.77%) by 50% and decrease it by 50%.

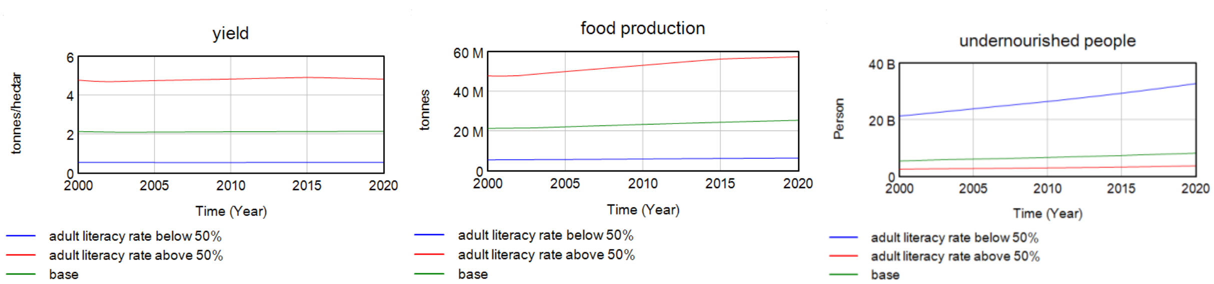


Fig 9a effect of yield   *Fig 9b effect on food production*   *Fig9c effect on undernourished people*

Figure 9: a-c showing sensitivity of adult literacy rate

Based on the above figure analysis, we can definitively state that the three variables with the strongest causal association are sensitive to both an increase and a 50% fall in the average literacy rate. As shown by the statistics above, increasing adult literacy has a stronger impact on yield through total factor productivity, which increases the food supply chain and reduces the prevalence of undernourished people. The reverse action is shown as the average literacy rate decreasing, which will decrease yield because there is a sensitive factor in the technology and knowledge of agricultural experts that will decrease yield and increase undernourished people, which will later decrease total factor productivity and make Detroit.

4.7. Policy Analysis

In this chapter we will mainly focus on examining future policy options, and analyzing scenarios on selected variables. Increasing food / cereal production and natural resource management are of primary priority in the attempt to maintain sustainable food supply for the population. Based on this we will have a three sector policy test and analysis using our model; namely economic policy, environmental and social aspect.

4.7.1 Economic Policy scenario

4.7.1. 1 Fertilizer use

Fertilizers are crucial to increasing food production to suit a global population that is estimated to reach roughly 10 billion by 2050. Improving agricultural production is one of Ethiopia's most pressing concerns for ensuring food security and poverty reduction. Given that soil fertility is one of the most pressing challenges, one logical option for increasing production is to increase fertilizer application and promote excellent agronomic practices. As a result, yearly fertilizer consumption in Ethiopia climbed from 3,500 t in the early 1990s to around 140,000 t in the early 1990s, and then to approximately 200,000, 400,000, and 550,000 t in 1994, 2005, and 2010, respectively. In the 2020/21 cropping year, the total amount of fertilizer available for application will approach one million tonnes (Tefera et al., 2012). This increase in fertilizer use, however, comes with its own set of considerations, including a major environmental impact.

Fertilizers contain components and chemicals like methane, carbon dioxide, ammonia, and nitrogen, all of which contribute considerably to the amount of greenhouse gases in the atmosphere. As a result, global warming and weather fluctuations are becoming more common.

In reality, nitrous oxide, a byproduct of nitrogen, is the third most significant greenhouse gas after carbon dioxide and methane. As part of its Farm to Fork strategy to achieve sustainable agriculture, the EU has set an ambitious aim of lowering the usage of chemical fertilizers by 20% by 2030. Furthermore, Japan has set a goal of cutting chemical fertilizer use by 20% by 2030 compared to 2016. There are fears, however, that simply reducing fertilizer use may result in a decline in productivity. Chemical fertilizers are projected to play an essential role in supporting greater food production in the future, and strategies for reducing their environmental impact should be considered (Mitsui, 2022).

The study illustrates one of the policy scenarios for boosting the key agricultural input; fertilizer consumption. In this section, the paper will consider boosting fertilizer consumption twice, which will have an impact on the primary factors of yield, GHG emissions, and undernourished people.

We will start with the business as usual (base) function to show the current trend and then apply a policy scenario in which we assume doubling a farmer's fertilizer usage because Ethiopia is one of the Sub-Saharan countries with the lowest consumption at 36.12 kg/hectare. The graph below depicts the impact of doubling fertilizer consumption beginning in 2025 and forecasting the impact on yield, GHG concentration, and undernourished people.

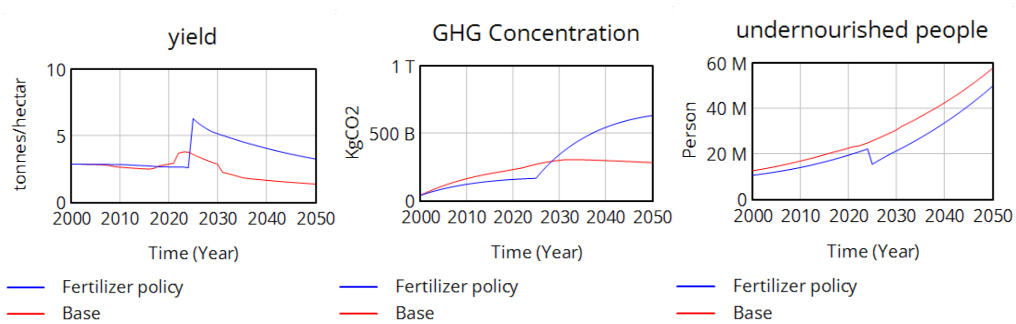


Fig 10a effect of yield   Fig 10b effect on food production   Fig10c effect on undernourished people

Figure 10: a-c showing fertilizer policy scenario

According to the following graph, increasing fertilizer usage by doubling in 2025 will result in a large-scale yield shift, but will subsequently continue at a declining pace as the GHG emission component raises over time. Because of the trade-off relationship between yield and GHG emissions, the undernourished population will have a significant decrease trend as production increases, resulting in a reduction in food shortages and a reduction in undernourishment. However, because this is not constant and will be affected by environmental factors, it will rise at an increasing pace as population, food consumption, and GHG emissions rise over time.

Thus, when addressing the increase in fertilizer usage to lower the incidence of undernourishment, we must be aware of the environmental picture because it has a tradeoff relationship with one of the world's environmental concerns. Though this trade-off is not as significant as the economic benefit, it will have a future impact on the stability of food security and sustainable agriculture, as well as raise worries about future health care difficulties that may arise as a result of greater GHG emissions. Overall, increased fertilizer consumption will have economic, social, and environmental consequences. As a result, addressing food security through increasing fertilizer use should be approached with caution, and various technological improvements are necessary to limit nitrogen and ammonia emissions and so mitigate the effect of GHG emissions.

4.7.1.2 Agro-tech advancement.

Modern farms and agricultural operations work far differently than those a few decades ago, primarily because of advancements in technology, including sensors, devices, machines, and information technology. Today's agriculture routinely uses sophisticated technologies such as robots, temperature and moisture sensors, aerial images, and GPS technology. These advanced devices and precision agriculture and robotic systems allow businesses to be more profitable, efficient, safer, and more environmentally friendly.

According to World Bank, 2023 report it emphasizes the need for developing nations to promote agricultural innovation and technology adoption in order to alleviate poverty, meet food demand, and cope with the negative effects of climate change. The recent relative stagnation in agricultural output, notably in Sub-Saharan Africa, emphasizes the need for new approaches to improve rural livelihoods. The Harvesting Prosperity: Technology and production Growth in Agriculture paper emphasizes the significance of increasing agricultural production, which has about double the impact on poverty reduction as manufacturing. The report investigates the factors that influence agricultural productivity and offers practical policy recommendations. Crop yields in Sub-Saharan Africa and portions of South Asia, on the other hand, have scarcely doubled in recent decades, with correspondingly modest reductions in poverty. Climate change and a dwindling natural resource base will have an influence on agriculture, especially in Africa and South Asia, making it critical to address these issues.

Africa and South Asia have the lowest Research & Development (R&D) spending relative to agricultural GDP, with Brazil and China leading the way. Because African countries have the lowest agricultural GDP, this spending difference poses a substantial concern. Governments should consider both public and private research and technology transfer to address this. Repurposing public agricultural funding can help to revitalize research systems, invest in higher education, and create conditions for private sector R&D. Private enterprises contribute over half of all R&D spending aimed at meeting the needs of farmers, and as much as one-quarter in large emerging economies. Policy methods for fostering greater private R&D in agriculture include lowering market participation barriers, increasing competitiveness, eliminating regulations, and enhancing intellectual property rights.

With having this in mind the next economic policy scenario will be on the increase of agriculture tech increment of 50% for the effect of technology development.

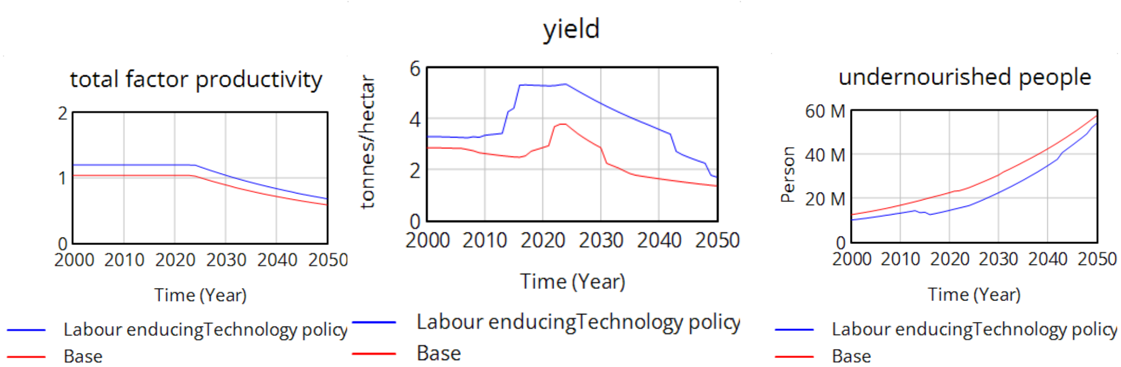


Fig 11a effect on total productivity Fig 11b effect on yield Fig 11c effect on undernourished people

Figure 11: a-c Technology advancement policy

From the above-illustrated figure, we can see that progress in increasing agro-tech development, particularly in the labour force, will have a significant impact on increasing total productivity, which implies an increase in yield and, as a result, a reduction in undernourished people over time. Thus, as a policy measurement, this study suggests that increasing labour inducing technology will have a greater impact, though this variable may have a delay factor, but it will be related to advancement of technology within the labour force, which will increase the opportunity for research and development that will increase the development of human capital base.

4.7.2 Social policy

Total factor productivity

4.7.2.1 Educational access

Education is one channel through which agricultural production can be increased. Numerous authors have proposed theories about how education affects production. Education has long been recognized as a powerful tool for shaping people's lives and making them meaningful, even in adulthood. It seems to reason that education and human survival have a favorable link (Ani, 2007). As a result, education becomes a viable strategy for agricultural development and farmer productivity. The farmer's ability to deal with disequilibrium produced by technological variations improves over time with education (Luh, 2009).

According to Hanushek et al. (2007), there are three processes via which education might influence economic growth. To begin, education can raise labour force human capital (labour productivity), leading in transitional growth towards a higher equilibrium level of production (augmented neoclassical growth theories) (mankiew et al., 1992). Second, education can increase the economy's inventive potential, which promotes economic growth (endogenous growth model,) according to Romar (1990). Third, education can promote economic growth by facilitating the diffusion and transmission of knowledge required to interpret and process new information (Benhabib, J., and Spiegal, M., 1994).

This three-step process of educational access utilization is illustrated below by simulating a policy scenario in which the average adult literacy rate rises from 51.77% to 70%. The outcome of the simulation policy scenario is depicted below;

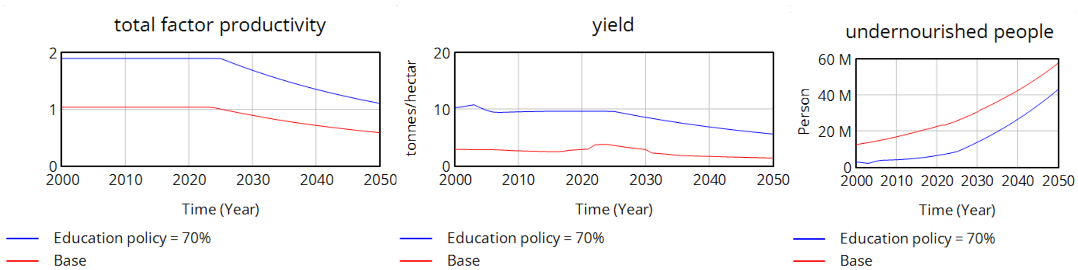


Fig 12a effect on total productivity Fig 12b effect on yield Fig 12c effect on undernourished people

Figure 12: a-c Educational policy

4.7.2.2 Access to Health care

TFP growth will keep diminishing marginal returns at bay, assuring long-term economic growth. A growing economy that does not pay attention to technical frontiers may encounter diminishing returns in growth rate, resulting in a shrinking economy. TFP, also known as productivity growth, has emerged as an essential determinant of a company's profitability, competitiveness, and growth. The literature on factors impacting productivity is growing in popularity (Fallahi et al, 2010).

In order to calculate overall production efficiency within a system, productivity is defined as the ratio of inputs to outputs. Citizens' health can be connected to productivity growth since well-being promotes individual productivity and a healthier labour force is associated with efficient human capital accumulation; hence, a healthy population is more likely to be productive than a sick one. Improvements in health outcomes are expected to have significant implications for citizens' well-being and potentially vast implications for productivity growth in general, but in SSA, inadequate health funding and poor health outcomes are regarded as major issues that may have hampered productivity growth in the region.

According to (Cole, 2006; Lipton, & De Kadt (1988); Antle & Pingali, 1994) emphasize the significance of health in production, stating that it can either improve or diminish a household's capabilities. When family and hired labour are not perfect substitutes or there are liquidity restrictions, poor health might lead to fewer days worked or reduced worker capacity, impacting output. The World Bank emphasizes the impact of diseases such as HIV/AIDS, malaria, and tuberculosis on reducing agricultural productivity by diminishing labour, productive adults' knowledge, and assets needed to cope with illness.

The primary goal of this policy scenario is to examine how expanding access to health care affects a country's total yield production. For the purposes of the analysis, we will enhance access to the health sector by 10% and observe the effects on the major casual variables.

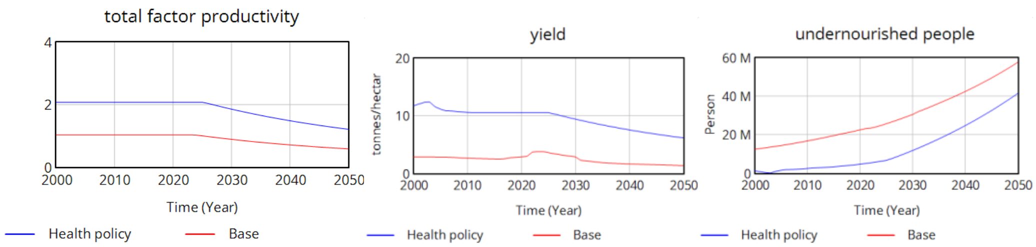


Fig 13a effect on total productivity Fig 13b effect on yield Fig 13c effect on undernourished people

Figure 13: a-c Health policy

Similarly, as seen in the simulation model, both the two major components of total factor productivity, education level (average literacy rate) and access to health care, have a reinforcing factor that will give us a higher agriculture yield, which will also increase economic growth through an increase in agricultural GDP, which will increase per capital income and standard of living, resulting in a development analogy. Though this policy is one fundamental solution to the problem of food insecurity, it takes a significant amount of time and investment before one can see the effect in the form of increased food productivity. Overall, despite the time lag, investing in human capital has reinforcing causality issues that will increase food productivity and decrease the prevalence of undernourished people without putting a strain on the environment and leading to more sustainable agricultural reform rather than focusing solely on increasing agricultural input, which has a negative effect on the eco-environmental condition and tradeoffs.

Environmental policy

Ethiopia is one of Sub-Saharan Africa's most vulnerable countries to climate change. This is due not only to the country's vulnerability to droughts and floods, but also to the fact that the majority of Ethiopians (80-85%) rely on agriculture and pastoralism for a living. With each successive drought and flood, the impact becomes even greater, particularly on poverty, hunger, and livelihoods, as those who are further behind face even greater obstacles and struggle to catch.

Food waste is another significant environment issue, causing a significant amount of food to go to waste and making environmental impact. This waste includes 1.3 billion tons of fruits, vegetables, meat, dairy, seafood, and grains that could be enough calories to feed every undernourished person on the planet. But wasted food isn't just a social or humanitarian concern—it's an environmental one. Wasted food also wastes energy and water, resulting in methane emissions. To reduce greenhouse gas emissions, consumers can take small steps such as delivering leftovers, freezing food, shopping smarter, and composting to keep inedible scraps out of landfills. By reducing food waste, we can contribute to a more sustainable future and reduce our greenhouse gas emissions.

Based on this analysis, we will try to decrease the food wastage rate by half in order to test the policy scenario on the environmental impact. The result of the simulation result based on base run is shown as below,

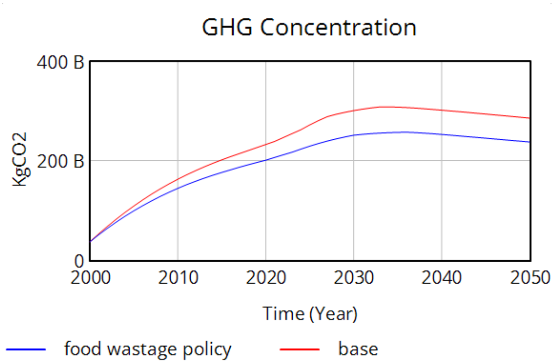


Fig 14 a GHG concentration on food wastage policy

All in all, as the world's population continues to rise, our objective should be to feed more people while wasting less of what we presently produce. Fortunately, there are numerous consumer-level measures we can take to make a major difference. We can all take little measures to reduce our emissions by sending leftovers to people in need, preserving food, shopping smarter, and composting to keep inedible scraps out of landfills.

Thus, as demonstrated by the food waste policy, lowering the food waste rate through modest steps of low food waste can have a beneficial environmental impact and lower greater food production emissions, resulting in the socioeconomic and environmental sustainability.

CHAPTER FIVE

Conclusion and recommendation

5.1 Conclusion

Ethiopia has seen a steady decline in the percentage of its population that consumes calories that are well below the minimum requirement over the last 15 years. However, this percentage continues to be higher than intended. This study has assessed the trends and status of the complex issue of food insecurity in a national level and list out the major influencing factor that form the casual relation using the green economy frame work and identify policy related issues using System dynamics that has assisted us in addressing and investigating this problem as it has unfolded in the various causalities relationships that will be used for further analysis in the definition of future policy options and testing of these policy options.

This study of food security necessitates investigating the interaction of (a) a growing population's consumption demand (food demand), (b) food production through which supplies are realized, and (c) environmental aspects (GHG emissions, precipitation). There are complex characteristics in each of these sectors, such as stocks, flows, time delays, non-linearity, and feedback cycles, that influence understanding of the main structure. Some of the complex relationships involved in the study of food insecurity include the effect of rainfall on cultivation land and yield, the effect of food supply-demand ratio on price, the effect of prevalence of undernourishment on total factor productivity, the effect of fertilizer use on yield and GHG emission, and so on.

This causal relationship reflects different policy scenarios in terms of social, economic, and environmental perspectives, in which the causality has demonstrated an offsetting relationship as well as reinforcing loops that affect food insecurity and produce vicious circles that are highly correlated and could have a long-term impact on one another.

From this insight, this paper discovers a method of increasing the social aspect of access to health and education as one of the prominent methods to mitigate the prevalence of undernourishment as they have a reinforcing loop and increasing health access will increase total factor productivity, which will increase yield and this yield will also decrease the prevalence of undernourishment, causing total factor productivity to induce more with having a reinforcing loop. Though an increase in fertilizer was assessed as a policy scenario with a short run high effect of increasing yield and decreasing undernourished people at a faster rate; this factor also has a counter effect on increasing GHG emissions and will have an effect on the social (health) and environmental effects over time; which will not guarantee the stability and sustainability of one economy. . This study also reveals that reducing food waste by half has a favorable impact on lowering GHG emissions and increasing environmental sustainability; consequently, everyone should make an effort to reduce food waste.

5.2 Policy Recommendations

According to the findings of this study, human capital must be prioritized not only for the society's health and education, but also for boosting productivity, economic growth, and meeting the international development agenda. Things may be more easily modified if due attention is paid to the human segment and the appropriate level of immunity. It is also vital, as part of the international development strategy, to attain universal access by 2030, which cannot be reached without development expenditures for the supply of safe drinking water and nutritional food.

In this regard, food poverty and malnutrition are more sensitive to the issue of human capital than fertilizer use since they have an environmental trade-off relationship. Although the use of fertilizer boosts agricultural productivity, we must be vigilant about emission levels and create innovative technology techniques to offset environmental problems. This problem can be addressed by taking a targeted approach, such as creating a social safety net and running an awareness campaign using all available communication channels. The network of basic health units, or any other grassroots network, can be better utilized to teach people of all ages about the need of appropriate nutrition. Another issue is a lack of nutrition knowledge at all levels of education. All of this is feasible within the restrictions of available financial resources, but prioritization is the only way forward. Policymakers can benefit from understanding the significance of these variables in increasing TFP and economic growth. There will be no need to deal with the difficulties of access to clean drinking water and malnutrition if the bottom-up strategy is used and local governments are empowered.

5.3 Limitations of the study and future research area

There are some limitations to the study. First, the study's boundary includes only cereals, which account for 58% to 69% of the population's daily caloric consumption at the national level. We investigate cereal consumption, production, and marketing from the inside out. A more comprehensive approach to studying food security would be to examine total agricultural production as well as total daily calorie consumption.

Second, this study aggregates data at the national level. As a result, the interpretation of the model's or research's results should be approached with caution. Results that are downscaled to regional or sub-regional levels are not always meaningful.

Third, the study only considers forest and arable land factors in the model's land sector because settlement and grass land are not considered. This structure is sufficient for the purposes of this thesis. However, there is room for improvement in the model by including the other factors that influence each other and demonstrating the look up tools more effectively.

Finally, in the yield formulation, this study uses precipitation as the only environmental factor and uses the effect of average rainfall as the only environmental factor; this effect is the same for all cereal types. However, depending on the environment and the condition of the cultivation area, each cereal may react differently to a change in average rainfall. This study also suggests future research areas on socioeconomic and environmental issues of various dimensions. Second, there is scope for developing models for each regional state in the country, allowing the problem and associated resources to be managed appropriately. Third, it is critical to investigate the policy implications of this research in order to determine whether, rather than increasing fertilizer use, we should prioritize human capital development in order to improve food security and investment in the area. Fourth, the system dynamic method presented in this thesis could be used to better study many complex issues in the country that involve delays, non-linearity, and feedbacks, such as water management, sustainable energy use, telecommunication and electric service expansion and planning, and so on. This is due to the fact that this method allows for sufficient flexibility in dealing with such complex issues. Finally, using system dynamics to study the economy, such as income, expenditure, and the supply chain in food insecurity issues, is a more appropriate way to unravel the complexity.

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Appendix

List of equations used in stock and flow diagram

Access to basic health care= SIMULTANEOUS (initial access to basic health care*effect of per capital income on access to basic health care 0.15) Units: 1

Agriculture GDP= SIMULTANEOUS (food production*price, 3.0314e+11) Units: birr

Arable land= INTEG (converted land, 1e+07) Units: hectar

Average adult literacy rate=0.5177 Units: 1/Year

Average calories from cereals= 347 Units: kilocalories/tonnes/Year

Average calories lost in post-harvest loss= 52.05Units: kilocalories/tonnes/Year

Average fertilizer consumption=858000 Units: tonnes/Year

Average food demand=780000 Units: kilocalories/(Year*Person)

Average food imports= 1.36787e+06 Units: tonnes

Average per capital income= 4800 Units: birr/Person

Average reforestation investment= 4.68e+11 Units: birr

Average yield= 1.2 Units: tonnes/hectar

Average growth rate of technology= 0.1 Units: Dmnl

Conversion rate= 0.0237 Units: 1/Year

Converted land= forest land*conversion rate*effect of food demand Units: hectar/Year

Disposal of GHG= GHG Concentration/Time of disposal Units: KgCO2/Year

Effect of health care on labor productivity= WITH LOOKUP (access to basic health care/inital access to basic health care, ([(0,0)-(10,10)],(0,0),(0,0.075),(0.14,1),(1,1.14),(1.2,1.2))) Units: Dmnl

Effect of food demand= WITH LOOKUP (Food demand /(average food demand*Population), ([(0,0)-(10,10)],(1,1),(1.2,1.112),(1.57,1.12),(2.8,1.2))) Units: Dmnl

Effect of forest investment on reforestation = WITH LOOKUP (forest inv't/average reforestation investment, ([(0,0)-(10,10)],(0,0.01),(0.101983,0.162879),(0.226629,0.356061),(0.478754 , 0.909091))) Units: Dmnl

Effect of GHG emission on perceptation = WITH LOOKUP (GHG Concentration, ([(0,0)-(10,10)],(2e+10,1.12),(5e+10,1),(1e+11,0.8),(1.5e+11,0.5),(2e+11, 0.4),(3e+11,0.33))) Units: Dmnl

Effect of health care on labour productivity= efefct of health care on labor productivity*access to basic health careUnits: Dmnl

Effect of income on fertilizer consumption= WITH LOOKUP (farm income, ([(0,0)-(10,10)],(1e+10,0.7),(2.4e+10,0.85),(2.8e+10,1),(3.6e+10,1.4),(4e+10,1.7),(5e+10,2),(6e+10,2.5),(8e+10,3.1),(1e+11,3.7))) Units: Dmnl

Effect of literacy rate on labor productivity= Effect of literacy rate on labor productivity agri Units: 1

Effect of literacy rate on labor productivity agri= WITH LOOKUP (Average adult literacy rate/initial literacy rate,([(0,0)-(10,10)],(0,0),(0.347,1),(1,1.3),(1.2,1.45)))Units: Dmnl

Effect of per capital income on access to basic health care= WITH LOOKUP (Per capital income/average per capital income, ([(0,0)-(10,10)],(0,0),(1,1),(2.2,3),(6,6)))
Units: Dmnl
Effect of precipitation on yield= WITH LOOKUP (Precipitation/mean annual precipitation,([(0,0)-(10,10)],(200,0.9),(400,1.09),(500,1.13),(600,1.135),(700,1.14),(800,1.142)))
Units: Dmnl
Effect of technology on capital productivity=tech agricullture^elasticity of agriculture to technology Units: 1
Effect of undernourished people on total productivity= WITH LOOKUP (Undernourished people/reference undernourished people, ([(0,0)-(10,10)],(0,2),(0.1,1.75),(0.2,1.5),(0.3,1.25),(1,1)))Units: Dmnl

effect on price= WITH LOOKUP (
"food demand-supply ratio",
([(0,0)-(10,10)],(1.1e-05,1.001),(1.33e-05,1.021),(2e-05,0.987),(3e-05,1))) Units: Dmnl

Elasticity of agriculture to technology=1.5Units: Dmnl
Entry of emission=food wastage emission share of fertilizer emission land use change emission*converted land Units: KgCO2/Year

farm income= price*Sales + fertilizer subsidy Units: birr
fertilizer effect= WITH LOOKUP (fertilizer application, ([(0,0)-(10,10)],(850000,2),(1e+06,2.2),(1.3e+06,2.5),(1.6e+06,3),(2e+06,3.7),(2.5e+06,4),(3e+06,4.4),(5e+06,5))) Units: Dmnl
Fertilizer application= average fertilizer consumption*effect of income on fertilizer consumption Units: tonnes/Year
Fertilizer emission factor= 733 Units: KgCO2/tonnes

fertlizer subsidy= 16410Units: birr

Food demand= minimum requirement of calories per person*Population Units: killocalories/Year

"food demand-supply ratio"= food demand/food supply Units: 1

Food import=average food imports*Rate of global food inflation Units: tonnes

Food production= SIMULTANEOUS (Yield*arable land, 5.86146e+09) Units: tonnes

Food shortage= -1*(food supply-food demand) Units: killocalories/Year

Food supply= total domestic food production in calories +imported food in calories-post harvest loss Units: killocalories/Year

Food wastage= Sales*food wastage rate Units: tonnes/Year

Food wastage emission= food wastage*food waste emission factor Units: KgCO2/Year

Food wastage rate= 0.6 Units: 1/Year

Food waste emission factor=   7 Units: KgCO2/tonnes

Forest inv't= share of reforestary inv't*Total GDP Units: birr

Forest land= INTEG (Reforestation-converted land,
1.85285e+07) Units: hectar

GHG Concentration= INTEG (entry of emission-disposal of GHG,   3.66331e+10) Units: KgCO2

Growth rate of improved storage technology= 0.0001 Units: Dmnl

Imported food in calories= average calories from cereals*food import Units: killocalories/Year

Initial access to basic health care= 0.05Units: Dmnl

inital literacy rate= 40.6 Units: 1/Year

Land use change emission=30300 Units: KgCO2/hectar

Mean annual precipitation= 750 Units: millimeter/Year

Minimum requirement of calories per person= 766500 Units: killocalories/Person/Year

Net population growth= Population*population growth rate Units: Person/Year "non- agriculture GDP"= 3.66809e+12 Units: birr
Per capital income= Total GDP/Population Units: birr/Person

Precipitation= effect of GHG emission on precipitation*mean annual precipitation Units: millimeter/Year

Population= INTEG (Net population growth 6.703e+07) Units: Person
Population growth rate= 0.03 NUnits: 1/Year

Post-harvest loss= food production*growth rate of improved storage technology*average calories lost in post-harvest loss Units: killocalories/Year

Price= refernce price*effect on price Units: birr/tonnes

Rate of global food inflation= 0.035 Units: Dmnl
Reference undernourished people= 23.45 Units: Person
Reference forest land= 1.85285e+07 Units: hectar/Year

Reference price= 1350 Units: birr/tonnes

Reforestation= effect of forest investment on reforestation*reference forest land Units: hectar/Year

Sales= food production-(food production*share of household consumption) Units: tonnes

Share of fertilizer emission= fertilizer application*fertilizer emission factor Units: KgCO2/Year

Share of household consumption= 0.5 Units: Dmnl

Share of reforestary inv't= 0.0001 Units: Dmnl

Tech agriculture= ACTIVE INITIAL (average growth rate of technology, 1) Units: Dmnl

Time of diposal=18 Units: Year

Total domestic food production in calories= average calories from cereals*food production Units: kilocalories/Year

total factor productivity= effect of health care on labour productivity*effect of literacy rate on labor productivity *effect of technology on capital productivity /effect of undernourished people on total productivity Units: Dmnl

Total GDP= Agriculture Gdp+"non- agriculture GDP" Units: birr

Undernourished people=Food shortage/minimum requirement of calories per personUnits: Person

yield= Average yield*effect of percepetation on yield*fertilizer effect*total factor productivity Units: tonnes/hectar