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Evaluating the Economic Impact and Food Security Implications of Climate Change in Ethiopia: An Economy-wide Analysis

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Abstract

The impact of climate change on Ethiopian agriculture and overall economy, as well as its implications on food security, is evaluated using a multi-country, multi-sector computable general equilibrium (CGE) model. The analysis employs the GTAP 10 Database and the GTAP-W model that differentiates between rainfed and irrigated agriculture. The economy-wide impact of climate change in 2050 is evaluated for two global emissions scenarios (A1 and B1), each from two global circulation models (GCMs) (CSIRO and MIROC). The results reveal that climate change induces a significant decline in agricultural production, resulting in a surge in market prices of crops. Climate change also depresses economic growth and results in substantial welfare loss. Moreover, the findings of the study reveal that climate change worsens the already grave food security situation in the country through its adverse effect on the 'food availability' and 'access to food' dimensions of food security. Therefore, government policy needs to be geared towards supporting adaptation to climate change in the country through the provision of access to credit, land, and climate information.

Keywords: Climate change; Food security; Computable General Equilibrium Model

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Introduction

Food and nutrition insecurity remains a serious challenge in Ethiopia. Moderate to severe food insecurity characterizes the lives of a staggering 69.9 million (58.1%) of the country's population, of which 25.3 million (21.1%) live in a severe food insecurity situation (FAO et al., 2023). Estimated at 27.6, the country's hunger index score is rated as serious according to the 2022 global hunger index score (von Grebmer et al., 2022). The grave food security situation is also reflected in the gloomy nutrition status prevalent in the country. About 21.9 percent (26.4 million) of the population is undernourished (FAO et al., 2023), and the extent of major nutritional indices (stunting, wasting, and underweight) and micronutrient deficiencies remains significant. The Ethiopian Demographic Health Survey (EDHS) estimates the national prevalence of underweight among children under age 5 at 24 percent and wasting at 10 percent (FDRE, 2019). Under-five child mortality and infant mortality rates stand at 67 and 48 deaths, respectively, per 1000 live births (FDRE, 2016). At 36.8 percent, stunting among children under age 5 is rated very high (von Grebmer et al., 2022). The country is thus in a dire food security situation.

Food and nutrition security play a significant role in the overall development of a country. According to a review conducted by Fernandes and Samputra (2022), several studies reveal the positive effect of food security on economic growth. Accordingly, the government of Ethiopia has demonstrated its commitment to fighting malnutrition and ensuring food and nutrition security as part of its development agenda. Major strategies and programs introduced by the government to improve food and nutrition security in the country include the Productive Safety Net Program (PSNP), National Nutrition Strategy (NNS), the National Nutrition Program (NNP), Nutrition Sensitive Agriculture (NSA) Strategy, and National Nutrition Policy (NNP). Besides, the country implemented its first and second five-year Growth and Transformation Plans (GTP I and GTP II) over the period 2010/11-2014/15 and 2015/16-2019/20, respectively, that resulted in remarkable economic performance. The Ethiopian economy grew, on average, at the rate of 10.1 percent and 8.2 percent during the GTP I and GTP II periods, respectively, and the rate of poverty declined from 30.4 percent in 2009/10 to 25.6 percent in 2020 (FDRE, 2020). As a result, the country has managed to considerably reduce malnutrition and improve the food and nutrition status of its population. The proportion of the population that is undernourished decreased from

37.1 percent in 2004-06 to 21.9 percent in 2020-22 (FAO et al., 2023), and the country's hunger index score dropped from 42.6 in 2007 to 27.6 in 2022 (von Grebmer et al., 2022). Similarly, child wasting, stunting, and mortality as a percent of children under five years old decreased from 12.4, 57.4, and 14.1 percent, respectively, in 2000-02 to 6.8, 36.8, and 4.9 percent, respectively, in 2019-21 (von Grebmer et al., 2022).

However, despite the substantial gains the country has achieved in sustaining economic growth, alleviating poverty, and improving food security, food insecurity is still quite significant and remains a serious challenge for the country. To make matters worse, climate change has emerged as a growing threat to the already grave food security situation in the country. In fact, climate change is a global challenge to food security that obstructs the progress towards a world without hunger (Wheeler and von Braun, 2013; FAO, 2015). The adverse effect of climate change on food security is well established (Porter et al., 2014; Mbow et al., 2019; Javadi et al., 2023; FAO and ECA., 2018; FAO et al., 2018). Climate change impacts food security through modifying physical characteristics such as temperature levels, precipitation patterns, and the frequency of extreme events (Mbow et al., 2019; Hasegawa et al., 2021; Porter et al., 2014). High sensitivity to weather makes agriculture extremely vulnerable to climate change (Nelson et al., 2009; Nelson et al., 2014; FAO, 2015). Therefore, climate change directly impacts agricultural production (Nelson et al., 2014; Ray et al., 2019; Porter et al., 2014; Lobell et al., 2011) and hence food prices (Nelson et al., 2010; Porter et al., 2014; Mbow et al., 2019), which translate into socioeconomic consequences that affect food security in all its dimensions (i.e., availability, access, utilization, and stability) (FAO, 2015; FAO and ECA., 2018; Porter et al., 2014).

Ethiopia relies heavily on agriculture, which accounts for 32.6 percent of gross domestic product (GDP), contributes 77 percent of export trade, and provides livelihood for 72.5 percent of the country's labor force (FDRE, 2020). However, the country's agriculture is predominantly a rainfed subsistent activity highly vulnerable to hydrological variability. With hydrological variability already inflicting high economic cost on the country (World Bank, 2006), the overarching significance of agriculture in the economy makes the country highly vulnerable to the impacts of climate change. Shocks related to agriculture induced by climate change will have severe consequences for the entire economy, threatening to reverse the progress the country has made over the years in reducing poverty and improving food and nutrition security. In light of this, analyzing the impact of climate change on the Ethiopian economy and examining the pathways through which climate change impacts the state of food security in the country constitutes a policy-relevant research agenda worth serious consideration.

Several studies have assessed the economic impact of climate change on the Ethiopian economy (Deressa, 2007; Deressa and Hassan, 2009; Aragie, 2013; Adinew and Gebresilasie, 2019; Kassaye et al., 2021; Gebreegziabher et al., 2015; Mideksa, 2010; Yalew et al., 2018; Robinson et al., 2011; Solomon et al., 2021). Some studies applied partial equilibrium analysis to examine climate change impacts on Ethiopian agriculture (Deressa, 2007; Deressa and Hassan, 2009; Aragie, 2013; Adinew and Gebresilasie, 2019). Results of these studies reveal that climate change would result in reduced agricultural output (Aragie, 2013; Adinew and Gebresilasie, 2019; Kassaye et al., 2021) and lower crop net farm revenue (Deressa and Hassan, 2009). Other studies have used computable general equilibrium (CGE) models to evaluate the economy–wide impact of climate change on the Ethiopian economy (Gebreegziabher et al., 2015; Mideksa, 2010; Yalew et al., 2018; Robinson et al., 2011; Solomon et al., 2021). Findings reveal that climate change would substantially reduce GDP (Gebreegziabher et al., 2015; Yalew et al., 2018; Robinson et al., 2011), increase income inequality (Mideksa, 2010), and affect the poor disproportionately (Robinson et al., 2011; Solomon et al., 2021). Studies conducted in Ethiopia essentially concentrate on climate change impacts on crop yield and production. Studies that directly assess the impact of climate change on food security in Ethiopia in terms of the dimensions of food security have not been reported as yet. This study attempts to fill this gap by examining the impact of climate change on food security in Ethiopia, focusing on the two dimensions of food security, namely ‘food availability’ and ‘access to food’.

To evaluate the impact of climate change on food security in Ethiopia, the study presented here employs a computable general equilibrium (CGE) model based on the revised version of the GTAP-W model (Calzadilla et al., 2010a). CGE models are capable of comprehensively analyzing climate change impacts across sectors and countries in a general equilibrium setting (Ginsburgh and Keyzer, 1997). Compared to previous studies, this study represents the first effort to apply a global CGE model to analyze economy-wide impacts of climate change on the Ethiopian economy and its consequences for food security in the country. The study distinguishes between rainfed and irrigated agriculture and incorporates water as a separate factor of production directly substitutable for other production factors in the production process of irrigated agriculture. The study also employs a reliable and widely accepted global database (the GTAP database) and a highly disaggregated agricultural sector. Besides, unlike previous CGE studies on Ethiopian agriculture, this study considers the impact of climate change-induced carbon fertilization on crop yield. Moreover, numerous economic indicators are considered in evaluating climate change impacts on the Ethiopian economy.

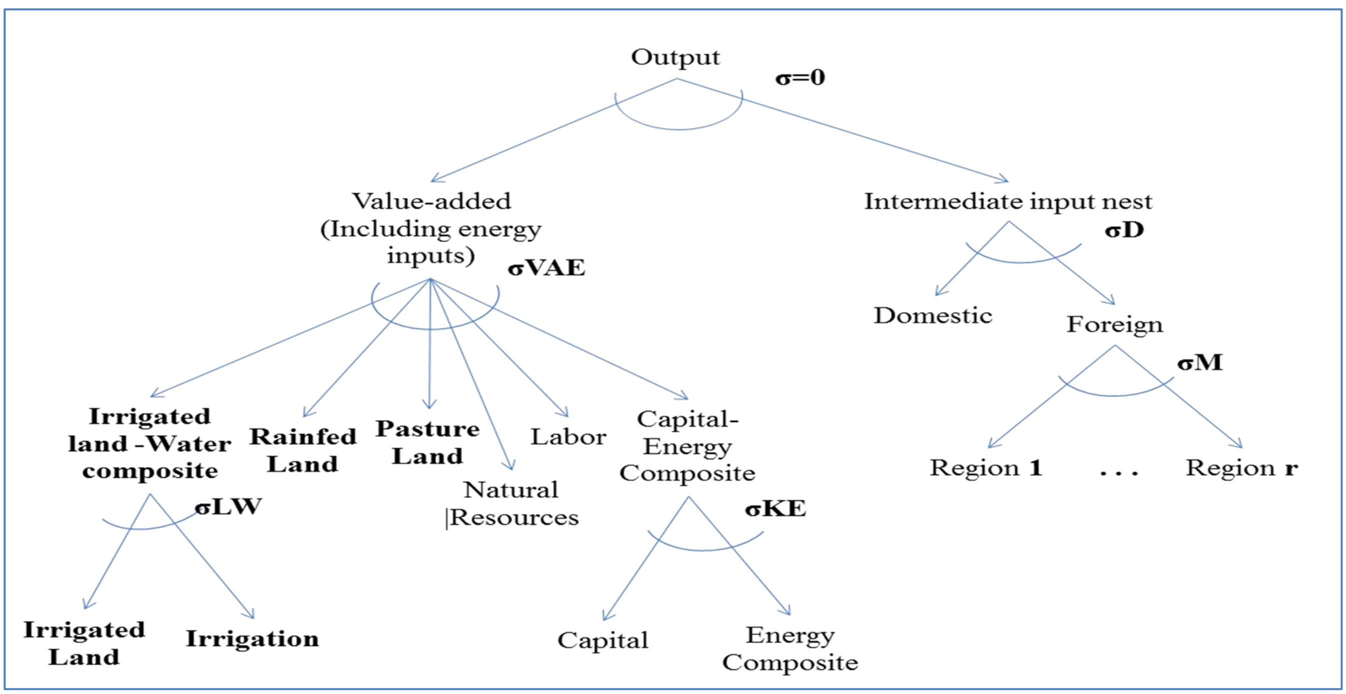
Modeling Framework and Data

The study applies the Global Trade Analysis Project GTAP) modeling framework (Hertel, 1997). Developed at the Center for Global Trade Analysis, Purdue University, USA, GTAP provides a global modeling framework and a common global database that offers researchers the opportunity to conduct model implementations and policy simulations with a common global database. GTAP is a static, multi-region, multi-sector CGE model of the world economy that investigates every aspect of an economy through its general equilibrium feature. The GTAP model comprises accounting relationships, behavioral equations, and global sectors essential to complete the model. The accounting relationships of the model guarantee the balance of receipts and expenditures for the agents identified in the economy, while the behavioral equations describe the behavior of profit and utility-maximizing agents in the economy through production and demand functions consistent with microeconomic theory (Brockmeier, 2001). The GTAP model considers a foreign trade structure characterized by the Armington assumption (Armington, 1969) and assumes perfectly competitive markets and constant returns to scale technology (Hertel, 1997). Based on the assumption of weak separability, the production system is set up as a series of nested constant elasticities of substitution (CES) functions combined through elasticities of substitution.

The analysis presented here adopts the new version of the GTAP-W model (Calzadilla et al., 2010), which is a refinement of the GTAP-W model introduced by Berrittella *et al*. (2007). The new GTAP-W model presents a new production structure that incorporates water in the GTAP model based on the GTAP-E version (Burniaux and Truong, 2002) developed for the analysis of energy markets and environmental policies. To account for water, the agricultural land endowment in the GTAP-E database is disaggregated into rain-fed land, irrigable land, and irrigation water based on the procedure outlined in Calzadilla et al. (2011) using data generated by the IMPACT model (Nelson *et al.* 2010). The model thus distinguishes between rainfed and irrigated agriculture and implements water as a factor of production directly substitutable in the production process of irrigated agriculture (Figure 1).

The GTAP model is provided with a common database referred to as the GTAP database of the world economy. The database provides complete global bilateral trade information, international transport margins, and protection data that link countries and regions in the database. The GTAP 10 Database, which includes 141 regions and 65 sectors and describes the world economy for four reference years (2004, 2007, 2011, and 2014) (Aguiar et al, 2019), is used in this study. The latest reference year of the database (i.e., 2014) is considered a baseline for the study. For this study, the 141 regions (of which 121 are individual countries and 20 aggregate regions) are aggregated into 6 regions: Ethiopia, Egypt, the Equatorial Lakes (EQL) region, Rest of North Africa, Rest of Sub-Saharan Africa, and Rest of the World (ROW) (See Appendix A). Similarly, the 65 sectors in the GTAP 10 Database are aggregated for this study into 18 sectors, of which 8 are agricultural sectors and 10 non-agricultural sectors (See Appendix B).

Figure 1: Revised GTAP-W Model: Truncated nested production structure



Source: Calzadilla *et al*. (2010).

Baseline and Climate Change Scenarios

Baseline scenario

Future climate change impacts the future economy. Therefore, climate change impacts are evaluated relative to a future benchmark equilibrium derived assuming a future with no climate change. The future benchmark equilibrium dataset for the GTAP-W model is derived using the method proposed by Dixon and Rimmer (2002). Since the base year of the GTAP 10 Database employed for the study is 2014, the baseline shows equilibrium in the world economy for this year. A 36-year macro-projection (2014-2050) that reflects the developments in terms of major macroeconomic variables that have taken place in the world economy since 2014 is, therefore, implemented in order to identify baseline conditions and outcomes for the year 2050, assuming no climate change. Table 1 shows the cumulative growth rates used to project the world economy towards the year 2050.

Table 1: Percent change in macroeconomic variables in 2050 compared to the baseline year 2014 by region under no climate change condition

Region	Agricultural land		Irrigation water	Population	Real[1] GDP	Capital[1] stock	Techno-Logical change[2]	Unskilled Labor force[1]	Skilled Labor force[1]	Pasture[2] land	Natural[2] Resource	Water[2]
	Rainfed	Irrigated										
Egypt	0.0[3]	20.6	11.5	49.2	385.7	362.9	64.4	1.1	169.9	95.6	589.3	447.4
Ethiopia	50.2	97.8	64.8	81.4	440.8	430.2	86.6	74.3	231.0	342.4	185.4	655.1
EQL Region	34.6	85.8	139.6	96.6	525.5	449.8	73.6	129.8	448.4	355.1	234.7	819.7
Rest of North Africa	6.9	22.3	36.8	34.1	214.8	205.7	60.2	-14.8	129.5	96.3	99.7	241.0
Rest of Sub-Saharan Africa	36.5	118.1	63.0	73.9	354.9	296.7	47.8	105.1	275.8	202.1	200.1	460.4
The rest of the world	-3.3	14.4	-4.2	23.8	150.4	135.9	43.7	1.8	76.6	51.9	90.1	167.1

Source: Own computation based on data from Nelson et al. (2010)

[1]Own computation based on data from Four et al. (2012)

[2]Based on macroprojection simulation results

[3]Rainfed agriculture hardly exists in Egypt.

Climate change scenario

In estimating the economy wide impact of climate change on Ethiopian economy and its repercussions on the state of food security in the country, climate change induced effects on (i) irrigation water supply, (ii) crop water requirements, (iii) rainfed and irrigated crop yields as well as (iii) land use changes in irrigated and rainfed agriculture are taken into consideration. CO_2 fertilization induced by climate change is also considered in assessing the impact of climate change on crop yields. The study assesses climate change impacts in 2050 for two global emissions scenarios (A1 and B1), each from two global circulation models (GCMs) (CSIRO[2] and MIROC[3]). The A1 scenario envisages a future characterized by high population growth and very rapid economic growth, coupled with rapid introduction of efficient technologies (IPCC, 2000). The B1 scenario foresees a future with similar population growth as in the A1 scenario but with rapid transformation in economic structure towards a service and information economy and transition to reduced material intensity and use of clean and efficient technologies (IPCC, 2000). Climate change-related changes in irrigated and rainfed crop yield, and crop water requirements in irrigated agriculture are computed based on data from Nelson et al. (2010) (Table 2). Changes in rainfed and irrigated land endowments due to climate change are also estimated based on data from Nelson et al. (2010). According to the projections of Nelson et al. (2010), climate change is expected to result in -3.3 and -28.7 percent change in rainfed and irrigated land endowments of the country, respectively, in 2050 under the A1 emissions scenario. The estimates stand at -1.3 and -28.2 percent, respectively, for rainfed and irrigated land endowments under the B1 emissions scenario.

[2] CSIRO Commonwealth Scientific and Industrial Research Organization; abbreviation for the CSIRO-Mk3.0 general circulation model (Nelson et al., 2010)

[3] MIROC abbreviation for the MIROC 3.2 medium resolution general circulation model (produced by the Center for Climate System Research, University of Tokyo; the National Institute for Environmental Studies; and the Frontier Research Center for Global Change, Japan) (Nelson et al., 2010)

Table 2: Percent change in agricultural land and crop water requirements due to climate change in 2050 compared to the baseline year 2014 by crop under the two global IPCC emissions scenarios

Crops	Rainfed yield		Irrigated yield		Crop water Requirement		Multifactor[1] productivity	
	A1 Scenario	B1 Scenario	A1 Scenario	B1 Scenario	A1 Scenario	B1 Scenario	A1 Scenario	B1 Scenario
Rice	-0.5	-0.3	-0.4	-0.2	0.0	0.0	-3.3	-2.1
Wheat	-21.7	-16.7	-19.3	-14.9	2.6	2.7	-15.8	-4.1
Other cereals	-4.7	-3.5	-4.2	-3.0	5.1	6.7	-8.0	-6.4
Other crops	-5.6	-4.2	-5.0	-3.8	5.4	7.7	-9.0	-4.2
Vegetables & fruits	-11.4	-8.7	-10.1	-7.7	11.4	9.4	-9.0	-4.2
Oilseeds	-5.6	-4.2	-5.0	-3.8	14.8	9.7	-9.0	-4.2
Sugar crops	-0.5	-0.3	-0.4	-0.2	0.0	0.0	-3.3	-2.1

Source: Own computations based on data from Ringler et al. (2010), Beyene et al. (2010), and Tubiello et al. (2006).

[1]Based on data from Roson and Sartori (2016).

Simulation Results

The effects of future climate change on Ethiopian agriculture and overall economy as well as its consequences on the state of food security in the country are assessed using several indicators including changes in land and water allocation across crops, crop production, market prices of crops, change in real GDP and economic growth, welfare effect and return to the primary factors labour (skilled and unskilled) and capital. Impacts on food security are evaluated using the two dimensions of food security, namely ‘food availability’ and ‘access to food’. In assessing the impacts of climate change on Ethiopian agriculture, the study zooms in on seven agricultural sectors most vulnerable to climate change. The climate change impact on crop production is used to assess the effect of climate change on the 'food availability' dimension of food security. The 'access to food' dimension of food security is evaluated through climate change effects on food prices, returns to the primary factors labour and capital, as well as household income. Economic impacts induced by climate change are evaluated relative to the 2050 benchmark equilibrium projected assuming no climate change.

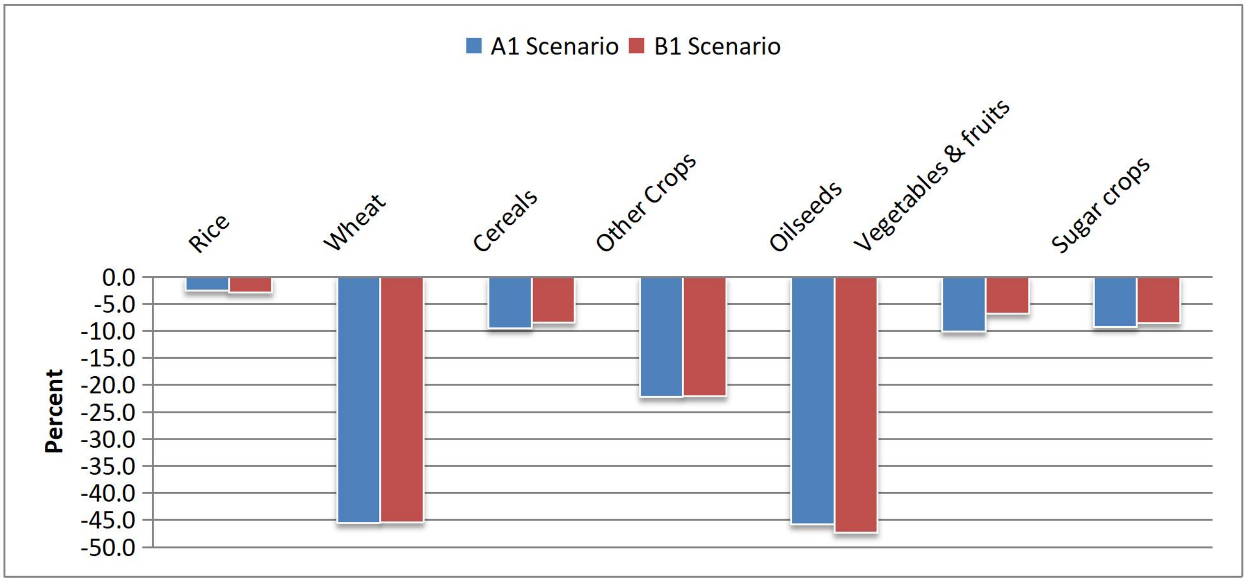
Climate change affects the availability and use of vital agricultural resources such as irrigation water, irrigation land, and rainfed land. The impact of climate change on these indispensable agricultural resources is reported in Table 3. Under the A1 scenario, rainfed land use declines in most agricultural sectors by 2.2 to 29.8 percent, while it increases by 3.6 percent in the rice sector and remains more or less stable in the other cereals sector. Crops most affected by climate change-induced decline in rainfed land are vegetables and fruits (29.8%), wheat 17.9%), and other crops (8.8%). In irrigated agriculture, climate change results in a dramatic fall in the use of irrigated land in all agricultural sectors (18.3 – 57.3%). Effects are quite prominent in the vegetables and fruits (57.3%), wheat (42.4%), sugar crops (40.3%), and other crops (35.6%) sectors. Similarly, climate change under the A1 scenario results in a significant decline in irrigation water use in all agricultural sectors, and the effects are dramatic in some sectors, including the vegetables and fruits (46.6%), wheat (40%), sugar crops (26.6%), and other crops (20.2%) sectors. Results for the B1 scenario reveal similar, but in most cases less prominent, effects of climate change on agricultural resource use compared to those for the A1 scenario (Table 3).

Table 3: Percentage change in land and water allocation across agricultural sectors in 2050 as a result of climate change compared to the baseline scenario

	Rainfed land		Irrigated land		Irrigation water	
	A1 Scenario	B1 Scenario	A1 Scenario	B1 Scenario	A1 Scenario	B1 Scenario
Rice	3.62	6.17	-26.5	-27.6	-9.6	1.6
Wheat	-17.9	-18.82	-42.4	-45.3	-40.0	-35.1
Other cereals	0.35	2.29	-23.4	-23.5	-4.6	-1.2
Other crops	-8.8	-6.01	-35.6	-36.8	-20.2	-19.8
Vegetables & fruits	-29.8	-30.76	-57.3	-60.1	-46.6	-51.9
Oilseeds	-2.23	-0.3	-18.3	-12.9	11.4	8.8
Sugar crops	-4.48	-1.17	-40.3	-41.4	-26.6	-17.7

Climate change impacts on land and water endowments are directly reflected in crop production. The decline in agricultural resource use due to climate change results in a substantial reduction in crop production (Figure 2). Results for the A1 scenario show a decline in the production of all crops. The climate change-induced decline in crop production is more pronounced for oil seeds (45.8%), wheat (45.5%), and other crops (22.2%). Similar results are observed for the B1 scenario in that production falls for all crops by 2.9 to 47.3 percent. Production losses are, however, more pronounced for oilseeds (47.3%), wheat (45.4%), and other crops (22.1%) (Figure 2). In general, climate change-induced losses in production under the B1 scenario are relatively less prominent compared to those under the A1 scenario. The decline in agricultural production under both scenarios is mainly attributable to the decline in irrigated land use, a fall in the productivity of irrigation water, and a decline in multifactor productivity[4] caused by climate change. The substantial loss in food production due to climate change inevitably results in reduced food availability and hence deterioration in the state of food security in the country.

Figure 2: Percentage change in agricultural production in 2050 due to climate change compared to the predicted baseline scenario



The market responds to changes in crop production through adjustments in the market prices of crops. Decline in crop supply due to reduced crop production caused by climate change necessarily results in increased market prices of crops. Accordingly, the results reveal a rise in market prices of all crops by 14.3 to 53.2 percent under the A1 scenario (Figure 3). The surge in price is dramatic for all crops, ranging between 32.9 to 53.2 percent except for vegetables and fruits that see a relatively lower increase in price (14.3%). More or less similar changes in crop prices are observed for the B1 scenario (Figure 3). Under this scenario, like that under the A1 scenario, the surge in price is quite substantial for all crops (29.7 – 53.7%) except for vegetables and fruits (2.4%). As a matter of course, the dramatic rise in crop prices adversely affects the 'access to food' dimension of food security and hence necessarily worsens the food insecurity situation in the country.

[4] Multifactor productivity refers to the productivity of all the inputs used in the production process. It measures output per unit of combined inputs and indicates the overall production efficiency of a sector or an economy (Apostolides, 2008).

Figure 3: Percentage change in market prices of agricultural production in 2050 as a result of climate change compared to the predicted baseline scenario

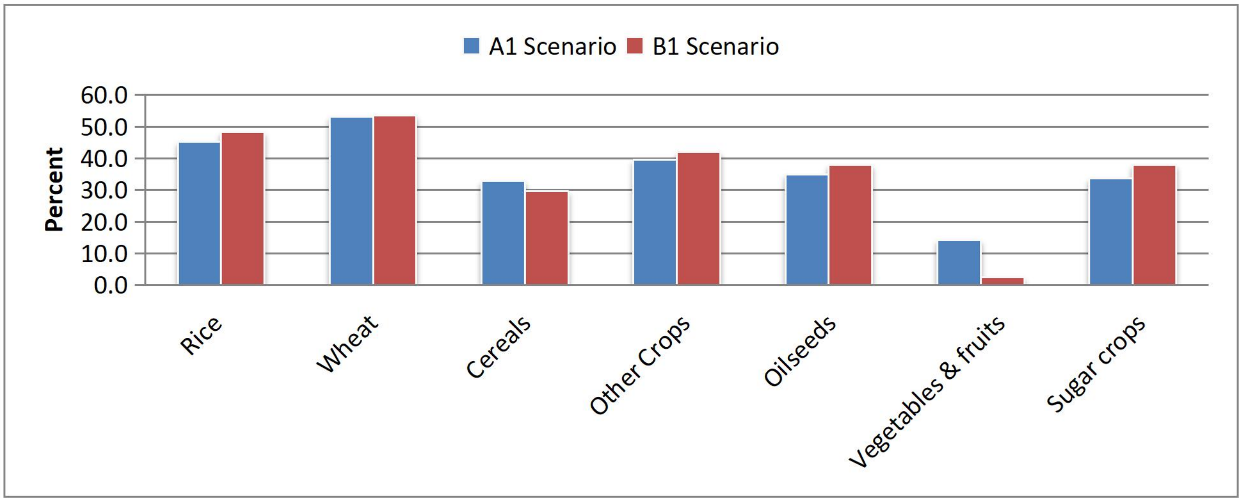


Table 4 depicts the macroeconomic impacts of climate change as measured by changes in real GDP, economic growth, and welfare effects. The results disclose that climate change inflicts a loss in real GDP amounting to 20 and 18 billion USD, respectively, under the A1 and B1 scenarios. This loss in real GDP is translated into a 7.4 percent and a 6.6 percent fall in economic growth, respectively. Climate change thus costs a significant proportion of the country's growth potential. Likewise, climate change results in significantly adverse welfare effects. As measured by the equivalent variation (EV)[5], the total welfare loss climate change causes in the country is in the order of USD 19 billion and USD 17 billion, respectively, for A1 and B1 scenarios (Table 4).

Table 4: Change in real GDP and welfare due to climate change relative to the predicted baseline scenario

Scenario	Economic Growth(%)	Real GDP (Billion USD)	Welfare(Billion USD)
A1 Scenario	-7.4	-20	-19
B1 Scenario	-6.6	-18	-17

[5] Equivalent variation measures here the amount of income that would have to be given to an economy before climate change so as to leave the economy as well off as it would be after climate change.

Moreover, climate change adversely affects the real return to primary factors, which measures return to factors relative to the price index of consumption expenditure. Climate change depresses, among other things, the real returns to unskilled and skilled labour and capital. The simulation results disclose a decline in the real returns to unskilled labour, skilled labour, and capital by 20, 14, and 15 percent, respectively, under the A1 scenario (Figure 4). Estimated at 16, 12, and 12 percent, respectively, results for the B1 scenario reveal significant but relatively lower effects on the real returns to unskilled labour, skilled labour, and capital. The results also reveal that climate change induces a 0.8 and 1.9 percent fall in household income under the A1 and B1 scenarios, respectively. The marked decline in the real return to labour and capital and the fall in household income in the face of a marked increase in crop prices inevitably aggravates the already dire food security situation in the country through its adverse effect on the 'access to food' dimension of food security. In particular, the substantially significant decline in the real return to unskilled labour (the lower-earning segment of the population), which is much higher than the decline in real GDP, indicates that climate change tends to aggravate poverty and hence food insecurity in the country.

Figure 4: Percent change in real return to primary factors

Sensitivity Analysis

In order to test the robustness of the model results on economic impacts and food security implications of climate change, sensitivity analysis is carried out. The sensitivity of the results on crop production and crop prices caused by climate change is tested for plus and minus 25 percent simultaneous change in the climate change-induced shocks to irrigation water, irrigation land, and rainfed land implemented in the model. The results show a substantial loss in production for all crops and hence an adverse effect on the food availability dimension of food security at the 95 percent confidence level (Figure 5), thereby indicating robust model results. The 95 percent confidence levels around the estimated model results are obtained following the procedure outlined in Burfisher (2011). Similarly, as Figure 6 depicts, the results reveal a 95 percent confidence that market prices of all crops increase dramatically over the range considered for the test. Test results for other variables (real GDP, welfare, and return to primary factors) reveal the same pattern. Thus, the sensitivity analysis results indicate robust model results testifying to the adverse economic impacts and serious food security implications of climate change in Ethiopia.

Figure 5: 95% confidence intervals around the change in crop production due to climate change

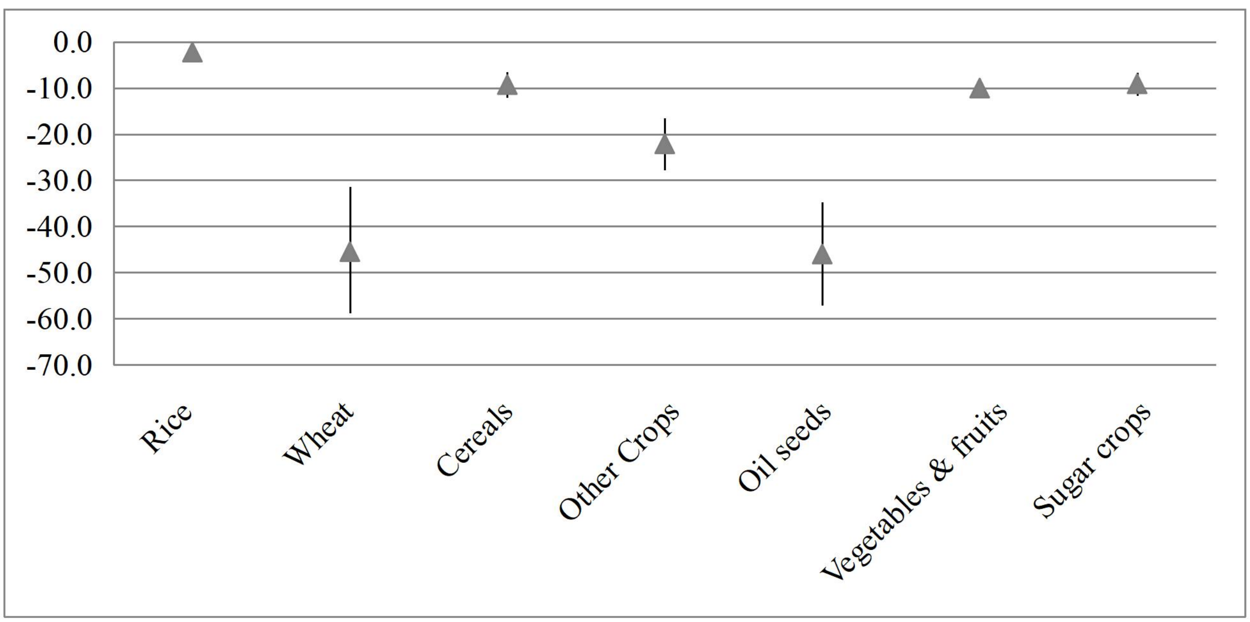
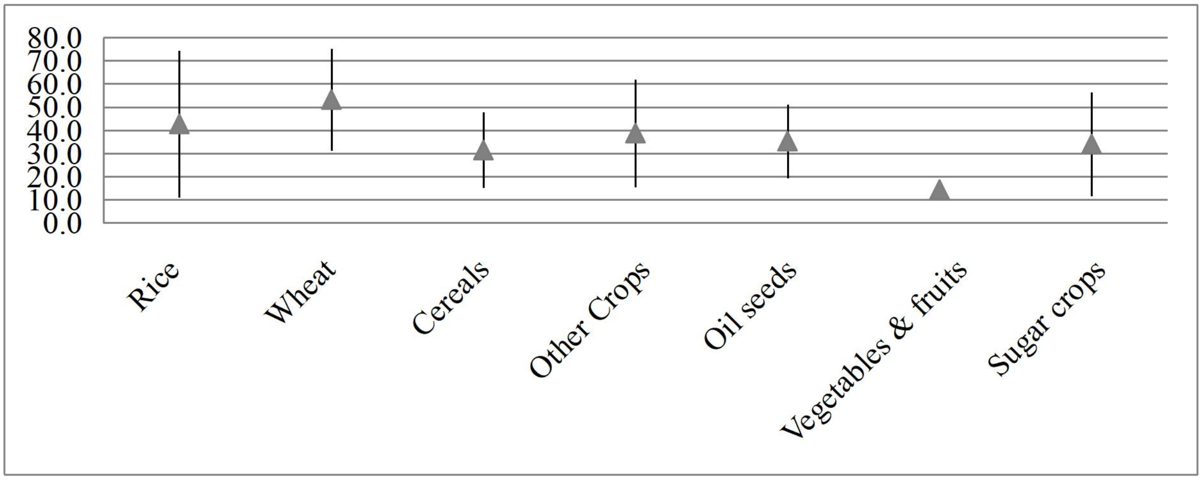


Figure 6: 95% confidence intervals around the change in crop prices due to climate change



Discussion and Conclusion

The study presented here evaluates the economic impacts of climate change and the resulting food security implications in Ethiopia. It constitutes one of the first efforts to use a global CGE model that distinguishes between rainfed and irrigated agriculture to analyze the impact of climate change on food security in Ethiopia. The impacts of two exogenous climate change scenarios (A1 and B1 scenarios) on agricultural endowments (i.e., rainfed land, irrigated land, and irrigation water resources) are assessed, and their economic repercussions and food security implications are evaluated. Economic impacts of climate change-induced changes in the use of agricultural resources are assessed in terms of effects on agricultural production, market prices of crops, real GDP, economic growth, welfare effect, real return to primary factors, and household income. Food security implications are evaluated based on the 'food availability' and 'access to food' dimensions of food security.

The findings of the study disclose significant adverse effects of climate change on Ethiopian agriculture and the overall economy. Agricultural production across all crops declines substantially due to climate change, resulting in escalating market prices of crops. Besides, climate change depresses real GDP, curtailing a substantial proportion of the country's growth potential and resulting in substantial welfare loss. Moreover, climate change causes a significant adverse effect on the real return to the primary factors, labour (skilled and unskilled), and capital, and reduces household income. The plunge in the real return to unskilled labour in particular, which is much higher than the decline in the rate of economic growth, indicates that climate change disproportionately affects the lower-earning group of the population and hence tends to aggravate poverty in the country. The consequences of climate change on food security are apparent. The substantial decline in crop production due to climate change reduces food availability, thereby aggravating the food security situation in the country. The surge in crop prices, coupled with the decline in real return to primary factors and household income, curtails access to food, thereby adversely affecting the state of food security in the country. Thus, climate change inflicts significant adverse effects on food security in Ethiopia through its impact on the 'food availability' and 'access to food' dimensions of food security.

In terms of impacts on the economy, the results reported in this study are more or less consistent with the findings of previous CGE studies on climate change that reveal climate change reduces crop production and results in a loss of GDP in the country. (Yalew et al., 2017; Solomon et al., 2021). The findings of this study are also consistent with previous findings on climate change impacts on a global scale that reveal food production, GDP, and welfare decline due to climate change (Calzadilla et al., 2011; Calzadilla et al., 2013a; Calzadilla et al., 2014). However, unlike the study presented here, previous studies do not explicitly address the link between climate change and food security.

In light of the serious implications of climate change on the already grave food security situation in the country, adaptation of the country's agriculture to climate change is imperative to improve food security. Adaptation to climate change contributes significantly to easing climate change impacts in Ethiopia (Baylie and Fogarassy, 2021) through its positive impact on crop productivity and hence farm net revenues (Di Falco, 2012). Relevant adaptation mechanisms to climate change in Ethiopia include expanding irrigation, use of different crop varieties, including drought-tolerant and early maturing crop varieties, as well as encouraging livestock ownership as a buffer for climate change-induced low yields or crop failure. However, lack of access to credit, land, and information constitutes a major barrier to adaptation to climate change in Ethiopia (Bryan et al., 2009). Therefore, government policy needs to be geared towards supporting farmers' adaptation to climate change through the provision of access to credit, land, and climate information.

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Appendix A: Regional Aggregation

Region	Description
Egypt	Egypt
Ethiopia	Ethiopia
Equatorial Lakes Region	Kenya; Rwanda; Tanzania; Uganda.
Rest of North Africa	Morocco; Tunisia; Rest of North Africa.
Rest of Sub-Saharan Africa	Benin; Burkina Faso; Cameroon; Cote d'Ivoire; Ghana; Guinea; Nigeria; Senegal; Togo; Rest of Western Africa; Central Africa; South Central Africa; Madagascar; Malawi; Mauritius; Mozambique; Zambia; Zimbabwe; Rest of Eastern Africa; Botswana; Namibia; South Africa; Rest of South African Customs.
Rest of the World	Australia; New Zealand; Rest of Oceania; China; Hong Kong; Japan; Korea; Mongolia; Taiwan; Rest of East Asia; Brunei Darussalam; Cambodia; Indonesia; Lao People's Democratic Republ; Malaysia; Philippines; Singapore; Thailand; Viet Nam; Rest of Southeast Asia; Bangladesh; India; Nepal; Pakistan; Sri Lanka; Rest of South Asia; Canada; United States of America; Mexico; Rest of North America; Argentina; Bolivia; Brazil; Chile; Colombia; Ecuador; Paraguay; Peru; Uruguay; Venezuela; Rest of South America; Costa Rica; Guatemala; Honduras; Nicaragua; Panama; El Salvador; Rest of Central America; Dominican Republic; Jamaica; Puerto Rico; Trinidad and Tobago; Caribbean; Austria; Belgium; Bulgaria; Croatia; Cyprus; Czech Republic; Denmark; Estonia; Finland; France; Germany; Greece; Hungary; Ireland; Italy; Latvia; Lithuania; Luxembourg; Malta; Netherlands; Poland; Portugal; Romania; Slovakia; Slovenia; Spain; Sweden; United Kingdom; Switzerland; Norway; Rest of EFTA; Albania; Belarus; Russian Federation; Ukraine; Rest of Eastern Europe; Rest of Europe; Kazakhstan; Kyrgyzstan; Tajikistan; Rest of Former Soviet Union; Armenia; Azerbaijan; Georgia; Bahrain; Iran Islamic Republic of; Israel; Jordan; Kuwait; Oman; Qatar; Saudi Arabia; Turkey; United Arab Emirates; Rest of Western Asia; Rest of the World.

Appendix B: Sectoral Aggregation

Sector	Detail Description
I. Agricultural Sectors	
Rice	Paddy rice
Wheat	wheat
cereals	Cereal grains not elsewhere classified (nec),
Other crops	Plant-based fibers; crops nec,
Oilseeds	Oil seeds
Vegetables and fruits	Vegetables, fruit, nuts
Sugar crops	Sugar cane, sugar beet
Livestock and meat products	Cattle, sheep, goats, horses; animal products nec; raw milk; wool, silk-worm, cocoons; meat: cattle, sheep, goats, horses; meat products nec;
II. Non-Agricultural Sectors	
Processed food	Vegetable oils and fats; Dairy products; Processed rice; Sugar; Food products nec; Beverages and tobacco products
Extraction	Forestry; Fishing; Minerals nec.
Coal	Coal mining
Crude	Crude oil
Gas distribution	Gas: Gas manufacture, distribution
Petroleum	Refined oil products
Electricity	Electricity
Manufacturing	Textiles; Wearing apparel; Leather products; Wood products; Paper products, publishing; Chemical products; Basic pharmaceutical products; Rubber and plastic products; Mineral products nec; Ferrous metals; Metals nec; Metal products; Computer, electronic and optic; Electrical equipment; Machinery and equipment nec; Motor vehicles and parts; Transport equipment nec; Manufactures nec; construction
Water distribution	Water
Services	Trade: Accommodation, Food and services; Transport nec; Water transport; Air transport; Warehousing and support activities; Communication; Financial services nec; Insurance; Real estate activities; Business services nec; Recreational and other services; Public Administration and defense; Education; Human health and social work; dwellings