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Modeling the Economywide Effects of Water and Energy Interventions in the Face of Climate Shocks in Ethiopia

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ABSTRACT

The Ethiopian economy relies predominantly on rainfed agriculture for income generation, export earnings, and rural livelihoods. However, the frequency and intensity of extreme ago-climatic events projected by climate scenarios suggest considerable and growing risks from climate change to the country's agri-food systems and the overall economy. This study assesses the economic impacts of recurrent climate shocks on the Ethiopian economy to 2040. The results indicate that recurrent climate shocks will lead to a reduction in Ethiopia's cumulative GDP from 2020 to 2040 compared to a "no climate change" baseline. Specifically, extreme weather events could cumulatively cost Ethiopia up to 17 percent (or US$ 534.3 billion) in GDP between 2020 and 2040 compared to a no-climate change baseline. The weight of the economic loss is concentrated in the agricultural production sector, with rural households and poorer households in urban areas being worst affected. Strategic investments in irrigation infrastructure and in hydroelectricity generation are found to be effective in mitigating some of the damage caused by recurrent climate variability.

Keywords: climate shock, water, energy, interventions, Ethiopia

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1 INTRODUCTION

Ethiopia faces significant climate change vulnerabilities in at least three areas that are crucial to the country’s long-term economic development. Firstly, agriculture is a major sector of the economy. It accounts for about 40 percent of national income and over 80 percent of export earnings and employs almost two-thirds of the workforce (World Bank, 2023; Eshetu and Mehare, 2020). The sector is already exposed to climate variability, and this could worsen under climate change. Secondly, hydropower remains a dominant energy source in Ethiopia's power system (Yalew, 2022), and its vulnerability to fluctuations in climate is evident from recurrent shortages (Carlsson et al., 2020; Mekonnen et al., 2022). Despite diversification plans into solar and geothermal sources, hydropower is expected to remain a major energy source in the coming decades, posing concerns about the impact of climate change on river flows and generation capacity. Lastly, heat stress could reduce labor and animal productivity whereas flooding would exacerbate the existing infrastructural deficit, particularly in rural areas where many farmers have limited access to markets.

Hydrological variability is one of the most significant climate variables in Ethiopia. For example, the year-to-year variability is stark, particularly in the South and South-Eastern regime, with annual rainfall varying between +36 percent and -25 percent of the mean (MoWIE, 2015; CGIAR, 2018). In fact, droughts have been the greatest and most recurring climate hazards in Ethiopia.

Likewise, statistics suggest an exponential increase in the frequency of natural hazards globally in the last several decades (UNDRR, 2020). Furthermore, low-probability high-impact events appear to be driving economic losses, as 72 percent of the global damage attributable to temperature and water-related anomalies since 1980 emanated from only 6 percent of ‘catastrophic’ events (Chatzopoulos et al., 2021). Gradually, climate change is being principally linked to changes in the occurrence, frequency, and intensity of extreme events (UNDRR, 2020). Increasing vulnerability of agriculture to extremes has been not only demonstrated regionally (Shukla et al., 2021; Schilling et al., 2020; Derbile et al., 2022) but also projected globally (Vogel et al., 2019; Chatzopoulos et al., 2021; Wing et al., 2021; van der Wiel and Bintanja, 2021).

The increasing need for scientific insights into the consequences of climate extremes is a recent development, as highlighted by Cogato et al. (2019) and Chatzopoulos et al. (2021), with a significant focus found in agricultural outlook reports (FAO, 2015; FAO, 2020). Besides other stressors on agri-food systems, such as population growth, environmental degradation, domestic conflicts, and global shocks like the COVID-19 pandemic and inter-country disputes affecting global supply chains, the risk of extreme events is expected to increase. In fact, considering the potentially grim global future if human actions on climate remain unchecked, some (FAO 2020; UNDRR, 2020) predict an increased risk of hunger, poverty, and the perpetuation of under-development. The stakes are particularly high in low-income developing countries due to their limited institutional and financial capacity to adapt to the effects of climate change.

In order to unravel the potential impacts of climate induced extreme weather events on the agri-food system, simulating recurrent events is essential (Amorim and Cai, 2015; Chatzopoulos et al., 2021; UNDRR, 2020). Despite substantial advancements in water-energy-economy nexus analysis, many studies overlook critical intersectoral linkages (Vinca et al., 2021). This paper contributes to this knowledge by utilizing a recursive-dynamic economywide model for Ethiopia under simulated recurrent climate shocks from 2020 to 2040. Specifically, we quantify the consequences of recurring drops in catchment flow water availability on key economic indicators like production, consumption, and household welfare at both regional and national scales. Our multi-sector economywide model is informed by data from catchment flow predictions for the country from several climate scenarios at agro-ecological scale, covering two major impact channels: reduced water availability for irrigation and rainfed agriculture, and water stress for energy production. Finally, this study explores benefits of two adaptation policy responses to mitigate some of the impacts of climate change on Ethiopia's economy: investment in irrigation and energy infrastructure. There is also a huge scope for enhancing irrigation water and energy use efficiency in the country. For instance, as per the country's Climate-Resilient Green Economy Strategy, efficient lighting and motors could increase energy use efficiency by up to 12 percent. By doing so, this article expands previous research on simulations of trend events (Kahsay et al., 2017; Komarek et al., 2019; Siddig et al., 2020; Hossain et al., 2023) such as studies on crop-yield effects, and single-case events (Mekonnen et al., 2022; Pauw et al., 2011) such as studies on one time drought effects by reflecting the recurrent nature of climate extremes.

The remainder of this article is organized as flows. Section 2 describes the climate change projections for Ethiopia and summarizes the nature of recurrent climate shocks in the country. Section 3 describes the economywide model and the design of the climate change simulations. Section 4 presents our results, and we conclude in Section 5 by discussing climate change's implications for economic development in Ethiopia and identifying areas for further research.

2 CLIMATE CHANGE IN ETHIOPIA

Ethiopia is primarily an agrarian economy, with over two-thirds of the population earning their livelihoods as smallholder farmers. These farmers typically rely on traditional technologies, practicing centuries old technologies, and so crop yields are low and rural poverty is high – constituting 90 percent of the poor nationwide (World Bank, 2020). With a steadily shifting share of urban population, most workers in the non-farm sector are employed in the agri-food light industries and informal sector. Coupled with a population growth of 2.4 percent (World Bank, 2023), and endowed with Africa's second biggest population, urban growth – at a rate of 4.8 percent (Yalew, 2022) – has placed considerable pressure on food security in the country.

Likewise, extreme climate variability poses a significant threat to Ethiopia's economy. Extended dry seasons have often led to production failures and food scarcities. Climatic projections also show that the country will be affected considerably by a rising temperature where mean annual temperature is predicted to increase by between 0.5 and 3.6^{o}C by 2070 (MoA, 2011) while other estimates (Setegn et al., 2011) push the level to 5^{o}C. Furthermore, changes in precipitation patterns are expected, with decreases in the northern regions where a significant portion of the population resides, while the sparsely populated southern areas could experience up to a 20 percent increase from the 1990s average (MoA, 2011). Soil moisture deficits are likely to worsen due to increased evapotranspiration in regions where rainfall is projected to decrease. Simultaneously, higher temperatures could reduce soil moisture levels in parts of the country, where average rainfall might increase. For instance, Setegn et al. (2011) predicted a 2 percent decline in soil moisture in the Ethiopian highlands due to rising air temperatures associated with climate change.

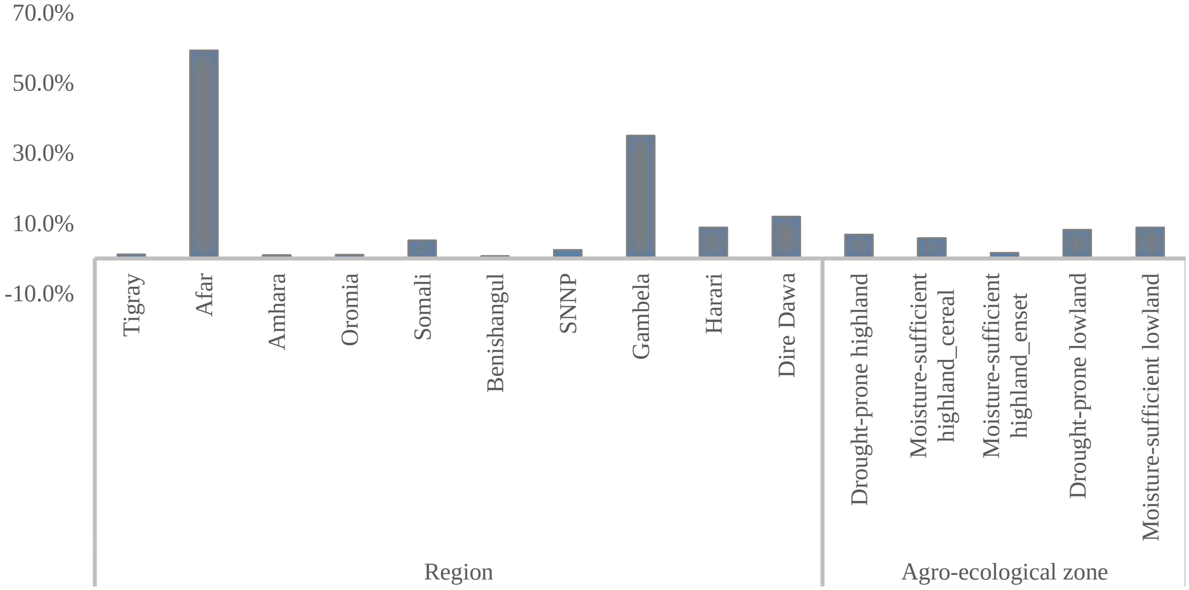
On top of the long-term changes in temperature and precipitation, climate change is also associated with increased intensity and frequency of extreme weather conditions. Droughts have been the greatest and most recurring climate hazards in Ethiopia, where the likelihood of these hazards is predicted to increase over the future as the climate changes. The country experienced over 10 major droughts over the last four decades and in the last decade major droughts have occurred in 2001, 2003, 2005/06, 2008/09, 2011 and 2015/2016 (USAID, 2018; UNDRR, 2020). Some were the strongest in terms of the number of people affected. The other face of extreme weather conditions in Ethiopia is flooding in the lower basins. The country has faced significant flooding events over the last four decades, specifically in the years 1988, 1993, 1994, 1995, 1996, and 2006 (MoA, 2011). These floods resulted in loss of life, resources, and property in different parts of the country.

The Ethiopian economy, especially its agricultural sector, faces significant exposure to the impacts of climate change and associated extreme weather conditions. This vulnerability arises from the country's geographic location, agricultural production methods, and limited adaptive capacity due to financial and technical constraints. Extreme weather conditions, such as drought and flooding, can cause environmental degradation and reduce land availability; the increasing seasonality of rainfall might also lead to reductions in water availability (Mekonnen et al., 2022; Setegn et al., 2011; Robinson et al., 2013); and the intensity and frequency of droughts might become costly, especially in terms of loss of livestock capital (Bogale and Erena, 2022; Aragie and Thurlow, 2022). Studies (Carlsson et al., 2020; Robinson et al., 2013) also predict that climate change can diminish factor productivity by impacting land and water quality.

One of the well-documented drought phenomena in Ethiopia is that of the 2003 (Admassu et al., 2007), where the total annual crop production during the year decreased by 21 percent compared with the average of the five previous years. The impact of the drought was particularly devastating for maize and sorghum: The reduction in maize and sorghum production in drought affected lowland areas reached between 70 percent and 100 percent, respectively, of the normal period levels of production. The country’s main agricultural export, coffee, was also hit hard with coffee harvests in coffee producing areas in western, southwestern, and eastern parts of the country declining by up to 30 percent due to the drought. In terms of the total number of people at risk, the 2003 drought affected over 12 million people (about 16 percent of the total population at that time) (USAID, 2018).

Irrigation infrastructure plays a crucial role in mitigating climate change impacts, mainly by stabilizing and enhancing water availability. Currently, only about 5 percent of the total cropland, approximately 1.1 million hectares (Chandrasekharan et al., 2021), is under irrigation in Ethiopia, falling significantly short of the over 3,798,700 hectares of potentially irrigable land (Awulachew et al., 2007). There is also substantial regional variation in access to irrigation (see Figure 1), with the highest share of irrigated (small scale) farmland found in the lowlands of Afar and Gambela, and the lowest in the highlands of Tigray, Amhara, and Oromia. These shares are closely consistent with those regional shares reported in Chandrasekharan et al. (2021).

Figure 1. The share of irrigated farmland across Ethiopia



Source: Author's compilation from CSA (2017).

Hydroelectricity is the largest renewable energy source in Ethiopia, accounting for around 95 percent of total renewable energy. However, hydroelectricity production varies with water resources availability and thus climate change. MoWIE (2015) estimates suggest that moderately extreme climatic events could significantly impact the country's electricity generation, possibly leading to a reduction in supply of about 15 percent of the total current demand by 2030 and amounting to an opportunity cost of $1bn in that year. In a bid to reduce heavy dependence on hydroelectricity, Ethiopia is emphasizing diversification of its energy mix, including solar, wind, and other off-grid energy sources (Mondal et al. 2017).

3 METHOD OF ANALYSIS

3.1 The economywide model

Extreme climate variability affects the local economy, primarily by disrupting the reliable availability of water and energy resources. These disruptions have profound effects on the production and productivity of the agricultural sector, ultimately influencing the entire economy. To comprehensively understand the economywide effects of recurrent climate shocks, we employ a multi-sector recursive dynamics Computable General Equilibrium (CGE) model for Ethiopia. This CGE model is based on a Social Accounting Matrix (SAM) and features a combination of nonlinear and linear relationships governing the behavior of the model's agents. Details on the structure and equations of the original model used in this study are found in Diao and Thurlow (2012). This model assumes a two-stage production process with activities following either Constant Elasticity of Substitution (CES) or Leontief technologies. In the first stage, intermediate input and value added generate the output of each activity based on CES technology. In the second stage, the use of intermediate inputs occurs in fixed proportions using Leontief technology, while the CES technology determines the formation of value added through primary production factors, with the optimal factor ratio determined by relative prices.

In this economic model, households maximize utility subject to Stone-Geary utility functions over disposable incomes. On the other hand, enterprises, government, and investment demand commodities in fixed proportions. The distribution of factor incomes is based on households' factor endowments. Households save and pay taxes and the balance is used for consumption spending. The latter is determined through a linear expenditure demand system, which allows for non-unitary income elasticities. The base version also includes multiple tax instruments and allows for a wide range of factor market clearing conditions and macroeconomic closures.

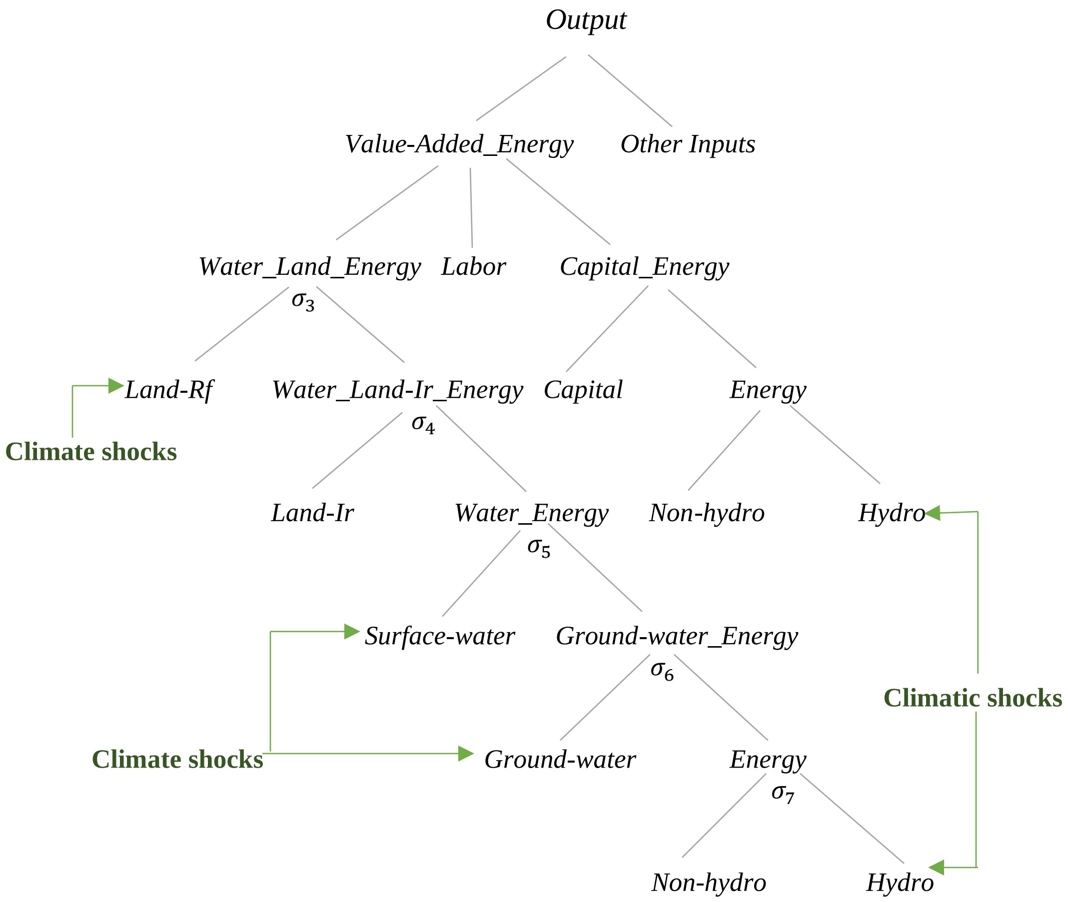
To better represent the climate-energy-food nexus, the original model production function was modified into a seven-stage nesting structure as in Figure 2. First, various water and energy types are identified and added into the value-added nesting, thereby capturing the close substitutability or complementarity these inputs have with land factor. Specifically, three types of water are considered, disaggregated by use. Two of these are water use for agriculture, separated into surface water and groundwater (Diao et al., 2008; Luckmann et al., 2014). Another water type constitutes water use for industrial and municipality purposes. Second, we assume that energy use in irrigation is differentiated from energy use for other uses to be able to create a neater nesting structure. Depending on data availability, the model can accommodate further water and energy types.

This detailed nested structure controls substitution between inputs, including water and energy. Users can specify the substitution possibilities at each level of the production nest by defining the substitution elasticities (σi) where *i* is the level of the nest at which the elasticity operates. Typically, ground-water and energy are considered close complementary inputs, given the energy needed to extract water. Similarly, irrigated land and water are viewed as less substitutable inputs since they are utilized jointly in the production process.

In the modified production structure, a single regionalized activity is responsible for producing a corresponding water resource. By utilizing additional production factors (capital, labor) and intermediate inputs (e.g., energy and consumables), the activity converts the resource into a water commodity. The produced water is then utilized as an input in various activities, whether in the agriculture or non-agriculture sectors. This approach is akin to the methodology utilized in studies like Luckmann et al. (2014) and Haqiqi et al. (2016). The production of ground water differs from surface water production due to the intensive use of energy for pumping in the former. We adopted a similar functional approach for the energy sector.

In activities that involve water consumption, different types of water commodities are utilized based on the specific input requirements outlined in the database. Irrigated agricultural activities utilize both agricultural land and one or more types of water commodities. It is useful to segment these activities and commodities to distinguish between those that can use a particular type of water and those that do not. Typically, non-agricultural activities do not involve the use of agricultural land but do utilize a municipal water type– in which case the land-water aggregate collapses to water-aggregate.

Figure 1. Production structure for modeling the food-energy-climate nexus



Source: Authors compilation

3.2 The database

The starting database for our application is a SAM for Ethiopia that represents economic transactions in 2018 (Aragie and Thurlow, 2021). It provides data on 80 commodities and activities, 13 production factor accounts, and three tax categories. The SAM furthermore includes 15 household types, first grouped according to rural-urban, and second according to income (five quintiles), which allows for the analysis of distributional effects. Rural households are further classified into farm and non-farm based on their principal income source.

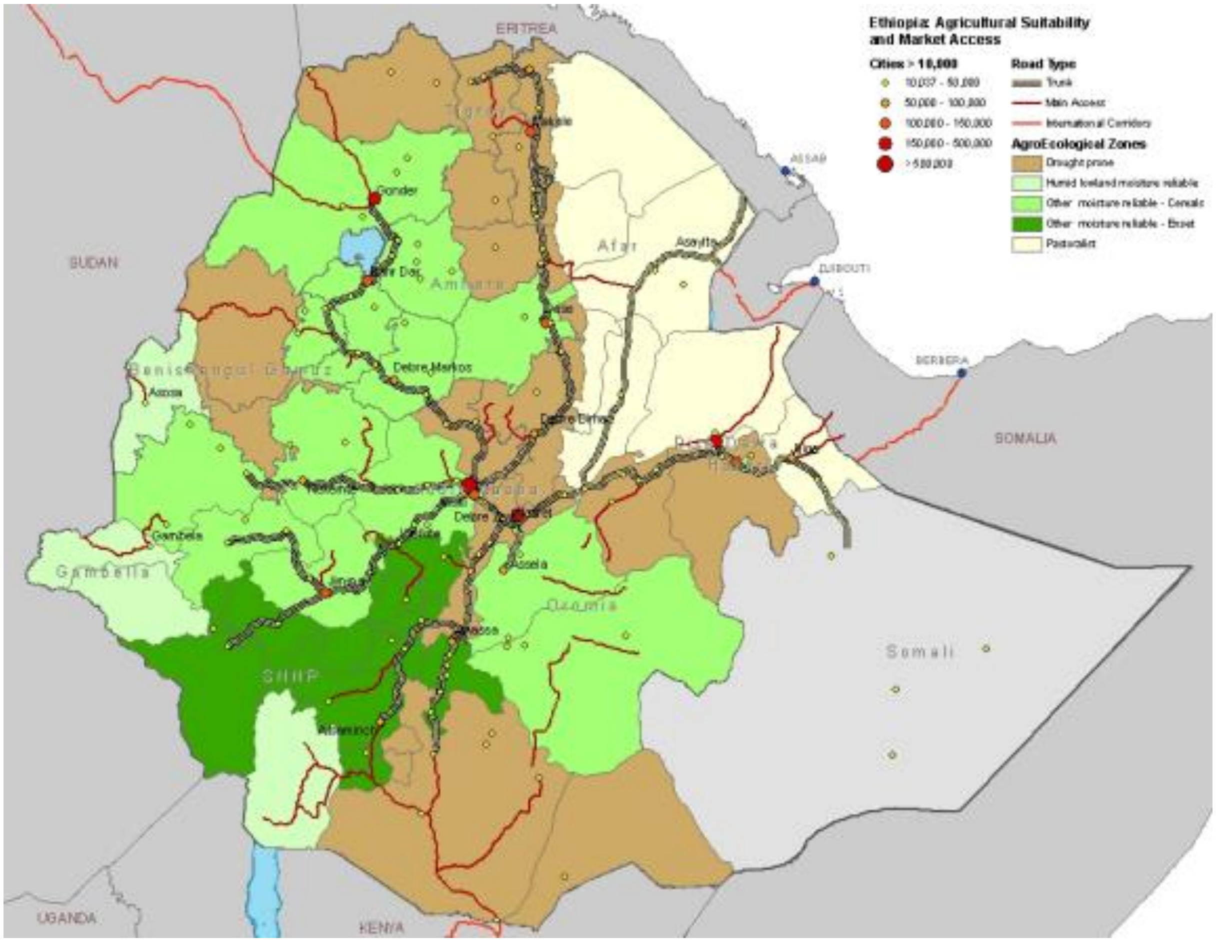
The SAM was modified to well represent the regional features of agriculture in the country. We do so by using data from the 2016/17 Annual Agricultural Sample Survey (AASS) which reports zonal level data on crop and livestock production (CSA, 2017). We use the zone to agro-ecology mapping from Tebekew et al. (2009). As such, the newly modified SAM distinguishes 31 agricultural activities further disaggregated by agro-ecology and 18 agro-processing sectors, constituting detailed agri-food sectors.

Using the AASS survey, which reports the size of irrigated land in ha for each crop and zone, in conjunction with the mapping of irrigated and rainfed agriculture in Ethiopia by Chandrasekharan et al. (2021) utilizing remote sensing methods, we segmented land into rainfed and irrigated categories. This classification is further disaggregated by agro-ecology to (i) reflect the spatial variation in the supply and use of strategic inputs, and (ii) be able to link spatially specific recurrent climate shocks to these factors. The value attributed to irrigated land in the new SAM is about 7 percent of the total land value, aligning closely with the Sub-Saharan Africa (SSA) average of 8 percent (Haqiqi et al., 2016). After introducing additional production factors, activities, and commodities, the adjusted SAM was subjected to a balancing procedure. Annex Table A1 lists selected SAM accounts.

The value of water in the economy remains poorly quantified (D'Odorico et al., 2020). The water sector, accounting for about 1 percent of total GDP, is represented by a single sector in the original SAM. To disaggregate this account, we used additional data from CSA (2017) and Chandrasekharan et al. (2021) on irrigation outreach in Ethiopia and from D'Odorico et al. (2020) and Mekonnen and Hoekstra (2011) on various aspects of water use. The calculation of the value of irrigation water use by sector and agro-ecology involves a two-step process. First, the cost of a cubic meter of water per ton of production ($\$/m^3/ton$) is determined by multiplying the respective sector's water footprint (m^3/ton) and the global estimate on crop-specific irrigation water values in $\$/m^3$ (D'Odorico et al., 2020). Then, this cost is multiplied by total production in tons to obtain the value of irrigation water use for each sector and agro-ecology. The water footprint is also agro-ecology specific and is derived from Mekonnen and Hoekstra (2011) using each administrative region's weight in each agro-ecology. The global estimate on crop-specific irrigation water values ($\$/m^3$) is from D'Odorico et al. (2020).

Thus, the water sector in the SAM is split into various products separated by use: agricultural use, and industrial and municipal use (by households). Water use in agriculture is also further separated into the five agro-ecological zones (see Figure 3) – including drought-prone highlands, moisture-sufficient highland-cereal based, moisture-sufficient highland-*enset* based, and drought-prone lowlands – depending on their shares in total irrigated land. There is a general absence of data on the magnitude and spatial distribution of ground water use in agriculture. However, we recognize the underdeveloped nature of ground water use in Ethiopia, and hence assume that the contribution of ground water in total water use in agriculture is only 8%. We also separate energy – contributing to 0.4 percent of GDP – into two major sources: hydro and non-hydro, both of which are further identified by final use in agriculture and the non-agricultural sector. With electricity consumption currently going principally to residential (46 percent), services (27 percent) and industry (26 percent) (Yalew, 2022), the share of agriculture is negligible.

Figure 2. Agro-ecological zones in Ethiopia



Source: Tebekew et al. (2009).

3.3 Scenario design

Regional predictions show noticeable effects of climate change and weather variability on the agricultural and non-agricultural sectors. These effects are propagated through changes in water and energy supply, crop water requirement, and changes in efficiency of production factors. In this study, we focus on the former channels, linking predicted annual catchment flow data obtained from 15 climate scenarios – constituting five climate models and three Shared Socioeconomic Pathways (SSPs) – to changes in water and energy production. Since climate variability is more disastrous than the change in long-term mean (Chatzopoulos et al., 2021; Siddig et al., 2020), we calculate the change in catchment flow from the recent trend level for each climate scenario and focused on years in which the predicted water flow is below the trend, i.e., we focused on the negative shocks.

To assess the impact of climate shock on the economy, we establish a baseline scenario where there is no climate change, serving as a reference (Baseline). Additionally, we simulate intervention scenarios focusing on (i) investment in irrigation, affecting irrigation sector productivity, and hence effective access to irrigation, and (ii) investment in power generation, affecting energy sector productivity, and hence energy output. We also examine a scenario depicting combined interventions in irrigation and electricity infrastructure.

Baseline scenario: This is a no climate change or business-as-usual scenario where the current average trend is assumed to continue without any influence from climate change throughout the simulation period (2018-2040). This scenario reflects development trends in the absence of climate change, serving as a relevant comparison basis for evaluating the climate change scenarios.

In the baseline, underlying rates of labor force growth and arable land growth, sectoral productivity growth, world prices, remittances, and foreign and capital inflows are imposed exogenously. In line with the recent slowdown in GDP growth, current short-term projection, and the extended simulation period, we assume a period long (2018-2040) average growth of just under 5 percent. The labor force growth is close to the population growth of 2.4 percent per year (World Bank, 2023), per capita income growing by over 2 percent, which entails a two-third increase in baseline per capita income over this period. Total factor productivity (TFP) trends for individual sectors in agriculture, industry and services are set in conformity with GDP projections for aggregated agriculture, industry, and services sectors. We assume fixed world prices for the country's exports and imports since the country is small enough to alter world prices.

In the equilibrium, we maintain a balanced closure between investment and savings for our long-run simulations. Real investment remains fixed at its initial absolute share of absorption, and private savings rates adjust accordingly to generate the required savings. This approach ensures a stable balance between investment and savings in the economic model. Meanwhile, product market equilibrium requires that the total supply of each good equals total private and public consumption, investment demand and total intermediate use. The dynamic interplay between supply and demand necessitates adjustments in market prices for various commodities, ensuring the preservation of this equilibrium. These fundamental assumptions remain consistent across all subsequent scenarios studied, providing a stable framework for analyzing the evolving economic dynamics.

Recurrent climate shock scenarios: In order to assess the impact of the climate scenarios on the Ethiopian economy, a two-step approach was followed in this study. The first step is obtaining the watershed hydrology and retrieving catchment runoff responses to changes in climate variables. This allows us to get an estimate of surface water runoff and thus water availability for the individual catchment units – agroecological zones in our case – identified. The second step uses the runoff estimate from the hydrologic model to calculate annual deviations in the runoff by catchment unit.

We obtain catchment runoff response to changes in climate variables from watershed hydrology models that use climate scenarios as input. We specifically use NedborAfstromnings Model (NAM) hydrologic model (DHI, 2011). The catchment flow data relates to a randomly selected list of Representative Concentration Pathways (RCPs) that are diverse enough to represent various climate predictions for Ethiopia. Likewise, we randomly selected climate scenarios relating to three of the five SSPs: (i) SSP1 - Sustainability (Low challenges to mitigation and adaptation), (ii) SSP3 - Regional Rivalry (High challenges to mitigation and adaptation), and (iii) SSP5 - Fossil-fueled Development (High challenges to mitigation, low challenges to adaptation). These three SSP scenarios relate to moderate and less and severe extreme shared socioeconomic trajectories.

A total of 15 climate scenarios, chosen at random, were employed to construct corresponding local climate shock scenarios. However, for clarity, we present and analyze six scenarios that encompass both the mildest and most severe outcomes on the economy. For a comprehensive list of all climate scenarios explored, please refer to Annex Table A2. The identification of climate shock or drought scenarios involved computing a percentage reduction in the predicted catchment flow from 2020 to 2040 compared with the recent historical trend (2001-2020).

However, we do not capture agricultural and infrastructure damage during floods due to excess catchment flows as these are generally small although they should not be neglected. Notably, this analysis was conducted independently for the five agro-ecological zones found in the country (as outlined in Table 1): D_P_H (drought-prone highlands), M_S_Hc (moisture-sufficient highland-cereal based), M_S_He (moisture-sufficient highland-enset based), D_P_L (drought-prone lowlands), and M_S_L (moisture-sufficient lowland).

This analysis yields a temporal heatmap displaying recurring declines in water flow across agro-ecological zones of Ethiopia (see Annex Figure 1 for the predicted drops in catchment flow across climate models for the five agro-ecological zones). The heatmap reveals heightened recurrent deviations in water flow during the early and mid-2030s, reflecting the impact of climate change-induced adverse weather events. These events are projected to have a direct detrimental influence on agriculture and the wider economy, particularly through the following two pathways considered in this study: (i) shifts in the productivity of the water and electricity sectors, leading to changes in water and energy outputs, and (ii) changes in the productivity of rainfed land. The arrows in Figure 2 identify these pathways.

In line with Hasan and Wyseure (2018), Mohammed et al. (2022) and Di Falco and Chavas (2008) we assume a direct correlation between reduced water availability and its impact on the productivity of both the water and energy sectors, as well as agricultural land.[1] For instance, Hasan and Wyseure (2018) found that in Ecuador, a 17 percent reduction in streamflow would result in up to a 13 percent decrease in hydropower generation. Moreover, Mohammed et al. (2022) observed a strong correlation (>90 percent) between a combined temperature and precipitation index and crop yield across Hungary. Regarding land productivity, Torres et al. (2019) found, in the case of Brazil, that a 30 percent reduction in rainfall would lead to a 10.2 percent drop in farmers' net-revenue. Given that land constitutes a 33.5 percent share of total farm income in Ethiopia (Aragie and Thurlow, 2021), this signifies a proportional decline in rainfed land productivity. In a different context, Di Falco and Chavas (2008) predicted a 13 percent reduction in agroecosystem productivity for a simulated 10 percent permanent reduction in rainfall.

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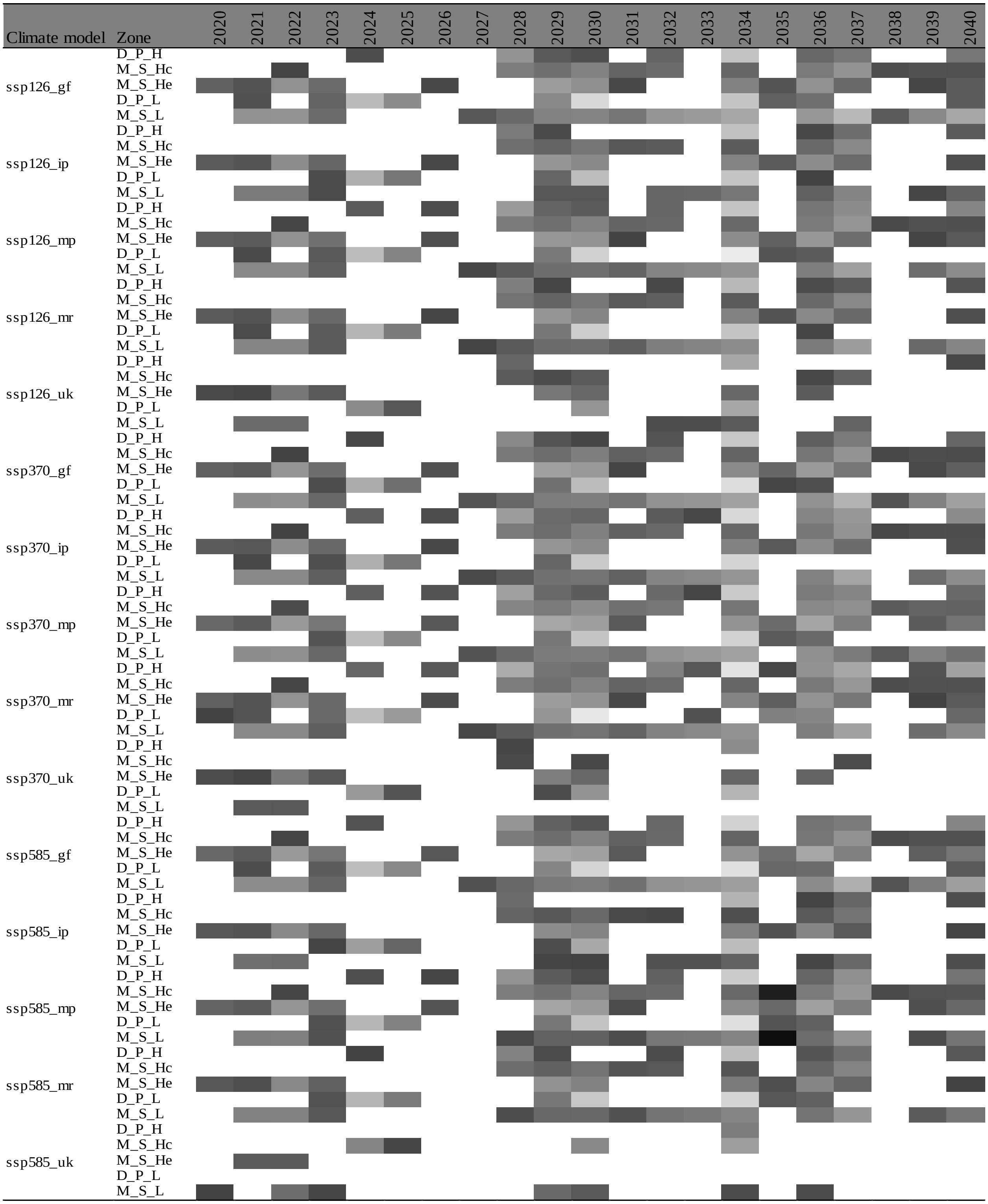
[1] In the simulations, the climate induced shock to the water and energy sectors is imposed as multi factor productivity shock at the stage where *Water_Land_Energy*, *Labor,* and *Capital_Energy* inputs are combined, i.e., at the second stage of the production nest. The shock to rainfed agriculture is imposed by altering the productivity of rainfed land, i.e., *Land-Rf* factor in Figure 2.

Table 1. Heatmap of the recurrent drop in water flow



Source: Authors compilation from predicted catchment flow data for Ethiopia.

Notes: D_P_H = drought prone highlands, M_S_Hc = moisture sufficient highland-cereal based, M_S_He = moisture sufficient highland-enset based, D_P_L = drought prone lowlands, and M_S_L = moisture sufficient lowlands. Darker colors reflect greater reductions in predicted catchment flow. See Annex Table A2 for full name of the climate scenarios.

Within the modeling framework, we include separate water sectors producing water for agricultural and municipal-industrial purposes to reflect differences in water quality between uses. Additionally, we identified region-specific sectors that generate irrigation water, reflecting variations in irrigation availability across different parts of the country and the current inability to transfer water between agro-ecological zones. This setup is instrumental in accurately capturing the region-specific effects of climate shocks. Meanwhile, we assume that climate induced change in energy supply affects all regions equally since much of electricity in Ethiopia, except few decentralized rural energy systems, is distributed to homes, businesses, and other consumers from a central hub.

Intervention scenarios: In addition to assessing scenarios illustrating climate variability, characterized by recurring deficits in water availability (catchment flow), this study investigates interventions aimed at enhancing Ethiopia's economic resilience to climate challenges and to mitigate associated economic repercussions. These interventions encompass investments in irrigation (Block et al. 2008; Arndt et al., 2014; Siddig et al., 2020; Vogel et al., 2019), bolstering electricity infrastructure (Arndt et al., 2014; Kahsay et al., 2017), and improving water and energy use efficiency (Mondal et al., 2018; Yalew, 2022). Others (e.g., Arndt et al., 2014 and Silchenko and Murray, 2023) also highlighted the importance of insurance and social protection, research and innovation, and early warning systems.

Given Ethiopia's substantial irrigation potential of more than 3,798,700 hectares (Awulachew et al., 2007), a significant untapped opportunity exists. To unlock this potential, the nation has set forth plans to elevate its medium and large-scale irrigation networks from the current 600,000 hectares to 1.2 million hectares during the ten years development plan period of 2021-2030 (PDC, 2021). This ambitious goal equates to expanding irrigated land one-fold, increasing annually by 11 percent on average. We assume that this is a little ambitious and the country can only expand its water sector capital by 7.5 percent annually until 2040, a rate just over the recent GDP growth.[2] We assume the same level of investment irrespective of the future climate scenarios examined. This intervention centers around expediting the rate at which infrastructure development occurs.

Similarly, Ethiopia's existing hydroelectric power generation capacity stands at 4,300 MW, significantly trailing behind its hydroelectric power generation potential, estimated to be approximately 45,000 MW (Awulachew et al., 2007; Mekonnen et al., 2022; Yalew, 2022). As part of its strategic vision, the country aims to augment its power generation capability to reach 13,500 MW by the year 2040, positioning itself as one of Africa's leading power producers (IEA, 2019; MoWIE, 2015). In

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[2] This is done by increasing capital factor in the irrigation sector by 7.5 percent annually. The energy sector intervention is also modeled as targeted increase in capital input in the sector.

particular, it aims at diversifying its renewable energy mix to 20 percent wind and solar, 10 percent geothermal and 70 percent hydropower, from the current hydropower share of 95 percent (Yalew, 2022). This trajectory aligns with the anticipated annual growth in electricity demand of 9-14 percent (Mondal et al., 2018; Yalew, 2022). A notable growth in electricity demand is also expected in the agricultural sector (EEP, 2014), mainly for pumping water for irrigation. In our simulations, for impact comparability reasons, we assume a similar level of investment in the hydro and agriculture focused non-hydro energy sources annually as in the irrigation sector. Again, we assume the same level of energy investments across climate scenarios examined, regardless of the predicted severity.

4 RESULTS AND DISCUSSION

4.1 Macroeconomic level effects

This section presents effects of recurrent climate shocks on selected macroeconomic indicators. While a total of 15 scenarios corresponding to 15 climate prediction scenarios were run, the results presented in this section focus on scenarios representing less extreme and more extreme outcomes: ssp126_mp, ssp126_uk, ssp370_mp, ssp370_uk, ssp585_mp, and ssp585_uk. For a comprehensive view of GDP effects across all climate scenarios considered, refer to annex Table A3. Notably, the _uk scenarios demonstrate less extreme macroeconomic outcomes, whereas the _mp models depict more extreme outcomes among the reported scenarios.

In the absence of climate change (i.e., under the no climate variability scenario), Ethiopia's cumulative GDP at market price and at factor cost would reach US$3,044.4 and US$2,922.8 billion for the period between 2020-2040 (Table 2). Meanwhile, model results indicate that predicted changes in precipitation and temperature, translated into the economic model as changes in the performance of water and energy sectors and the productivity of rainfed agriculture (land) makes the Ethiopian GDP at market price worse off, with declines ranging from 2.9 percent (or US$88.4 billion cumulative GDP) to 17.6 percent (or US$534.4 billion cumulatively) for the 2020-2040 period. This confirms findings from previous studies (Robinson et al., 2013; CGIAR, 2018) that estimate that climate change could shrink Ethiopia's economy by more than 10 percent by the mid-century compared to a no-climate change baseline. Our GDP effect estimates – implying a 1.5 percent annual loss on average – are closely in line with the 1.7 percent loss predicted by Pauw et al. (2011) on Malawi. The effect on GDP at factor cost mirrors the effect on GDP at market price. The impacts are more pronounced for the three _mp scenarios. Table 2 also shows a substantial adverse effect on exports across all scenarios compared to the effect on imports. This is due to the direct and significant impact of the analyzed shocks on the agricultural sector, which contributes substantially—over 80 percent—to the country's export revenues. The worst scenario, i.e., ssp370_mp, implies a 7-percentage point average reduction in export growth over the simulated period.

Table 2. Change in macroeconomic indicators (2020-2040), in billion 2018 USD

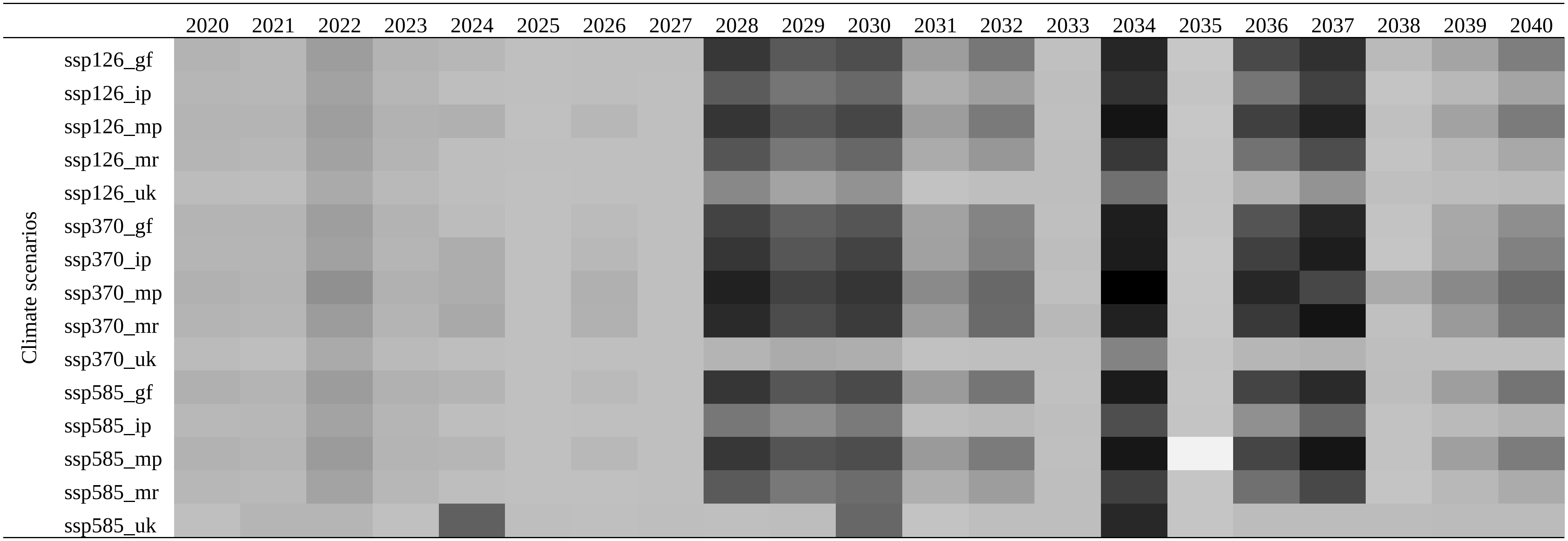
	Baseline cumulative value (2020-2040)	ssp126_mp	ssp126_uk	ssp370_mp	ssp370_uk	ssp585_mp	ssp585_uk
		Change in cumulative value from baseline scenario, 2020-2040					
A) Recurrent climate shock							
GDP at market price	3,044.4	-15.1%	-5.0%	-17.6%	-2.9%	-14.6%	-6.8%
GDP at factor cost	2,922.8	-14.9%	-5.0%	-17.2%	-2.8%	-14.3%	-6.7%
Export	288.7	-26.7%	-9.7%	-30.3%	-5.7%	-25.9%	-13.1%
Import	646.6	-11.9%	-4.3%	-13.5%	-2.5%	-11.6%	-5.8%
		Percentage point change from climate shock scenario, 2020-2040					
B) Irrigation investment under climate shock							
GDP at market price	3,044.4	0.4%	0.4%	0.4%	0.5%	0.4%	0.4%
GDP at factor cost	2,922.8	0.6%	0.7%	0.6%	0.7%	0.6%	0.7%
Export	288.7	0.4%	0.3%	0.3%	0.3%	0.5%	-0.4%
Import	646.6	1.0%	1.2%	0.9%	1.3%	1.0%	1.2%
C) Electricity investment under climate shock							
GDP at market price	3,044.4	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
GDP at factor cost	2,922.8	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
Export	288.7	0.5%	0.6%	0.5%	0.6%	0.5%	0.5%
Import	646.6	0.2%	0.2%	0.2%	0.3%	0.2%	0.2%
D) Irrigation and electricity improvement under climate shock							
GDP at market price	3,044.4	0.6%	0.7%	0.6%	0.7%	0.6%	0.6%
GDP at factor cost	2,922.8	0.9%	0.9%	0.9%	1.0%	0.9%	0.9%
Export	288.7	1.5%	1.8%	1.3%	1.9%	1.5%	1.7%
Import	646.6	0.6%	0.8%	0.6%	0.8%	0.7%	0.8%

Note: Scenarios reported are with less extreme and more extreme outcomes

However, when factoring in interventions in the irrigation and energy sectors in response to climate variability, the accumulated GDP at factor cost experiences an increase of approximately 0.9 percent, equivalent to around US$26.6 billion, in comparison to the GDP under the corresponding climate shock scenario (see Panel D in Table 2). This is equivalent to a 5-34 percent reduction in the cumulative loss in GDP over the period considered depending on the severity of the climate change impacts across the scenarios, with the _mp scenarios demonstrating the least percentage reduction in losses. Most of this reduction in GDP loss is registered when investments in irrigation are considered. This stronger adaptation effect of irrigation investment compared with other interventions aligns with findings from Kahsay et al. (2017), Arndt et al. (2014) and Siddig et al. (2020). Not only does GDP recover when water and energy sector interventions are implemented, exports and imports also improve associated with the gain in GDP.

Table 3 presents a heatmap illustrating the specific years with lower, moderate, or higher effects of recurrent climate shocks on real GDP in Ethiopia across the considered climate scenarios. These effects spread between light grey – demonstrating lower effects of climate shocks on climate – to dark grey – demonstrating a greater effect on GDP. The table shows that the late 2020s and mid- to late 2030s will witness severe economic impacts on the country. Once again, the heatmap of annual effects highlights that the _mp scenarios depict are more extreme impacts. The severity of these losses is attributed to the predicted year-on-year shortfall in water runoff and precipitation compared to the current trend recorded for each region and climate scenario.

Table 3. Heatmap of annual effect of recurrent climate shocks on real GDP (2020-2040)



4.2 Sectoral and regional level effects

Panel A of Table 4 reports the percentage change in the cumulative value of regional GDP relative to the business-as-usual (i.e., no recurrent climate shock) scenario between 2020 and 2040, focusing on the agricultural sector. The climate scenarios that exhibit the most significant impact on national GDP also result in substantial cost for the agricultural sector, both regionally and at the national level. Arguably, the weight of the economic loss is concentrated in agriculture, constituting about 50 percent of the cumulative loss under the most extreme scenario and 45 percent of the loss under the least extreme scenario despite the sector contributing around 25 percent of the cumulative GDP during the period. The reduction in share of agriculture is owing to a gradual shift in the economic structure over the two-decade period considered in the analysis in addition to the impact of the recurrent shocks examined on the sector itself. Cumulatively, agricultural GDP under the _mp climate scenarios is about a fifth less compared to the sector's GDP without the shock. This magnitude of estimated loss in agriculture is higher than the 15-18 percent real GDP loss reported in Kahsay et al. (2017) for Nile basin countries. The effect is particularly severe in moisture-sufficient *enset*-based highlands (M_S_He) and moisture-sufficient lowlands (M_S_L) of Ethiopia. See Figure 1 on the geographic distribution of the agroecological zones in Ethiopia.

The succeeding panels in Table 4 depict the point changes from the percentage changes reported in panel A, reflecting the impacts of interventions analyzed. These panels underscore the significance of irrigation and energy interventions in averting some adverse effects of climate variability induced by climate change. As shown in the corresponding panels of Table 3, implementing combined irrigation and electricity interventions at the simulated levels would dampen the adverse effects on agriculture by 1.1-1.4 percent. Most of these gains are again achieved through investments in irrigation. At a regional level, the gains from these interventions are particularly marked in drought-prone lowlands of Ethiopia, where irrigated agriculture plays a dominant role (see Figure 1). The economic impact of irrigation would be more pronounced if the second season effect was accounted for. However, the modeling framework adopted in this study does not operate at seasonal/sub-annual levels, and thus is unable to fully reflect the production increase from irrigation in the lean season.

The study also showed a slight complementarity between energy and irrigation interventions. However, the extent of this interconnection is somewhat diminished by the apparent shift from non-hydropower sources to the relatively abundant hydroelectric power as the hydroelectric capacity expands due to the simulated development in infrastructure. This complementarity would also become more pronounced if groundwater usage in agriculture, which relies on energy as a complementary input, were to grow from its current nascent stage, and if groundwater extraction were widely recognized as a climate adaptation strategy.

Table 4. Change in cumulative regional GDP (2020-2040), in billions of 2018 USD

	Baseline cumulative value (2020-2040)	ssp126_mp	ssp126_uk	ssp370_mp	ssp370_uk	ssp585_mp	ssp585_uk
		Change in cumulative value from baseline scenario, 2020-2040					
A) Recurrent climate shock							
Agriculture GDP	773.7	-25.6%	-8.8%	-29.4%	-5.0%	-24.7%	-11.8%
D_P_H	205.4	-24.0%	-8.2%	-26.3%	-4.4%	-21.2%	-4.3%
M_S_Hc	412.9	-23.9%	-6.8%	-28.4%	-2.1%	-23.4%	-16.6%
M_S_He	123.8	-34.7%	-16.7%	-39.2%	-15.8%	-35.8%	-9.3%
D_P_L	14.2	-18.1%	-7.0%	-20.0%	-5.8%	-17.2%	-5.1%
M_S_L	17.4	-25.4%	-8.7%	-29.2%	-4.2%	-22.2%	-9.5%
National GDP	2,922.8	-14.9%	-5.0%	-17.2%	-2.8%	-14.3%	-6.7%
		Percentage point change from climate shock scenario, 2020-2040					
B) Irrigation investment under climate shock							
Agriculture GDP	773.7	0.8%	0.9%	0.7%	1.0%	0.8%	0.9%
D_P_H	205.4	0.8%	0.9%	0.7%	1.0%	0.8%	1.0%
M_S_Hc	412.9	0.8%	1.0%	0.8%	1.1%	0.9%	1.0%
M_S_He	123.8	0.5%	0.5%	0.4%	0.5%	0.5%	0.4%
D_P_L	14.2	1.9%	1.7%	1.9%	1.7%	1.9%	1.8%
M_S_L	17.4	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
National GDP	2,922.8	0.6%	0.7%	0.6%	0.7%	0.6%	0.7%
C) Electricity investment under climate shock							
Agriculture GDP	773.7	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%
D_P_H	205.4	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%
M_S_Hc	412.9	0.4%	0.4%	0.4%	0.4%	0.4%	0.4%
M_S_He	123.8	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
D_P_L	14.2	0.5%	0.5%	0.5%	0.5%	0.5%	0.5%
M_S_L	17.4	0.4%	0.4%	0.4%	0.5%	0.4%	0.5%
National GDP	2,922.8	0.3%	0.3%	0.3%	0.3%	0.3%	0.3%
D) Irrigation and electricity improvement under climate shock							
Agriculture GDP	773.7	1.2%	1.3%	1.1%	1.4%	1.2%	1.3%
D_P_H	205.4	1.1%	1.3%	1.1%	1.3%	1.2%	1.4%
M_S_Hc	412.9	1.2%	1.5%	1.2%	1.5%	1.3%	1.3%
M_S_He	123.8	0.8%	0.8%	0.8%	0.9%	0.8%	0.7%
D_P_L	14.2	2.3%	2.2%	2.4%	2.1%	2.4%	2.2%
M_S_L	17.4	0.9%	1.0%	0.9%	0.9%	0.9%	1.0%
National GDP	2,922.8	0.9%	0.9%	0.9%	1.0%	0.9%	0.9%

Note: Scenarios reported are with less extreme and more extreme outcomes.

4.3 Household consumption effects

A recent World Bank study (World Bank, 2020) notes that about 90 percent of the poor in Ethiopia are concentrated in rural areas, where agriculture serves as the primary source of livelihood. To evaluate the impact of climate shock scenarios on different household groups, we assess the percentage change in cumulative consumption spending (2020-2040) compared to the baseline (no climate change scenario), as presented in Table 5. The outcomes are segmented by household location (rural and urban) and poverty level.

The analysis demonstrates that scenarios with more severe impacts on GDP correspond to more severe effects on household consumption spending, and vice versa. Further, model results indicate a relatively stronger effect on consumption than the effect on GDP. This phenomenon can be attributed to climatic variability directly and strongly affecting agricultural products, which form a significant portion of consumption expenditure in Ethiopia and many other developing nations. This aligns with the findings of Siddig et al. (2020), who observed similar stronger effect on household consumption (-7.6 percent) compared to the effect on cumulative GDP (-2.8 percent) over the period from 2018 to 2050 in the case of Sudan. In rural areas, the impact on consumption is similar for both poor and non-poor households. However, in urban areas, real consumption for the urban poor is significantly affected compared to their non-poor counterparts. This is because the incomes of urban poor households are closely tied to value chains within the agri-food system, which are highly exposed to the adverse impacts from climate shocks. Hossain et al. (2023) also observed this stronger effect on the urban poor is the case of Bangladesh. At the national level, the cost of climate shocks in terms of forgone consumption remains substantial for the poor.

Investing in irrigation and electricity infrastructure to mitigate the adverse impacts of climate change would slightly reduce losses in consumption spending; this effect is comparable to the reduction in GDP impact from these interventions. Most of the recovery in consumption (almost two-thirds) is attributable to the irrigation intervention. However, non-poor households in rural areas benefit the most from improved irrigation development, as they are more likely to cultivate high-value irrigated crops. On the other hand, energy development benefits both rural and urban households equally and appears to have a distribution-neutral impact.

Energy and irrigation interventions do not merely affect consumption, but can also enable the production of high-value, nutritious foods such as fruits and vegetables that require higher amounts and more frequent water. Fruits and vegetables are tipped to help diversify consumption towards healthy diets (Baye et al., 2022; Pauw et al., 2023). Fodder irrigation (Bizumana et al., 2023) is also emerging in the country and, if fully tapped, could help mediate recurrent livestock death linked to droughts, ultimately increasing access to animal source food. Although well-designed small-scale irrigation programs have the potential to increase farmers income and productivity and bridge seasonal production gaps, they are not yet sufficiently developed.

Table 5. Change in cumulative consumption spending (2020-2040), in billions of 2018 USD

	Baseline cumulative value (2020-2040)	ssp126_mp	ssp126_uk	ssp370_mp	ssp370_uk	ssp585_mp	ssp585_uk
		Change in cumulative value from baseline scenario, 2020-2040					
A) Recurrent climate shock							
All households	1,996.2	-16.9%	-5.8%	-19.6%	-3.3%	-16.4%	-7.8%
Poor	414.6	-17.7%	-6.3%	-20.3%	-3.7%	-17.2%	-8.4%
Non-poor	1,581.6	-16.7%	-5.6%	-19.4%	-3.2%	-16.1%	-7.6%
Rural households	1,414.4	-17.6%	-6.1%	-20.3%	-3.5%	-17.0%	-8.2%
Poor	397.4	-17.4%	-6.2%	-19.9%	-3.6%	-16.9%	-8.3%
Non-poor	1,017.0	-17.7%	-6.0%	-20.4%	-3.5%	-17.1%	-8.1%
Urban households	581.8	-15.3%	-5.0%	-17.9%	-2.9%	-14.7%	-6.8%
Poor	17.2	-24.1%	-8.2%	-27.9%	-4.7%	-23.3%	-11.1%
Non-poor	564.6	-15.0%	-4.9%	-17.6%	-2.8%	-14.5%	-6.7%
		Percentage point change from climate shock scenario, 2020-2040					
B) Irrigation investment under climate shock							
All households	1,996.2	0.4%	0.5%	0.4%	0.5%	0.4%	0.5%
Poor	414.6	0.3%	0.4%	0.3%	0.4%	0.3%	0.3%
Non-poor	1,581.6	0.5%	0.5%	0.4%	0.6%	0.5%	0.5%
Rural households	1,414.4	0.4%	0.5%	0.3%	0.5%	0.4%	0.4%
Poor	397.4	0.3%	0.4%	0.2%	0.4%	0.3%	0.3%
Non-poor	1,017.0	0.4%	0.5%	0.4%	0.5%	0.4%	0.5%
Urban households	581.8	0.6%	0.6%	0.5%	0.6%	0.6%	0.6%
Poor	17.2	0.7%	0.8%	0.6%	0.8%	0.7%	0.7%
Non-poor	564.6	0.6%	0.6%	0.5%	0.6%	0.6%	0.6%
C) Electricity investment under climate shock							
All households	1,996.2	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
Poor	414.6	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
Non-poor	1,581.6	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
Rural households	1,414.4	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
Poor	397.4	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
Non-poor	1,017.0	0.2%	0.2%	0.2%	0.2%	0.2%	0.2%
Urban households	581.8	0.3%	0.2%	0.3%	0.2%	0.3%	0.2%
Poor	17.2	0.3%	0.3%	0.4%	0.4%	0.3%	0.3%
Non-poor	564.6	0.3%	0.2%	0.3%	0.2%	0.3%	0.2%
D) Irrigation and electricity improvement under climate shock							
All households	1,996.2	0.6%	0.7%	0.6%	0.8%	0.7%	0.7%
Poor	414.6	0.5%	0.6%	0.4%	0.6%	0.5%	0.6%
Non-poor	1,581.6	0.7%	0.8%	0.7%	0.8%	0.7%	0.7%
Rural households	1,414.4	0.6%	0.7%	0.5%	0.7%	0.6%	0.7%
Poor	397.4	0.4%	0.6%	0.4%	0.6%	0.5%	0.5%
Non-poor	1,017.0	0.6%	0.7%	0.6%	0.8%	0.6%	0.7%
Urban households	581.8	0.8%	0.8%	0.8%	0.9%	0.8%	0.8%
Poor	17.2	1.0%	1.1%	1.0%	1.2%	1.0%	1.1%
Non-poor	564.6	0.8%	0.8%	0.8%	0.9%	0.8%	0.8%

Note: Scenarios reported are with less extreme and more extreme outcomes.

5 CONCLUSION AND POLICY RECOMMENDATION

Examining the economic impacts of climate change is a complex task due to its numerous channels of influence and substantial levels of uncertainty in climate change impact and adaptation assessments. In this study, we assessed (i) the economywide effects of recurrent climate shocks on the Ethiopian economy until 2040, and (ii) also examined the impacts of water and energy interventions in averting some of the effects of climate change. To address the inherent uncertainty, we adopted several distinct climate change projections that encompass a wide range of predicted alterations in Ethiopia's catchment flow and water availability at an agro-ecological scale. We did so by using a modified economywide model calibrated to a modified 2018 SAM for Ethiopia that reflects regionally disaggregated agricultural operations and spatial differences in access to and use of strategic inputs, such as water use for irrigation.

Our results indicate that recurrent climate shocks will substantially reduce Ethiopia's cumulative GDP in 2020-2040 relative to a 'no climate change' baseline. Estimates of these damages range from 2.9 to 17.6 percent of baseline cumulative GDP, depending on which climate projection is considered. Climate projections under _mp scenarios are identified to have a severe effect across Ethiopia. Arguably, the weight of the economic loss relative to the size of the sector is concentrated in agriculture, constituting close to 50 percent of the cumulative loss under the most extreme scenario, i.e., nearly double the share of the sector in cumulative GDP in 2020-2040 and 45 percent of the loss under the least extreme scenario. Climate's adverse effects are also diverse across agro-ecologies of Ethiopia, where *enset*-based moisture-sufficient highlands (M_S_He) and moisture-sufficient lowlands (M_S_L) are the worst affected. The effect on the non-agricultural sector also remains considerable. This result therefore suggests the strong linkage effect of climate impact channels specifically targeting the agricultural sector and also underscores the importance of accounting for multi-sector impact channels of climate uncertainty.

Results further show dissimilar effects across households in Ethiopia. Poorer households in urban areas and rural households in general are the worst affected. Incorporating distributional and spatial analyses is crucial to pinpoint vulnerable segments of society and formulate effective adaptation strategies.

Our analysis suggests that investments in irrigation infrastructure to smooth out the irregular availability of water for agriculture and robust energy development strategy, including increased reservoir capacity for hydroelectricity generation are likely to be effective at reducing the damages from climate variability in Ethiopia. Irrigation infrastructure emerges as the most effective given its role in agriculture and the sector's contribution to overall GDP. In addition to the interventions assessed in this study, other response options such as increased resource use efficiency should be considered for further analysis.

The results of this analysis should be interpreted in light of the following. We focused on water shortages due to belove average catchment flow associated with climate change, although climate change is also associated with above average abundant rainfall and catchment flow in some years. Whereas our scenario design would potentially exert downward bias since we focus on negative shocks only, there is also some aspect of climate change disasters – such as flooding – that we did not account for. Our modeling framework would benefit from the introduction of a reservoir system that helps to smooth out water availability between years of abundant rainfall and drought years. A probabilistic assessment of years of extreme conditions and magnitude of shocks is another avenue in improving the scenario design. Further, the actual cost of the investments - but only the associated expansion in strategic capital - is not internalized in the model. This implies that the direct, indirect, and fiscal implications are unaccounted for.

REFERENCES

Admassu, H., Georgis, K., Nikus, O., Mekasha, A., Yesuf, M., Tesfaye, K., and Mahoo, H. F. 2007. A review of impacts of climate variability and change on semi-arid agricultural systems of Ethiopia: Action steps and principles for adapting agriculture to climate variability and change. https://studylib.net/doc/7421409/1-a-review-of-impacts-of-climate-variability-and-change-o... Accessed on June 23, 2022.

Amorim, L. and Cai, J. 2015. Modelling recurrent events: a tutorial for analysis in epidemiology. *International Journal of Epidemiology*, 324–333. doi: 10.1093/ije/dyu22.

Aragie, E. and Thurlow, J. 2022. Modeling the recovery dynamics of Ethiopia cattle population. *Journal of Arid Environments*, 197: 104664. https://doi.org/10.1016/j.jaridenv.2021.104664

Aragie, E. and Thurlow, J. 2021. 2018 Social Accounting Matrix for Ethiopia A Nexus Project SAM. International Food Policy Research Institute, Washington DC, USA.

Arndt, C., Asante, F. and Thurlow, J. 2014. Implications of climate change for Ghana's economy, WIDER Working Paper, No. 2014/020, ISBN 978-92-9230-741-7, The United Nations University World Institute for Development Economics Research (UNU-WIDER), Helsinki, https://doi.org/10.35188/UNU-WIDER/2014/741-7.

Awulachew, S. B., Yilma, A. D., Loulseged, M., Loiskandl, W., Ayana, M. and Alamirew, T. 2007. Water resources and irrigation development in Ethiopia. Colombo, Sri Lanka: International Water Management Institute (IWMI). IWMI WorkingPaper 123.

Baye, K., D. Mekonnen, J. Choufani, S. Yimam, E. Bryan, J.K. Griffith and C. Ringler. 2022. Seasonal variation in maternal dietary diversity is reduced by small-scale irrigation practices: a longitudinal study. *Maternal and Child Nutrition*, 18:e13297.

Bizimana, J-C., Derseh, M.B., Adie, A. and Kiker, G.A. 2023. Simulated economic and nutritional impacts of irrigated fodder and crossbred cows on farm households in southern Ethiopia. *World Development Perspectives*, 31: 100517.

Block, P., Strzepek, K., Rosegrant, M. and Diao, X. 2008: Impacts of Considering Climate Variability on Investment Decisions in Ethiopia. *Journal of Agricultural Economics*, 39:171-181.

Bogale, G.A. and Erena, Z.B. 2022. Drought vulnerability and impacts of climate change on livestock production and productivity in different agro-Ecological zones of Ethiopia. *Journal of Applied Animal Research*, 50(1): 471-489.

Carlsson, F., Demeke, E., Martinsson, P. and Tesemma, T. 2020. Cost of power outages for manufacturing firms in Ethiopia: A stated preference study. *Energy Economics*, 88: 104753.

CGIAR. 2018. Climate Resilient Green Economy Strategy. Sector-wise GTP II Implementation Monitoring Checklist. CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS), East Africa. URL: https://ccafs.cgiar.org/publications/climate-resilient-green-economy-strategy#.XGH6Ac9KhBw

Chatzopoulos, T., Domínguez, I.P., Toreti, A., Adenäuer, M. and Zampieri, M. 2021. Potential impacts of concurrent and recurrent climate extremes on the global food system by 2030. *Environmental Research Letters*, 16:124021.

Chandrasekharan, K. M.; Subasinghe, C.; Haileslassie, A. 2021. Mapping irrigated and rainfed agriculture in Ethiopia (2015-2016) using remote sensing methods. Colombo, Sri Lanka: International Water Management Institute (IWMI). IWMI Working Paper 196. doi: https://doi.org/10.5337/2021.206.

Cogato, A., Meggio, F., De Antoni, M. and Marinello, F. 2019. Extreme weather events in agriculture: a systematic review. *Sustainability*, 11:2547.

CSA. 2017. Agricultural Sample Survey 2016 / 2017 (2008 E.C). Central Statistical Agency (CSA). Addis Ababa.

Derbile, E.K., Bonye, S.Z. and Yiridomoh, G.Y. 2022. Mapping vulnerability of smallholder agriculture in Africa: Vulnerability assessment of food crop farming and climate change adaptation in Ghana. *Environmental Challenges*, 8: 100537.

DHI. 2011. DHI Mike 11: A Modelling System for Rivers and Channels, Reference Manual; Danish Hydraulic Institute (DHI). DHI Water & Environment: Hørsholm, Denmark.

Di Falco, S. and Chavas, J-P. 2008. Rainfall Shocks, Resilience, and the Effects of Crop Biodiversity on Agroecosystem Productivity. *Land Economics*, 84 (1): 83–96.

Diao, X., Dinar, A., Roe, T. and Tsur, Y. 2008. A general equilibrium analysis of conjunctive ground and surface water use with an application to Morocco. *Agricultural Economics*, 38(2): 117–135.

D’Odorico, P. Chiarelli, D.D., Rosa, L. and Rulli, M.C. 2020. The global value of water in agriculture. *Economic Sciences*, 117 (36) 21985-21993.

EEP. 2014. Power Sector Development. Ethiopian Electric Power Corporation. Addis Ababa, 2014. Available at: https://pubs.naruc.org/pub.cfm?id=537C14D4-2354-D714-511E-CB19B0D7EBD9. Accessed on July 22, 2023.

Eshetu, F. and Mehare, A. 2020. Determinants of Ethiopian Agricultural Exports: A Dynamic Panel Data Analysis. *Review of Market Integration*, 12(1–2), 70–94. https://doi.org/10.1177/0974929220969272

FAO. 2020. The impact of climate variability and extremes on agriculture and food security: An analysis of the evidence and case studies. Background paper for The State of Food Security and Nutrition in the World 2018. ISSN 2521-7259.

FAO. 2015. Climate change and food security: risks and responses. Food and Agriculture Organization of the United Nations (FAO). ISBN 978-92-5-108998-9.

Haqiqi, I., Taheripour, F., Liu, J. and Mensbrugghe, D. 2016. Introducing Irrigation Water into GTAP Data Base Version 9. *Journal of Global Economic Analysis*, 1(2): 116-155.

Hasan, M.M. and Wyseure, G. 2018. Impact of climate change on hydropower generation in Rio Jubones Basin, Ecuador. *Water Science and Engineering*, 11(2): 157-166.

Hossain, S.S., Cui, Y., Delin, H. and Zhang, X. 2023. The economic influence of climate change on Bangladesh agriculture: application of a dynamic computable general equilibrium model. *International Journal of Climate Change Strategies and Management*, 15(3). 353-370.

IEA. 2019. Ethiopia Energy Outlook. International Energy Agency (IEA). https://www.iea.org/articles/ethiopia-energy-outlook

Kahsay, T.N., Kuik, O., Brouwer, R. and Van Der Zaag, P. 2017. The Economy-Wide Impacts of Climate Change and Irrigation Development in The Nile Basin: A Computable General Equilibrium Approach. *Climate Change Economics*, 8(1): 1750004.

Komarek, A.M., Thurlow, J., Koo, J. and De Pinto, A. 2019. Economywide effects of climate-smart agriculture in Ethiopia. *Agricultural Economics*, 50(6): 765-778.

Luckmann, J., Grethe, H., McDonald, S., Orlov, A. and Siddig, K. 2014. An integrated economic model of multiple types and uses of water, *Water Resources Research*, 50, 3875–3892.

Mekonnen MM, Hoekstra AY. 2011. The green, blue and grey water footprint of crops and derived crop products. *Hydrology and Earth System Sciences*, 15(5):1577–600.

Mekonnen, T.W., Teferi, S.T., Kebede, F.S. and Anandarajah, G. 2022. Assessment of Impacts of Climate Change on Hydropower-Dominated Power System—The Case of Ethiopia. *Applied Sciences*, 12(4):1954. https://doi.org/10.3390/app12041954.

MoA. 2011. Forests, Rangelands and Climate Change in the Near East Region. Ministry of Agriculture. Federal Democratic Republic of Ethiopia. Addis Ababa. Ethiopia.

Mohammed, S., Alsafadi, K., Enaruvbe, G.O. et al. Assessing the impacts of agricultural drought (SPI/SPEI) on maize and wheat yields across Hungary. *Scientific Reports*, 12, 8838.

Mondal, MAH., Bryan, E., Ringler, C., Mekonnen, D. and Rosegrant, M. 2018. Ethiopian energy status and demand scenarios: Prospects to improve energy efficiency and mitigate GHG emissions. *Energy*, 149: 161-172.

Mondal, Md. A.H., E. Bryan, C. Ringler, and M. Rosegrant. 2017. Ethiopian power sector development: Renewable based universal electricity access and export strategies. *Renewable & Sustainable Energy Reviews*, 75:11-20.

MoWIE 2015. Ethiopia's Climate-Resilient Green Economy - Climate Resilience Strategy: Water and Energy. Ministry of Water, Irrigation and Energy (MoWIE), Addis Ababa.

Pauw, K., Ecker, O., Thurlow, J and Comstock, A.R. 2023. Measuring changes in diet deprivation: New indicators and methods. *Food Policy*, 117: 102471.

Pauw, K., Thurlow, J., Bachu, M. and Van Seventer, V.E. 2011. The economic costs of extreme weather events: A Hydrometeorological CGE analysis for Malawi. *Environment and Development Economics*, 16: 177-198. doi:10.1017/S1355770X10000471.

PDC. 2021. Ten Years Development Plan: A pathway to prosperity 2021-2030. Planning and Development Commission. Federal Democratic Republic of Ethiopia.

Robinson, S., Strzepek, K. and Cervigni, R. 2013. The Cost of Adapting to Climate Change in Ethiopia: Sector-Wise and Macro-Economic Estimates. Ethiopia Strategy Support Program II, ESSP Working Paper 53. Addis Ababa.

Schilling, J., Hertig, E., Tramblay, Y. and Scheffran, J. 2020. Climate change vulnerability, water resources and social implications in North Africa. *Regional Environmental Change*, 20(15).

Setegn, S., Rayner, D., Melesse, A., Dargahi, B., Srinivasan, R. and Wörman, A. 2011. Climate change impact on agricultural water resources variability in the northern highlands of Ethiopia. Melesse (ed.) In Nile River Basin. 241-265. Springer Netherlands.

Shukla, R., Gleixner, S. Yalew, A.W., Schauberger, B., Sietz, D. and Gornott, C. 2021. Dynamic vulnerability of smallholder agricultural systems in the face of climate change for Ethiopia. *Environmental Research Letters*, 16(4).

Siddig, K., Stepanyan, D., Wiebelt, M., Grethe, H. and Zhu, T. 2020. Climate change and agriculture in the Sudan: Impact pathways beyond changes in mean rainfall and temperature, *Ecological Economics*, 169: 106566.

Silchenko, D. and Murray, U. 2023. Migration and climate change – The role of social protection. *Climate Risk Management*, 39: 100472.

Tebekew, T., Amoge, A., Teferra, B., Seyoum, Z., Amha, M., Beyene, H., Fisseha, E., Tsehaye, E. and Ahmed, H.A. 2009. Ethiopia Input Output Table and Social Accounting Matrix. Ethiopian Development Research Institute. Addis Ababa.

UNDRR. 2020. Human cost of disasters: An overview of the last 20 years 2000-2019. UN Office for Disaster Reduction (UNDRR). Center for Research on the Epidemiology of Disasters (CRED). Geneva.

USAID. 2018. Economics of Resilience to Drought: Ethiopia Analysis. USAID Center for Resilience. https://2017-020.usaid.gov/sites/default/files/documents/1867/Ethiopia_Economics_of_Resilience_Final_Jan_4_2018_-_BRANDED.pdf

van der Wiel, K. and Bintanja, R. 2021. Contribution of climatic changes in mean and variability to monthly temperature and precipitation extremes. *Communications Earth & Environment*, 2(1). https://doi.org/10.1038/s43247-020-00077-4

Vinca, A., Riahi, K., Rowe, A. and Djilali, N. 2021. Climate-Land-Energy-Water Nexus Models Across Scales: Progress, Gaps and Best Accessibility Practices. *Frontiers in Environmental Science*, 9:691523.

Vogel, E., Donat, M.G., Alexander, L.V., Meinshausen, M., Ray, D.K., Karoly, D., Meinshausen, N. and Frieler, K. 2019. The effects of climate extremes on global agricultural yields. *Environmental Research Letters*, 14(5).

Wing, I.S., De Cian, E. and Mistry, M.N. 2021. Global vulnerability of crop yields to climate change. *Journal of Environmental Economics and Management*, 109: 102462.

World Bank. 2023. World Development Indicators. The World Bank Group, Wahington, D.C.

Yalew, A.W. 2022. The Ethiopian energy sector and its implications for the SDGs and modeling. *Renewable and Sustainable Energy Transition*, 2: 100018.

APPENDIX

Annex Table A1. Structure of selected accounts in the CGE model for Ethiopia

Commodities and sectors:

Agriculture: Maize; Sorghum and millet; Rice; Wheat and barley; Other cereals; Pulses; Groundnuts; Other oilseeds; Irish potatoes; Sweet potatoes; Other roots; Leafy vegetables; Other vegetables; Sugarcane; Tobacco; Cotton and fibers; Nuts; Bananas; Other fruits; Leaf tea; Coffee; Cut flowers; Other crops; Cattle; Raw milk; Poultry; Eggs; Small ruminants; Other livestock; Forestry; Capture fisheries.

Mining: Coal and lignite; Crude oil; Natural gas; Other mining

Manufacturing: Meat processing; Fish and seafood processing; Dairy; Fruit and vegetable processing; Fats and oils; Maize milling; Sorghum and millet milling; Rice milling; Wheat and barley milling; Other grain milling; Sugar refining; Coffee processing; Tea processing; Other foods; Animal feed; Beverages; Tobacco processing; Cotton yarn; Textiles; Clothing; Leather and footwear; Wood products; Paper products and publishing; Petroleum products; Fertilizers and herbicides; Other chemicals; Non-metal minerals; Metals and metal products; Machinery and other equipment; Electrical equipment; Vehicles and transport equipment; Other manufacturing;

Utilities: Hydropower-agriculture, Hydropower-non-agriculture; Non-hydropower-agriculture; Non-hydropower-non-agriculture; Surface water D_P_H; Surface water M_S_Hc ; Surface water M_S_He; Surface water D_P_L; Surface water M_S_L; Ground water D_P_H; Ground water M_S_Hc ; Ground water M_S_He; Ground water D_P_L; Ground water M_S_L; Other water supply (industrial and municipal).

Services: Construction; Wholesale & retail trade; Transportation & storage; Accommodation; Restaurants and food services; Information & communication; Finance & insurance; Real estate; Business services; Public administration; Education; Health & social work; Other services.

Factors:

Labor: Rural uneducated; Rural primary; Rural secondary; Rural tertiary; Urban uneducated; Urban primary; Urban secondary; Urban tertiary.

Land: - D_P_H rainfed; D_P_H irrigated; M_S_Hc rainfed; M_S_Hc irrigated; M_S_He rainfed; M_S_He irrigated; D_P_L rainfed; D_P_L irrigated; M_S_L rainfed; M_S_L irrigated.

Capital: D_P_H crop capital; M_S_Hc crop capital; M_S_He crop capital; D_P_L crop capital; M_S_L crop capital; D_P_H livestock capital; M_S_Hc livestock capital; M_S_He livestock capital; D_P_L livestock capital; M_S_L livestock capital; Mining capital; Other capital.

Households: Rural farm - quintile 1; Rural farm - quintile 2; Rural farm - quintile 3; Rural farm - quintile 4; Rural farm - quintile 5; Rural nonfarm - quintile 1; Rural nonfarm - quintile 2; Rural nonfarm - quintile 3; Rural nonfarm - quintile 4; Rural nonfarm - quintile 5; Urban - quintile 1; Urban - quintile 2; Urban - quintile 3; Urban - quintile 4; Urban - quintile 5.

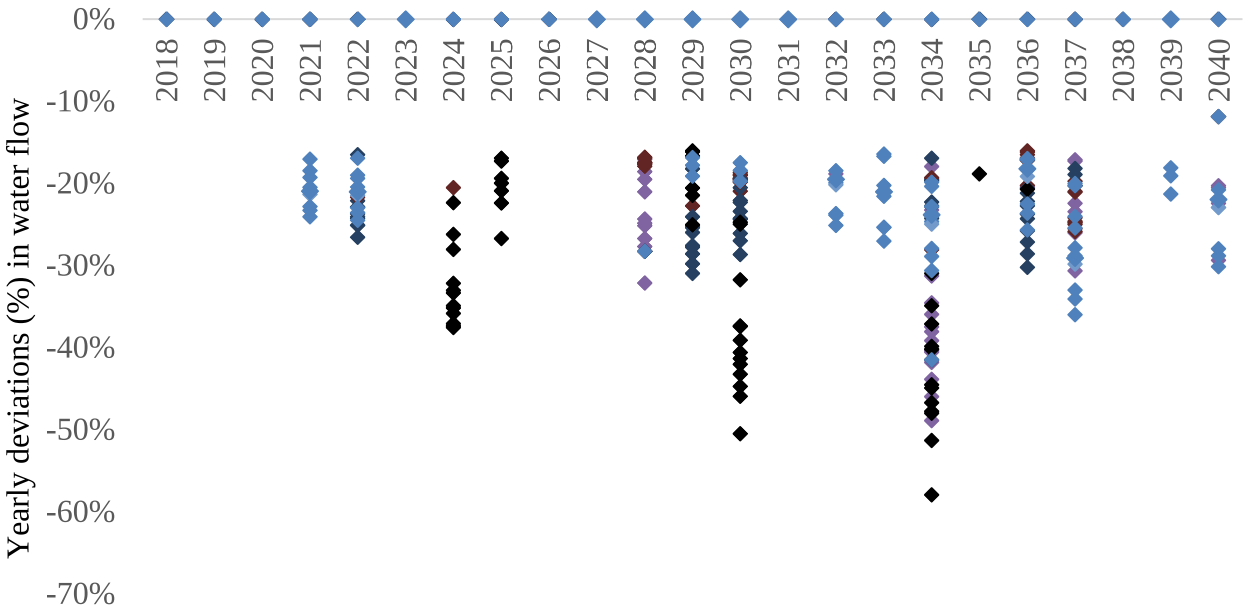
Source: Compiled by authors

Annex Table A2. The full set of climate scenarios considered in the study

Scenarios		Shared Socioeconomic Pathways (SSPs)	Climate models
ssp126_gf		ssp126	gfdl_esm4
ssp126_ip		ssp370	ipsl_cm6a_lr
ssp126_mp		ssp585	mpi_esm1_2_hr
ssp126_mr			mri_esm2_0
ssp126_uk			ukesm1_0
ssp370_gf			
ssp370_ip			
ssp370_mp			
ssp370_mr			
ssp370_uk			
ssp585_gf			
ssp585_ip			
ssp585_mp			
ssp585_mr			
ssp585_uk			

Source: These scenarios are randomly selected from the climate and hydrologic model for Ethiopia
Note: Out of the five SSPs, we randomly select three: ssp126, ssp370, and ssp585, which gives a diverse mix of future pathways. The selected SSPs respectively reflect a sustainable option (green road), regional rivalry (a rocky road), and fossil-fueled development.

Annex Figure 1. Predicted drops in catchment flow: all scenarios, 5 AEZs



Annex Table A3. Change in macroeconomic indicators (cumulative 2020-2040) - full set of climate scenarios

	Baseline comulative value (2020-2040)	ssp126_gf	ssp126_ip	ssp126_mp	ssp126_mr	ssp126_uk	ssp370_gf	ssp370_ip	ssp370_mp	ssp370_mr	ssp370_uk	ssp585_gf	ssp585_ip	ssp585_mp	ssp585_mr	ssp585_uk
GDP at market price	79.2	-13.1%	-9.9%	-13.9%	-10.0%	-4.6%	-12.4%	-13.5%	-16.1%	-14.9%	-2.7%	-13.8%	-7.3%	-13.4%	-9.5%	-6.2%
GDP at factor cost	76.0	-12.9%	-9.7%	-13.6%	-9.9%	-4.6%	-12.2%	-13.3%	-15.8%	-14.6%	-2.6%	-13.5%	-7.2%	-13.1%	-9.3%	-6.1%
Consumer price index	92.3	-14.7%	-10.0%	-15.3%	-10.0%	-3.6%	-13.8%	-14.5%	-18.3%	-16.2%	-1.7%	-15.5%	-6.6%	-14.9%	-9.2%	-5.1%
Export	7.4	-23.8%	-18.6%	-24.9%	-18.8%	-9.0%	-22.7%	-24.4%	-28.3%	-26.4%	-5.3%	-24.9%	-14.1%	-24.2%	-17.8%	-12.2%
Import	-16.9	-10.4%	-8.1%	-10.9%	-8.2%	-4.0%	-9.9%	-10.6%	-12.4%	-11.5%	-2.3%	-10.9%	-6.2%	-10.6%	-7.8%	-5.3%

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