IMPACT OF CLIMATE CHANGE ON HOUSEHOLDS WELFARE IN AFRICA

Ph.D. Thesis

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İKLİM DEĞİŞİKLİĞİNİN AFRİKA'DA HANEHALKI REFAHINA ETKİSİ

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ÖZET

İKLİM DEĞİŞİKLİĞİNİN AFRİKA'DA HANEHALKI REFAHINA ETKİSİ

Doungahiré Abdoul Karim ZANHOUO
İktisat Anabilim Dalı
Anadolu Üniversitesi Sosyal Bilimler Enstitüsü, Mayis, 2021
Danışman: Prof. Dr. Bulent AÇMA

Bu tezde, ilk olarak iklim değişikliğinin Burkina Faso ve Afrika'daki hanelerin refahı üzerindeki etkisini simüle edilmiştir. İklim değişikliğinin tarım verimi ve tarım arazileri üzerindeki etkisini tanımlamak için kısmi denge modeli olan IMPACT modelinin çıktısını kullanılmıştır.

Bölüm I'de yapılan bu tanımlayıcı analiz, iklim değişikliğinin mahsul veriminde düşüşe ve hasat edilen alanda artışa neden olacağını göstermektedir. Bu sonraki etkiler, iklim değişikliğinin hane halklarının refahı üzerindeki etkisini analiz etmek için küresel bir statik CGE modeli olan GTAP modeline dahil edilmiştir. GTAP simülasyonlarının sonuçları, iklim değişikliğinin Burkina Faso'da hanelerin refahında bir düşüşe yol açacağını ortaya koymaktadır. Örneğin, iklim değişikliğinin küresel refah üzerindeki toplam iklim değişikliği etkisi ortalama%14 azalacaktır.

İkinci olarak, GTAP standart modelini kullanarak Afrika Kıta Serbest Ticaret Alanının Afrika'daki iklim değişikliğine uyumdaki rolü incelenmiştir. Afrika bölgeleri arasında ticaret tarifelerinin% 90'ının kaldırılmasını içeren ticaret serbestleştirme senaryoları tanımlanmıştır. Simülasyon sonuçları, ticaretin serbestleştirilmesinin iklim değişikliğindeki refah kaybını telafi etmek için refah kazancı üretebileceğini göstermektedir. Örneğin çalışma, ticaret tarifelerinin kaldırılmasının, küresel refahta iklim değişikliği altında ulaşılan seviyeye göre% 26'lık bir artışla sonuçlanacağını göstermektedir. Bununla birlikte, ticaretin serbestleştirilmesinden elde edilen refah kazancı ülkeler arasında eşitsiz bir şekilde dağıtılacaktır.

Teknolojideki ilerleme, AfCFTA tarafından üretilen ana refah itici güç olacaktır. Bu nedenle, 2021 Ocak ayının başlarında başlatılan bu yeni kıtasal serbest ticaret alanından yararlanmak için ülkeler, teknolojik ilerlemeyi iyileştirmeli ve yerel sanayiyi geliştirmelidir.

Anahtar Sözcükler: Burkina Faso, Afrika, AfCFTA, iklim değişikliği, hane halkı, refah, iklim değişikliğine uyum, GTAP, CGE, IMPACT Modeli.

ABSTRACT

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WELFARE IN AFRICA

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In this thesis, we first simulate the impact of climate change on households' welfare in Burkina Faso and Africa. We use the output of a partial equilibrium model, the IMPACT model, to describe climate change's impact on agriculture yield and cropland. This descriptive analysis in chapter I shows that climate change will decline crop yields and increase harvested area. These impacts are later included in the GTAP model, a global static CGE model to analyze climate change's effect on households' welfare. The GTAP simulation outcomes reveal that climate change will lead to a fall in households' wellbeing in Burkina Faso. For instance, It is shown that the total climate change effect on global welfare will decrease by 14% on average due to climate change. Secondly, we examine the African Continental Free Trade Area's role in climate change adaptation in Africa using the GTAP standard model. We define trade liberalization scenarios consisting of removing 90% of trade tariffs among the African regions. The simulation results demonstrate that trade liberalization can generate welfare gain to compensate for climate change welfare loss. For example, the study indicates that trade tariffs removal will result in a 26% increase in global welfare than the level achieved under climate change. However, the welfare gain from trade liberalization will be unequally distributed among countries. Technology progress will be the main welfare driver generated by the AfCFTA. Therefore, to benefit from this new continental free trade area launched in early January 2021, countries should improve technology progress and develop the local industry.

Keywords: Burkina Faso, Africa, AfCFTA, climate change, households, welfare, climate change adaptation, GTAP, CGE, IMPACT**.**

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ETİK İLKE VE KURALLARA UYGUNLUK BEYANNAMESİ

Bu tezin bana ait, özgün bir çalışma olduğunu; çalışmamın hazırlık, veri toplama, analiz ve bilgilerin sunumu olmak üzere tüm aşamalarında bilimsel etik ilke ve kurallara uygun davrandığımı; bu çalışma kapsamında elde edilen tüm veri ve bilgiler için kaynak gösterdiğimi ve bu kaynaklara kaynakçada yer verdiğimi; bu çalışmanın Anadolu Üniversitesi tarafından kullanılan "bilimsel intihal tespit programı"yla tarandığını ve hiçbir şekilde "intihal içermediğini" beyan ederim. Herhangi bir zamanda, çalışmamla ilgili yaptığım bu beyana aykırı bir durumun saptanması durumunda, ortaya çıkacak tüm ahlaki ve hukuki sonuçları kabul ettiğimi bildiririm.

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(Öğrencinin Adı Soyadı)

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ABBREVIATIONS

AfCFTA	African Continental Free Trade Area
CDE	Constant-Elasticity-of-Transformation
CES	Constant Elasticity of Substitution
CET	Constant Elasticity
CGE	Computable General Equilibrium
COMESA	Common Market for Eastern and Southern Africa
DGPER	Direction Générale de la Promotion de l'Economie Rurale
EAC	East African Community
ECA	Economic Commission for Africa
ECCAS	Economic Community of Central African States
ECOWAS	Economic Community of West African States
EPPA	Environment Partnership Program for Accession
ESM	Earth System Model
EV	Equivalence Variation
FAO	Food and Agriculture Organization
FPU	Food Production Unit
GCM	Global Climate Models
GDP	Gross Domestic Product
GFDL-ESM2M	Geophysical Fluid Dynamics Laboratory
GHG	Greenhouse gas
GNP	Gross National Product
GTAP	Global Trade Analysis Project
HADGEM2	Hadley Centre Global Environment Model version 2
ICES	Intertemporal Computable Equilibrium System
IFPRI	International Food Policy Research Institute
IMPACT	International Model for Policy Analysis of Agricultural Commodities and Trade
IPCC	Intergovernmental Panel on Climate Change
IPSL-CM5A	Institute Pierre Simon Laplace Model
LDC	Least Developed Countries
MENA	Middle East and Nord Africa

MIROC	Model for Interdisciplinary Research on Climate
NAPA	National Adaptation Programs of Action
OECD	Organization for Economic Co-operation and Development
RCP	Representative Concentration Pathway
SAM	Social Accounting Matrice
SDGs	Sustainable Development Goals
SSA	Sub-Saharan Africa
SSPs	Shared Socioeconomic Pathways
UNCTAD	United Nations Conference on Trade and Development
UNEP	United Nations Environment Programme

INTRODUCTION

The threat of climate change is one of our century's main issues since it jeopardizes humanity's survival by affecting the environment and livelihoods. Natural disasters in the last decades prove the reality of climate change. According to Myles et al. (2018), in the decade of 2006-2015, 20 to 40% of the global human population has already experienced a temperature increase of more than 1.5% above the 1850-1900 [1] level for at least one season. This increase in temperature accompanies irregular rainfall and natural disasters such as drought, bush fires, and floods. In turn, these physical effects of climate change are translating into social and economic consequences. Economic activity is, at the same time, a source of climate change through the emission of greenhouse gases and a target of the climate change impacts.

The Intergovernmental Panel on Climate Change (IPCC) (2007) projects that climate change will cost 1.5 to 3.5% of the global economy and diversely affect regions worldwide. Developing countries are more likely to be hardly affected since they do not have the necessary resources and technology for climate change adaptation (Mendelsohn et al., 2006). For instance, it is shown that 80% of damages from climate change will occur in developing countries (Mendelsohn et al., 2006). These countries are more vulnerable to climate changes since agriculture, one of the most exposed sectors, is the ground of their economy (Stern, 2006). According to FAO (2009), developing counties will face a decrease of 9 to 21% in their overall potential agricultural productivity due to global warming. Among these countries, sub-Saharan African countries, which are already food insecure, will be severely affected by climate change. In these countries, climate change's economic impact may create social consequences such as conflict, migration, and diseases. To cope with climate change and its effects, two strategies are generally used: adaptation and mitigation. Choosing the right strategy, however, requires estimating the extent of global warming and its impacts. However, there is insufficient literature related to the socio-economic impacts[2] of climate

[1] This period corresponds to the pre-industrial period.

[2] such as water resources, transport, migration, violent conflict, energy supply, space cooling, labor productivity, and tourism and recreation

change (Tol, 2018), particularly in developing countries. This literature is minimal and focuses on the damaging effects of climate change on African countries' economies (Abidoye & Odusola, 2015). There is, therefore, a need for more scientific research to estimate the magnitude of climate change and its effects on the African continent.

In this Ph.D. thesis, we aim to contribute to this literature by providing new insight into the socio-economic impacts of climate change in Africa in general and particularly in Burkina Faso and the role of trade liberalization in climate change adaptation. This thesis is structured as follows.

In the first chapter, we describe the effect of climate change on the agriculture sector in Burkina Faso using the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) simulations outcomes, a partial equilibrium model developed by the International Food Policy Research Institute (IFPRI). This chapter's primary purpose is to present the projected effect of global warming in the Burkina Faso agriculture sector according to different climate change scenarios. This descriptive analysis shows that, on average, climate change will result in a decrease in cereals yields and production in Burkina Faso. However, the magnitude of these variations a function of the climate change scenario considered. Moreover, harvested cropland will increase with an average rate of 1.5% due to climate change.

In the second chapter, we investigate the effects of climate change on households' welfare in Africa in general and particularly in Burkina Faso. Therefore, we use a General Equilibrium Model, precisely the Global Trade Analysis Project (GTAP) model, where we incorporate cropland and agriculture yields variation as of climate change shocks. The results demonstrate that these climatic shocks will have a negative impact on households' global welfare in Burkina Faso. For instance, the research reveals that compared to the baseline scenario, climate change will lead to a welfare loss estimated at up to 14% in Burkina Faso by 2050.

In the third chapter, we analyze the impact of trade liberalization on climate change adaptation in Africa. In the GTAP model, we include trade tariffs elimination between African countries due to the African Continental Free Trade Area. The simulation results show that removing 90% of trade tariffs among African countries will generate necessary gains to compensate for climate change's negative effect at the continental level. However, this gain will be disproportionately distributed across the regions in the continent. Some parts, such as South Africa, North Africa, and COMESA, will benefit from trade tariffs removal. In contrast, other regions, namely East Africa, West Africa, and Central Africa, will see their welfare levels deteriorate after trade liberalization.

The last section concludes that this thesis improves our understanding of climate change's impact on welfare in Africa and suggests trade as a climate change adaptation strategy. This section also provides recommendations for public policies and future studies.

CHAPTER 1

CLIMATE CHANGE AND AGRICULTURE SECTOR IN BURKINA FASO

Introduction

Burkina Faso is one of the African countries already influenced by the effects of climate change. In this country, climate change manifests itself by a gradual decline in the length of the rainy season, frequent droughts, floods, heatwaves, and dust storms. According to González et al. (2011), in Burkina Faso, the effects of climate change are such that *‘‘in a single area, it can be observed both floods and drought within a few months*.” The country will be remarkably affected because its economy is mainly rural and based on the agriculture sector. The farming sector of the country is less developed and implemented in small areas. It is dominated by rainfed agriculture, representing more than 90% of the exploited areas (Zidouemba, 2017). In the country, a good agriculture season is depending on good rainfall and ideal temperature. As a result, climate change will affect this agriculture sector particularly and, therefore, impact households. These facts associated with the absence of technology make the country very vulnerable to climate change and constitute a significant problem for achieving food security and reducing poverty.

Consequently, it is essential to assess climate change effects and identify adaptation and mitigation strategies. However, to our best knowledge, limited studies are examining Burkina Faso's situation. Among the existing studies, Ouedraogo et al. (2006) assess global warming's impact on the agriculture sector in Burkina Faso by using the Ricardian approach. Their research shows that a marginal increase in temperature will decrease agricultural revenue by $19.9 per hectare. In contrast, an additional reduction of 1mm per month of precipitation will result in a loss of $ 2.7 per hectare in agricultural income. However, the Ricardian approach adopted is a crop model focusing only on production and hence presents some limits as it overvalues climate change costs (Arndt et al., 2015). Zidouemba (2017) uses a CGE model to analyze the economic effects of climate change in Burkina Faso. He assumes that rainfall variability and the decline of crop yields will be the direct physical effect of climate change and finds that climate change will reduce national welfare. Besides, his study shows that the magnitude of climate change impact varies according to the scenario considered. Zidouemba's (2017) study presents a limit since the climate change effects on crop yields included in the CGE model are based solely on assumptions.

Furthermore, the use of a global economic model may underrate the magnitude of climate change's effect on agriculture. Therefore, the question about the extent of climate change effects on the agriculture sector in Burkina Faso is still relevant. This chapter provides new insights into the impact of climate change on the agriculture sector in Burkina Faso. For that, we present in the first section an overview of climate change in the country. The second section analyzes the state of the agriculture sector in Burkina Faso. Finally, section III displays the climate change impacts on the agriculture sector in Burkina Faso using IMPACT model simulations' outcomes.

1.1. Climate change in Burkina Faso

1.1.1. Overview of Burkina Faso climate

Burkina Faso is located in a Sahelian zone, characterized by elevated temperatures and irregular rainfall. There are three climatic zones:

- The Sahelian zone occupies the northern part of the country and receives less than 600 mm of rainfall per year.
- The north Sudan zone rainfall varies between 600 and 900 mm per year.
- Southern Soudan zone with rain that is a little over 900 mm per year.

Burkina Faso has two seasons: the long dry season, which is characterized by dry winds, warm air, and a wet season. The rainy season lasts between 60 and 160 days from the North to South side of the country. The temperature level is very volatile across the country. For instance, the average annual temperature is between 27 and 30 °C, but it can reach 45 °C or fell to 15 °C in some areas. The maximum temperature is observed in May and June during the wet season, while the minimum temperature is reached in December and January, at the beginning of the dry season. Climate change in Burkina Faso manifests itself by more significant rainfall variability and frequent natural disasters such as drought, floods, heatwaves, locusts, and dust storms. In the following two subsections, we will analyze some climate change variables such as temperature and rainfall during the last fifty years.

1.1.2. Temperature trends in Burkina Faso

A continuous variation of temperature levels generally characterizes global warming. The Sahelian country, Burkina Faso, which is already marked by high temperatures, will experience a variation in maximum, minimum, and average temperatures. Studies in Burkina Faso have shown that temperatures have changed over the last 50 years. Authors such as Oueslati et al. (2017) and De Longueville et al. (2016), in their studies, have shown that the maximum and minimum temperatures have experienced a positive variation respectively since 1959 and over the period 1950-2013. Also, Bambara et al. (2018), examining the evolution of temperatures in two cities of Burkina Faso, shows that Ouagadougou's average temperature level increased from 28.2 to 28.8°C, from 1956-1985 to 1986-2015. Below, we present in Figure 1.1 the evolution of the average monthly temperatures from 1960 to 2015 for May, June, July, August, and September, which correspond to the rainy period in Burkina Faso. This figure's analysis shows a sawtooth evolution of temperature levels for the months analyzed with a growing general trend. Indeed, the coefficients of the trend equations are positive. This result confirms the results of previous studies on the temperature level in Burkina Faso. This uptrend is predicted to continue to grow, according to studies. Indeed, in a study by the World Bank (2011), it is shown that Burkina Faso will experience a rise in the temperature level of 3 to 4°C during the period 2080-2099 compared to its status in the 1980-1999 period. To sum up, Burkina Faso is expected to be hotter in the following decades due to climate change.

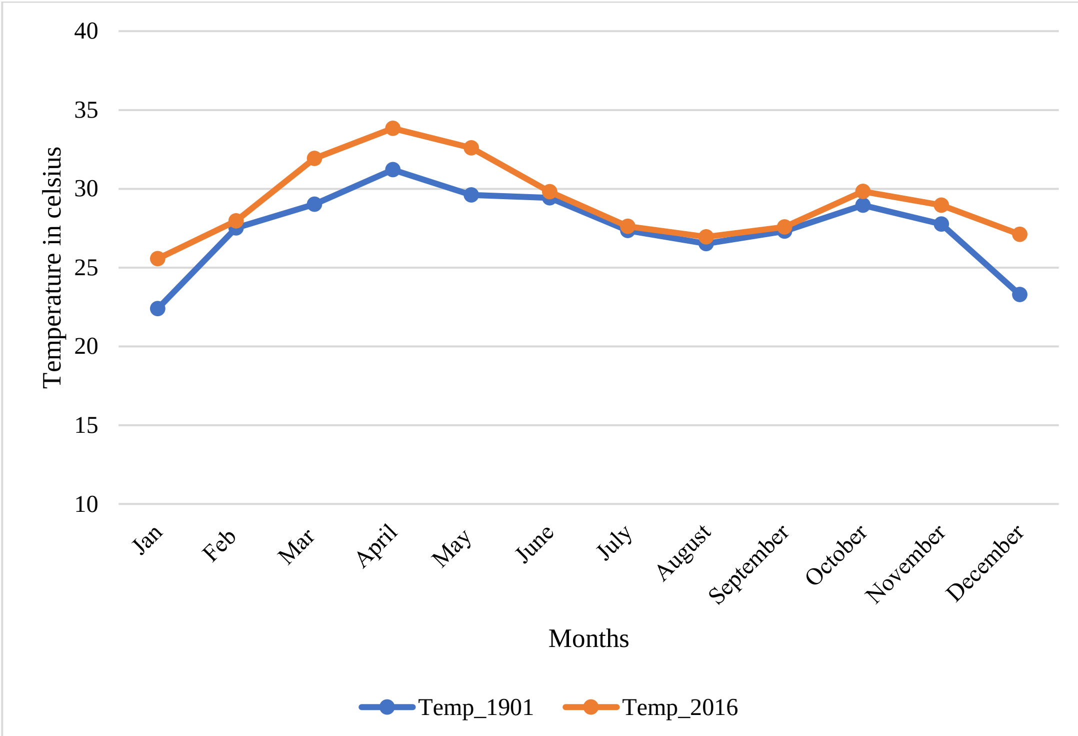

Figure 1.1. *The average monthly temperature in Burkina Faso 1901 and 2016*

Source: *Built by the author using World Bank (2020) data*

1.1.3. Trends of rainfall in Burkina Faso over 1901-2016

Burkina Faso is a country where the precipitation is only up to 900 mm in the best-watered area. Figure 2 below presents the evolution of average rainfall during the rainy season, which covers May, June, July, August, and September. This figure shows a downward trend in rainfall since 1960 for all months except August. August, the rainiest month in Burkina Faso, is experiencing a smooth evolution of its rainfall level, with a generally rising mean trend. For May, there is a steady decline in the average quantity of rainfall since 1992. This result is explained by the late start of the rainy season in Burkina Faso in recent decades due to global warming. For the other months, there is a sawtooth trend with a slight downward inclination. However, although climate change has not yet had a substantial effect on the quantity of rainfall, it has had many consequences on the distribution of rainfall over time and space. Previously, studies have attempted to examine the effect of climate change on rainfall in Burkina Faso. For instance, De Longueville et al. (2016) discovered in their study that from 1950 to 2013, the total volume of rain in Burkina Faso has a decreasing trend. Indeed, all stations analyzed show a decreasing trend, with more than 50% of the stations having statistically significant decreasing trends. Also, climate change has caused many rainfall-related disasters such as floods and droughts in recent years. These effects constitute a substantial problem for the country and particularly for the agriculture sector. Droughts and floods are obstacles to agriculture production and reaching food security due to their negative impacts on soil quality and crop productivity.

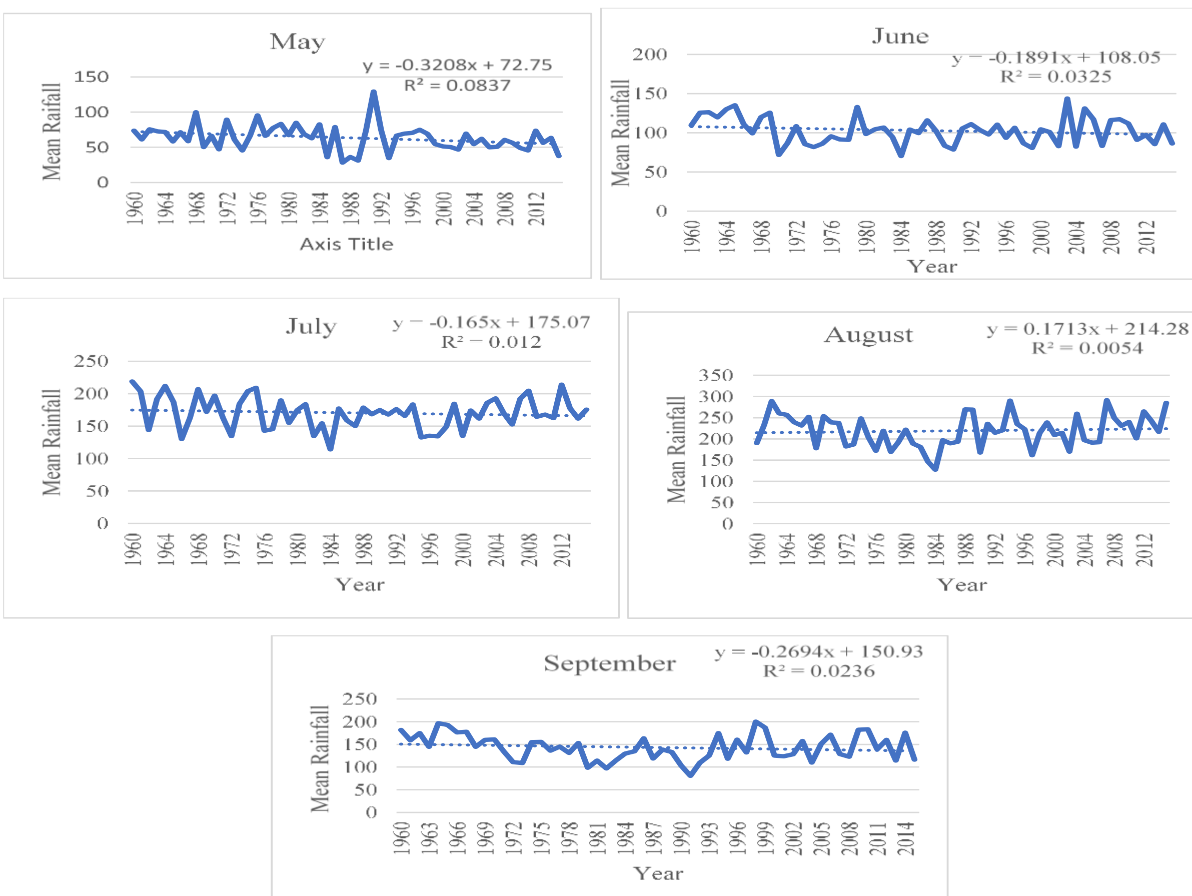

Figure 1.2:*Average Monthly rainfall in Burkina Faso in 1901-2016*

Source: *Built by the author using World Bank (2020) data*

1.1.4. Hazard risk related to climate change in Burkina Faso.

The stakes in terms of hazards are summarized below in figure 4. The climate change risks in Burkina Faso include drought mortality risk, flood mortality risk, and bush fires.

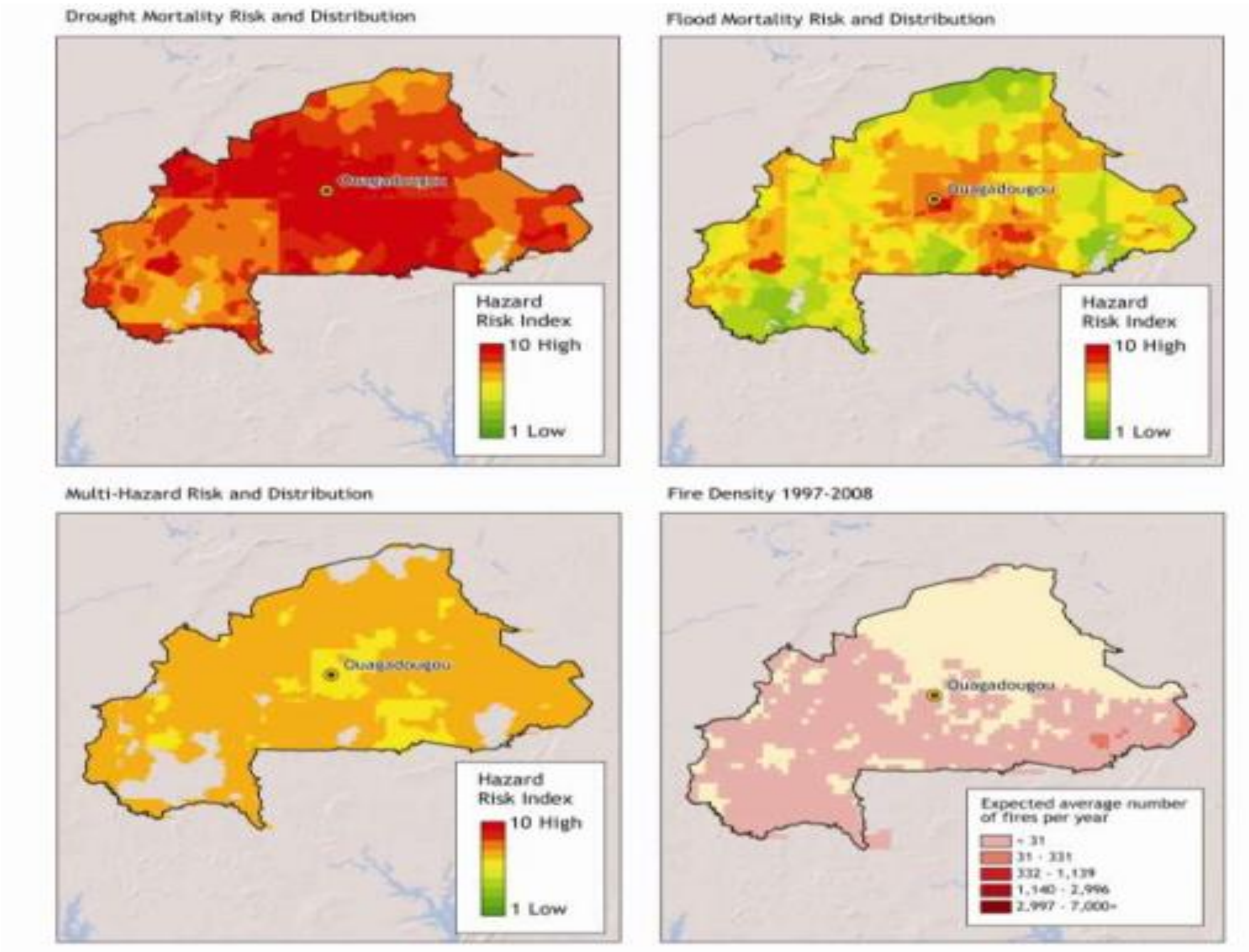

Figure 1.3:*Risks expectance of climate-related hazards across Burkina Faso (World Bank 2011)*

1.2. The agriculture sector in Burkina Faso

Agriculture is the primary economic activity in Burkina Faso. It occupies more than 87% of the active population and contributes up to 33.83% of GDP on average, over 2000-2010 (DGPER, 2013). On the one hand, Burkina Faso's agriculture is analyzed through the evolution of the main harvest varieties' areas and, on the other hand, through the production levels' change. The country's arable land is estimated at 12 million hectares, with only 6 million hectares cultivated in 2016 (FAO 2019). The main products are food crops and cash crops. Of the food crops, cereals (sorghum, millet, maize, rice, and fonio) account for more than half of the cultivated land. In 2017, the total area planted for cereals was around four million hectares (FAO 2019). We also have the legumes and tubers whose main crops are cowpea, groundnut, sweet potato, yam. Cotton, sesame, peanut, soy, and sugar cane are the main cash crops. In 2017, total cereal production was estimated at 4.06 millions tonnes, while seed cotton production was 0.85 million tonnes, according to FAO (2019) statistics.

In Figure 5, the annual production of major crops is presented. This figure shows that in 1961-2019, the main crop productions have an increasing trend. Burkina Faso's agriculture is poorly mechanized with low use of modern inputs and power tools. According to the DGPER, in 2010, only 44% of farmers have mechanized equipment (plow, seed drill) with a utilization rate of improved seed estimated at 15%. As a result, this agriculture remains very unproductive with meager yields. For example, in 2017, grain yields were around one tonnes/ha 2017. However, these yields have improved significantly during the last years, increasing from 0.4085 tonnes per hectare in 1961 to one tonnes per hectare in 2017. This observation is shown in Figure 5, which has an increasing trend over the last half-century. Besides, this agriculture remains dominating by the rainfed system. Only about twenty-four thousand ha of land are irrigating for a potential of 2.3 thousand. Irrigated crops are rice, sugar cane, and vegetable. Market gardening is also practiced in irrigated perimeters and small individual vegetable gardens in peri-urban areas. Climate change, which has already contributed to agricultural land degradation and irregular rainfall, will worsen this state of the country's agriculture sector.

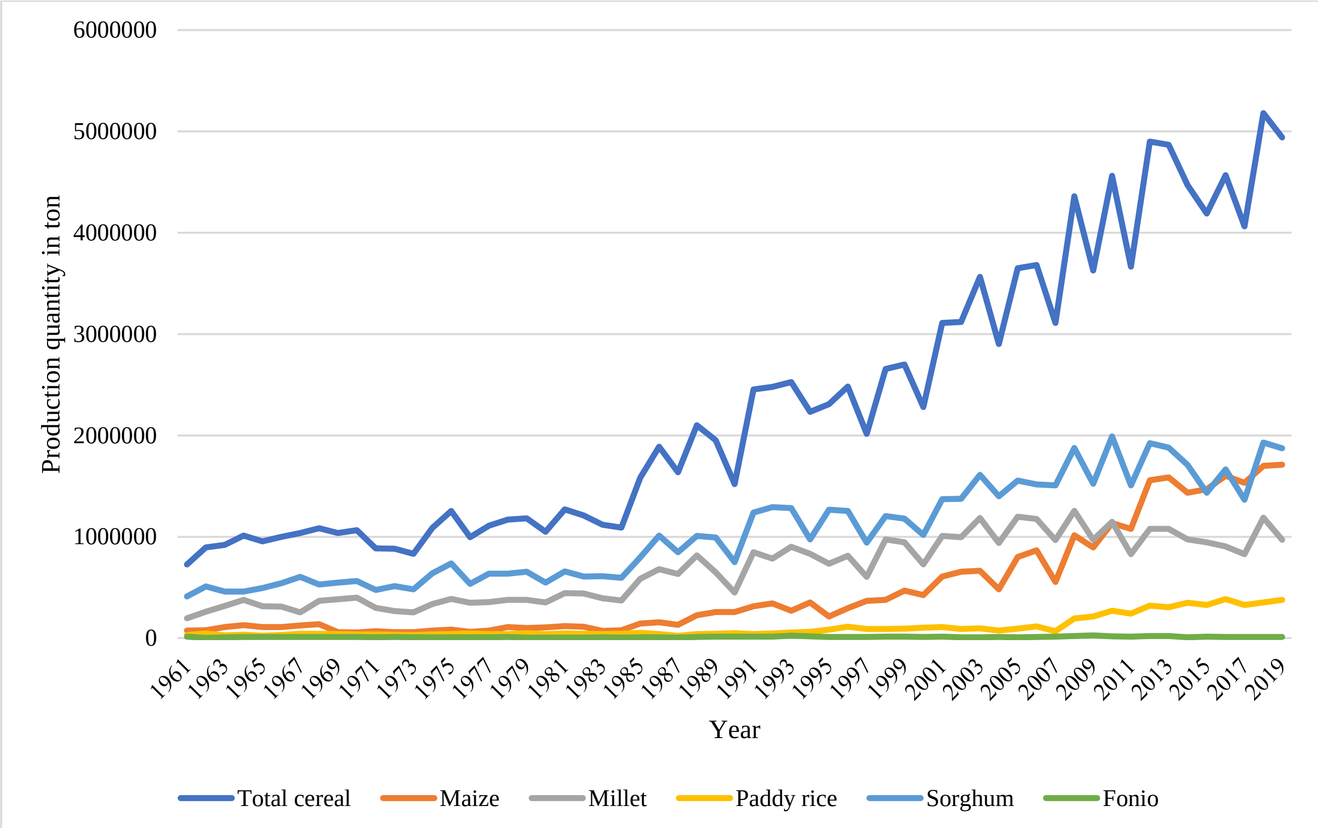

Figure 1.4: *Main cereals production quantity Over 1961-2019*

Source*:* *Made* by *the author using FAO (2020) data*

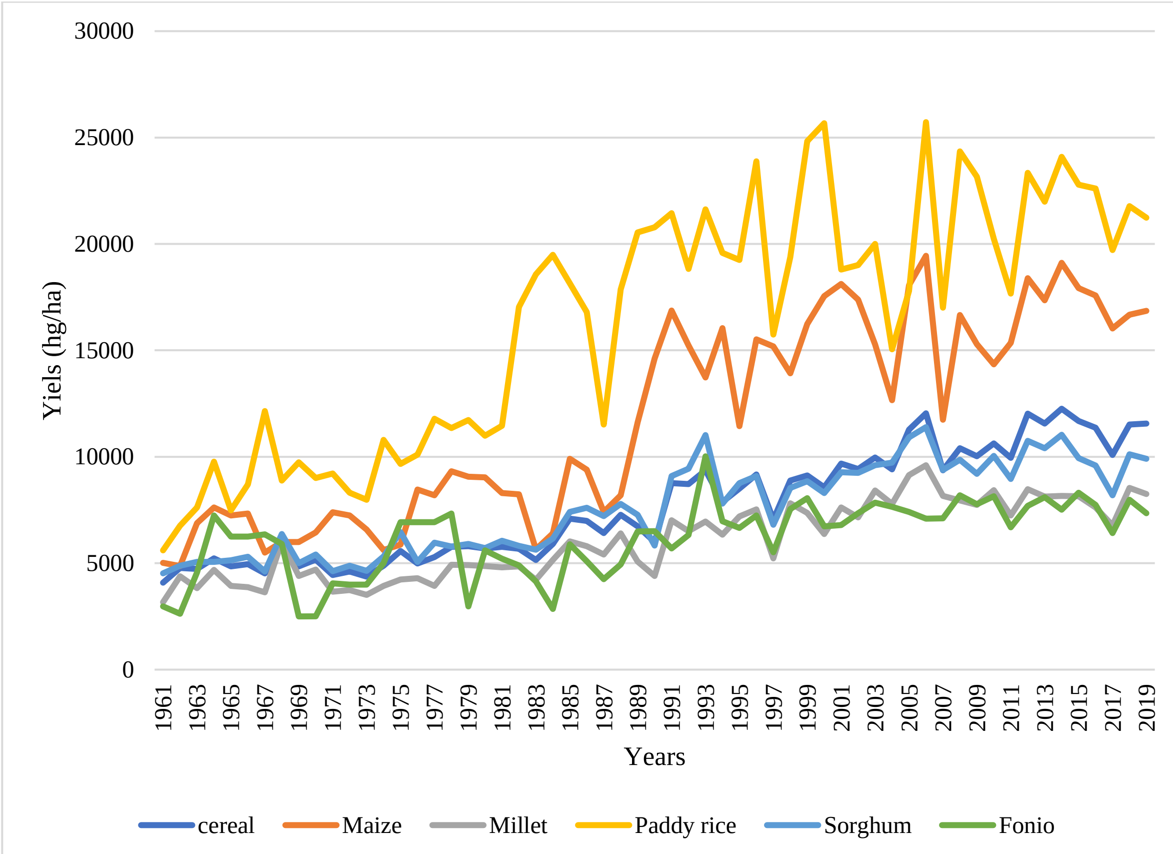

Figure 1.5. *Average cereals crop yields Over 1961-2017*

Source: *Made by the author using FAO (2020) data*

1.3. Impact of climate change on the agriculture sector

In this section, we analyze the impact of climate change on the agriculture sector in Burkina Faso using the outputs of the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model, which is a partial equilibrium model built by Robinson et al. (2015).

1.3.1. IMPACT model description

The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) was established by a team of researchers of the International Food Policy Research Institute (IFPRI). It is a partial equilibrium model that uses a supply and demand equations system to analyze food production, food demand, prices, trade, income, and the population at the national and international levels. The first version of IMPACT was developed at the beginning of the 1990s, and the latest version is IMPACT 3, updated in 2015. The model is built for different scenarios analyses and offers a comprehensive specification of the agriculture sector's production function and productivity shocks. Therefore, the model can assess socioeconomic trends and biophysical and physical phenomena effects on the agriculture sector. IMPACT's core model is a multimarket model that includes 159 countries and is used to determine 62 agricultural commodity market yearly prices at the national and global levels. The agricultural production is determined for the 320-food production unit (FPU), which corresponds to 154 water basins. Country and regional agricultural sub-models are linked through trade (Calzadilla, Zhu et al. 2011).

The structure of the IMPACT model is presented in figure 7. It shows the relations among the IMPACT's different modules. We distinguish five components (a climate model, a water model, a crop model, a macroeconomic model) and the multimarket model. The climate model delivers inputs that include temperature and precipitation to the water and crop simulation models (Robinson et al. 2015). Besides, the macroeconomic model supplies demographic and economic growth inputs to the water and multimarket models. The water model and the multimarket have two ways of relationships over time. These different models are used together to simulate outputs that include agriculture commodities prices and production, trade, harvested areas, yields, and consumption. Some of these outputs are used to describe the effect of different climate change scenarios on the agriculture sector in Burkina Faso.

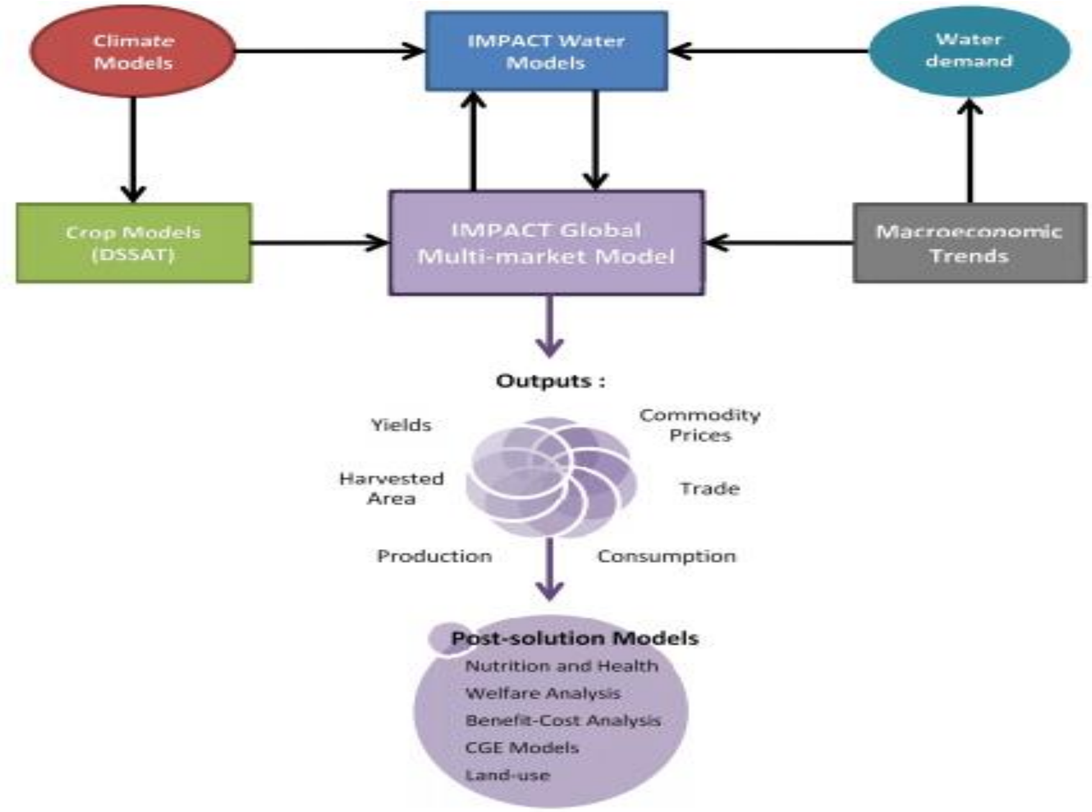

Figure 1.6. I*MPACT model*

Source: *Robinson, et al., (2015)*

1.3.2. Climate scenarios in IMPACT simulation

Climate change shocks included in the IMPACT model simulation are drawn from the IPCC's climate scenarios, including their fifth assessment report on the climate change effect. These scenarios are set to help researchers and governments to analyze the world's capacity to respond to future climate and economic shocks (Robinson et al. 2015). Two essential elements are used to build these climate change scenarios: The Shared Socioeconomic Pathways (SSPs) and the Representative Concentration Pathways (RCPs).

1.3.2.1.Shared Socioeconomic Pathways (SSPs)

SSPs describe the plausible alternative trends in society and ecosystems' progress during the 21st century in the world (O'Neill et al., 2014). Shared Socioeconomic Pathways give different economic growth trends, population, and urbanization that contribute to climate change. Five probable SSPs were identified with evocative names given to describe them. They are respectively named from the SSP1 to SSP5, Sustainability, Middle of the Road, Regional Rivalry, Inequality, and Fossil-fueled Development. A further description of each of these five scenarios can be read in the paper of (O'Neill et al. 2014). GDP and population growth are the SSPs variable used in the IMPACT simulations.

Figure 8 presents Burkina Faso's GDP trends up to 2100 according to different SSPs. The trend of Burkina Faso's population is relatively similar for the five scenarios until 2050. By 2050, some differences will be observed in the trends per scenario. SSP3 and SSP4 give the same population tendencies and constitute the scenarios where the Burkina Faso population will be at its higher level. SSP1 and SSP5 also present the same population trends but predict the lowest population size for Burkina Faso. However, SSP2 is the medium scenario in terms of population size for Burkina Faso.

In terms of economic growth, the five scenarios show the same trends up to 2060 and depart. From the best scenario to the worse, we can respectively sort them as SPP1, SSP5, SPP2, SSP3, and SSP4.

For this chapter, the SSP2 scenario IMPACT's outputs are used for describing climate change's impact on the agriculture sector of Burkina Faso.

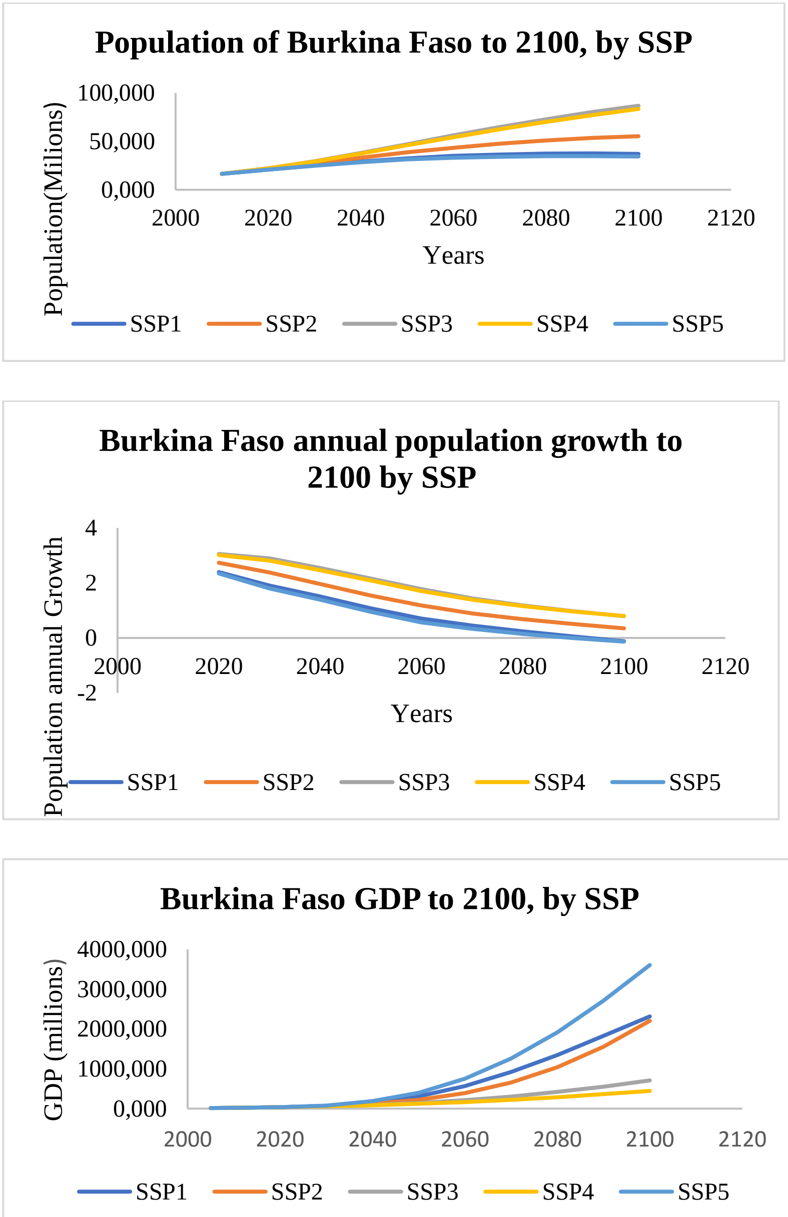

Figure 1.7.*Probable population level and GDP by SSPs*

Source: *Built by the author using IMPACT model outcomes*

*1.3.2.2.*Representative Concentration Pathways

The Representative Concentration Pathways (RCPs) describes the future climate change scenarios according to the levels of greenhouse gas emissions observed during the 21st century. Four RCPs scenarios are estimated over a period up to 2100. These scenarios are defined based on the estimated radiative forcing level by 2100, ranging from 2.6 watts per square meter (W / m2) to 8.5 W /m2 (Robinson et al. 2015). This radiative forcing lead to increased temperature, entraining glaciers' melting, and increased sea level. Figure 9 describes the level of CO2 concentration and total radiative force by RCP up to 2100. 2.6 watts per square meter is the lowest radiative forcing level and represents the scenario with the lowest level of CO2 concentration. 8.5W/m2 is the highest radiative forcing level and corresponds to the highest level of CO2 concentration. In the IMPACT model, 8.5W/m2 is used for stimulations.

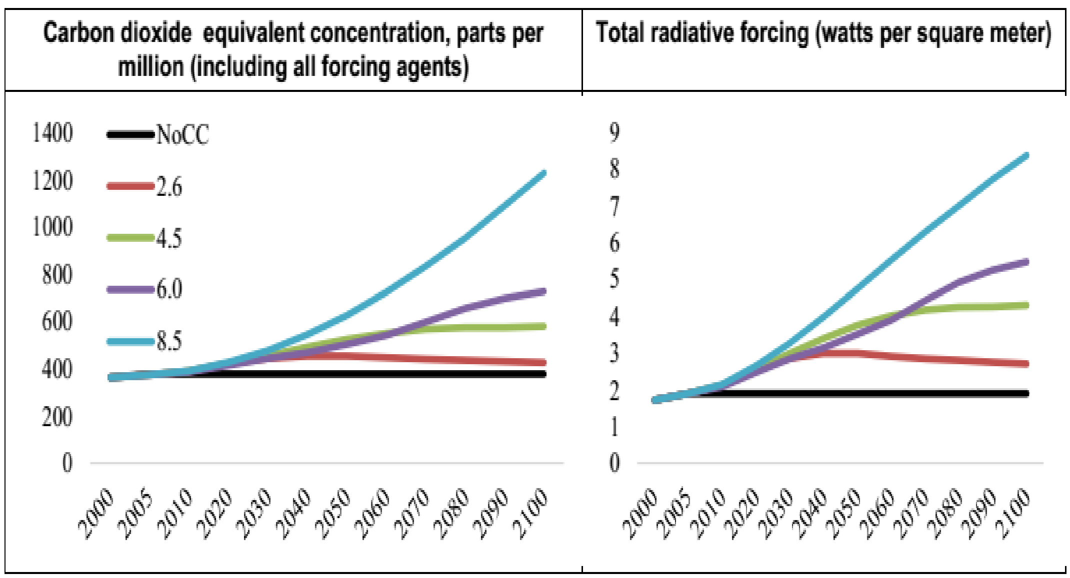

Figure 1.8. *Probable CO2 concentration and radiative forcing by RCP*

Source: Robinson, et al., (2015)

To provide weather variables to the crop model, the RPCs are simulated in four different Earth System Models (ESMs). These ESMs include the Earth System Model 2 of the Geophysical Fluid Dynamics Laboratory (GFDL-ESM2M), the Hadley Centre Global Environment Model version 2 (HADGEM2), the Institute Pierre Simon Laplace Model (IPSL-CM5A), and the Model for Interdisciplinary Research on Climate (MIROC-ESM)[3] . Each ESM has different assumptions about future climate change and predicts different temperatures and precipitation levels. These different predictions allow the IMPACT authors

[3] Find more information about each ESM at Robinson, et al. (2015) page 96

to consider the uncertainties in the prediction of climate change data. Table 1 presents the scenarios considered in IMPACT model simulations.

Table 1.1. *The different scenarios and ESMs IMPACT output are considered*

Scenarios	*SSP*	*RCP*	*GCM*
SSP2-NoCC	2	None (constant unchanging climate)	n/a
SSP2-GFDL	2	8.5	GFDL
SSP2- HADGEM2	2	8.5	HGEM
SSP2-IPSL	2	8.5	IPSL
SSP2-MIROC	2	8.5	MIROC

Source: Made by the author

1.3.2. Climate change impact on the agricultural sector in Burkina Faso

Climate change affects the agriculture sector in many ways. It has direct and indirect effects. The direct effects of climate change on agriculture include crop yield, productivity, and harvested areas. Besides, weeds resistance, new insects, and diseases are some of the indirect consequences of climate change in the agriculture sector.

This section will describe some of the direct impacts of climate change on agriculture in Burkina Faso.

1.3.2.1.Climate change impact on agricultural lands

One of the ways climate change affects the agricultural sector is through the arable croplands. Global warming will have positive and negative effects on agricultural lands depending on the geographical areas. It is shown that regions in high latitudes will benefit from climate change, while global warming will cause land losses in lower latitude regions. In a paper, Zhang & Cai (2011) show that climate change will increase cropland in areas such as Russia, China, and the USA; and will cause cropland decline in regions such as South America and Africa.

Furthermore, they show that climate change will decrease the total arable lands in the world. In the same vein, Kotir (2011) reveals that one of the consequences of climate change in Sub-Saharan Africa is reducing arable land. This negative effect of climate change is likely due to the physical impact of global warmings, such as floods and drought.

This section analyzes the climate change effect on total agricultural lands in Burkina Faso according to four climate change scenarios. We first present the variation of the total harvested cereal area in Burkina Faso as simulated by the IMPACT model. In the model, cropland is a function of land cost variation, the marginal revenue of the product, and some nonprice trends. The IMPACT simulations show that compared to the scenario without climate change (SSP2-NoCC), the four climate change scenarios show an increase in total harvested cropland with an average rate of 1.5%. Figure 10 shows that the SSP2-MIROC scenario leads to the highest increase of arable lands in Burkina Faso. However, when we conduct the study by cereal type, the four scenarios' results differ a bit from each other. The three scenarios (SSP2-IPSL, SSP2-GFDL, SSP2-HGEM) predict a decrease in maize area, while the SSP2-MIROC scenario forecasts an increase in the maize areas. This difference can be explained by the uncertainties associated with the projection of future climate change. On the other hand, for cereals such as millet, rice, sorghum, the model predicts an increase in their harvested area.

In sum, according to the simulations, climate change will increase the total harvested area in Burkina Faso, and the impact differs according to the type of cereal considered.

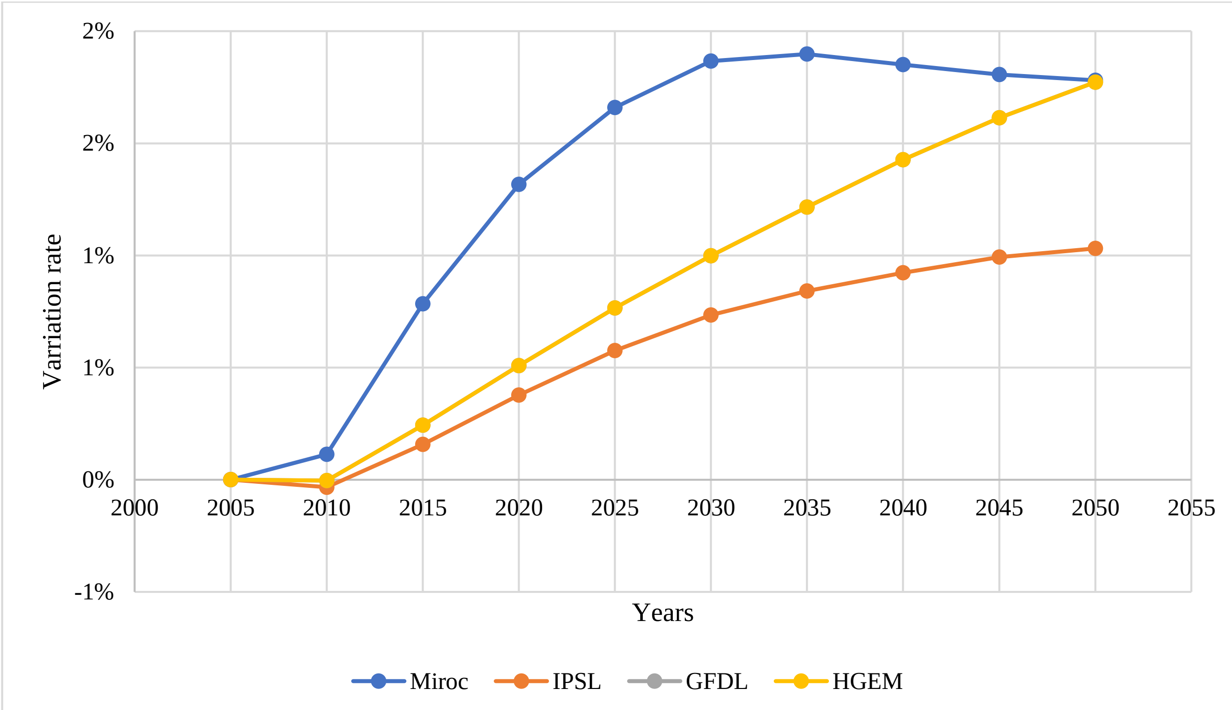

Figure 1.9. *Variation of cereal total land by climate change scenario*

Source*: Built by the author using IMPACT simulation outcomes*

1.3.2.2.Impact of climate change on crop yields

Beyond cropland, climate change will affect agricultural yields. Many studies on the effects of climate change on agriculture in Africa have shown that climate change will negatively affect agricultural yields. Roudier et al. (2011) find that climate change will lead to a yield loss with a median loss close to 11% in a review of 16 recent West Africa studies. In their paper, Van Oort & Zwart (2018) show that climate change will be particularly harmful to some cereals. They find that irrigated rice yield in West Africa will decline by 21% during the wet season and 45% in the dry season. In this chapter, the IMPACT data show that climate change will negatively affect cereal yields in Burkina Faso. Indeed, compared to the baseline scenario (SSP2-NoCC), three climate change scenarios (SSP2-IPSL, SSP2-GFDL, SSP2-HGEM) predict a decline in cereals yields. Figure 11 presents the variation of cereals yields in climate change scenarios compare to the baseline scenario. The average estimated yield losses are 5%, 7%, 6%, respectively, in the SSP2-IPSL, SSP2-GFDL, SSP2-HGEM scenarios. Besides, the variation of yield is negatively associated with the time parameter.

On the other hand, the analysis by type of cereal shows that cereals will be affected differently. The three scenarios of climate change predict that maize will be the most affected cereal in Burkina Faso. Indeed, maize crop is expected to lose on average 21%, 16%, and 18% in the period 2005-2050, respectively, in the SSP2-IPSL, SSP2-GFDL, SSP2-HGEM scenarios. Millet is the less affected in SSP2-IPSL and SSP2-HGEM scenarios. Moreover, SSP2-GFDL predicts that rice will be less affected by climate change, and rice yields will benefit from climate change with an expected 1% increase in yield.

Contrary to the above scenarios, the SSP2-MIROC scenario predicts that climate change will increase agricultural yields. Compared to the baseline scenario, the simulations show that the SSP2-MIROC scenario will cause an average increase in cereals yields of 6% over the period 2005-2050.

These differences in predicting climate change effects can be explained by the lack of accurate climate data in Africa. However, we can conclude that the results of the SSP2-IPSL, SSP2-GFDL, SSP2-HGEM scenarios are closer to reality and are in the same direction as the previous studies.

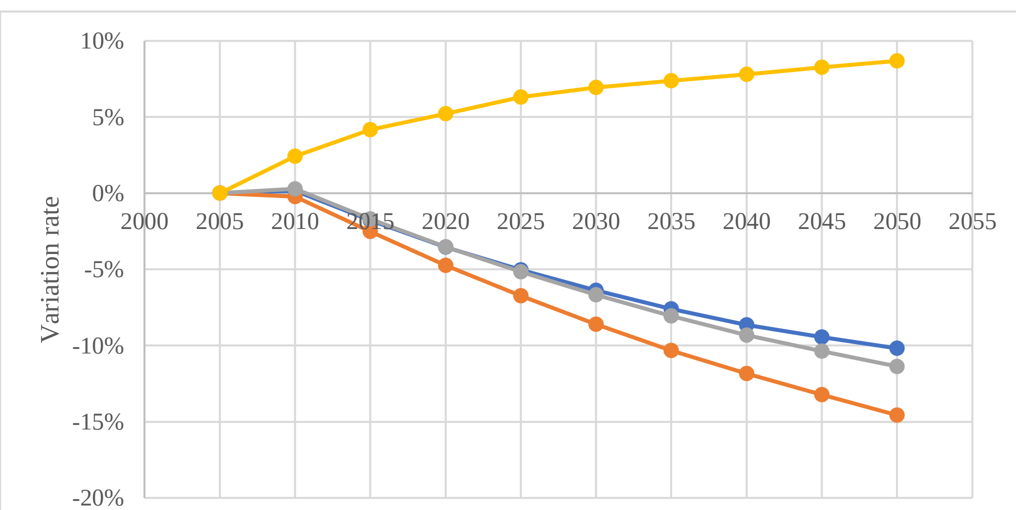

Figure 1.10: *Variation of cereal yields after climate change by scenario*

Figure 1.10. *Variation of cereal yields after climate change by scenario*

1.3.2.3.Impact of climate change on cereal production

The total production equals to cereals' yield times the total cereals' harvested area. In the above sections, we have studied the effect of climate change on cropland and cereals' yields. The simulation results indicate that climate change will positively impact cereals' harvested area and negatively affect cereals' yields. This section aims to assess the total climate change effect on cereals' production in Burkina Faso. Figure 12 shows the cereals' total production variation in four climate change scenarios. The average change in cereals' total production is negative for three scenarios. Indeed, SSP2-ISPL, SSP2-HGEM, SSP2-GFDL respectively show that climate change will cause a 4.7, 4.8, and 6.7% decline in cereals' total production during the period 2005-2050 in Burkina Faso. However, the scenario SSP2-MIROC demonstrates that climate change will be beneficial for cereal production. It displays an increasing rate of the cereals' total production with an average rate of 7.1% over the period 2005-2050 in Burkina Faso.

Moreover, Figure 12 illustrates that climate change started to affect cereals production in 2010, and the highest decrease rate is forecasted to be in 2050 for three scenarios. This decreasing rate is similar to the decreasing proportion of the cereals' yields found above. Therefore, we can say that the total cereals production is more sensitive to the yields contraction than to the cropland gain from climate change. Besides, we display in table 2 the average cereal production variation by type of cereal and by scenario, over 2005-2050. From this Table, we can see that grains will be affected differently by the scenario. In the scenarios SSP2-IPSL, SSP2-GFDL and HGEM, maize will be the most affected with an average decline rate, respectively equal to 24%, 39%, and 20% over the period 2005-2050. The findings results are similar to previous studies by Sultan et al. (2013) in West Africa.

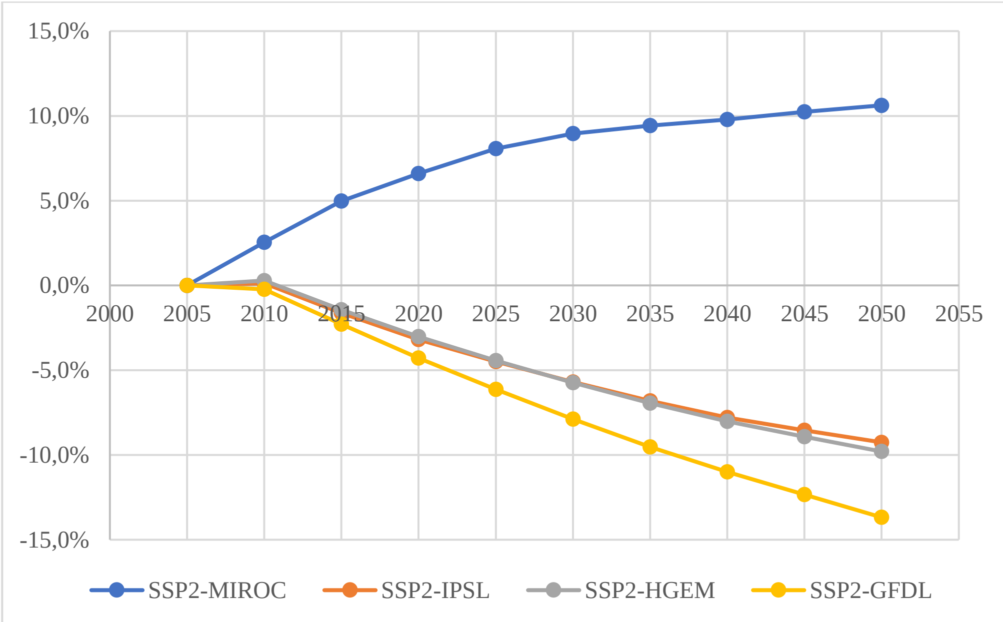

Figure 1.11. V*ariation of total cereal production after climate change by scenario*

Source: *By the author with IMPACT simulation outcomes*

Table 1.2*: Average cereal production variation by type of cereal and by scenario over the period 2005-2050*

Scenarios	***SSP2-IPSL***	***SSP2-GFDL***	***SSP2-HGEM***	***SSP2-MIROC***
CER-Maize	-24%	-39%	-20%	2%
CER-Millet	0%	-11%	2%	17%
CER-Rice	0%	10%	1%	0%
CER-Sorghum	-2%	-10%	-5%	2%

SSP2-IPSL: *Scenario using Institute Pierre Simon Laplace Model climate model and Shared Socioeconomic Pathways 2*

SSP2-GFDL: *Scenario using Geophysical Fluid Dynamics Laboratory model and Shared Socioeconomic Pathways 2*

SSP2-HGEM: *Scenario using* Hadley Centre Global Environment Model version 2 climate model and *Shared Socioeconomic Pathways 2*

SSP2-MIROC: Scenario using Model for Interdisciplinary Research on Climate model and *Shared Socioeconomic Pathways 2*

Source: *Built by the author using IMPACT simulations results*

Conclusion

In Burkina Faso, climate change's physical effects such as drought, floods, temperature increase, and rainfall variability bring about economic and social impacts. This chapter describes the impact of climate change on cereals production in Burkina Faso using the IMPACT model's outcomes. IMPACT is a partial equilibrium model, including a climate model, crop models, water management model, and macroeconomic model. Climate models, crop models, and water management models have been used to estimate yield variation due to climate change. In different scenarios, we examine the effect of climate change on cereals harvested land, yields, and total production during 2005-2050. The results show that climate change will negatively affect cereals' production in three climate change scenarios (SSP2-ISPL, SSP2-HGEM, SSP2-GFDL). For instance, it reveals that global warming will lead to a 4.7, 4.8, and 6.7% reduction of total cereal production in SSP2-ISPL, SSP2-HGEM, SSP2-GFDL, respectively. Besides, the three scenarios predict that maize will be the most affected cereal. The trend of cereal production is similar to the yield trend.

On the other hand, the crop harvested land is expected to increase, but this increase will not reverse the deteriorating effect of climate change on cereal production. These effects of climate change on the agricultural sector will lead to consequences on households' wellbeing, particularly on families that depend on this sector. In the following chapters, we will examine the impacts of climate change on households' welfare.

CHAPTER 2

IMPACT OF CLIMATE CHANGE ON HOUSEHOLDS' WELFARE IN BURKINA FASO.

Introduction

In the previous chapter, we have examined the effects of climate change on the agriculture sector in Burkina Faso. We have shown that the farming sector will be negatively affected by climate change. These effects will lead to an overall wellbeing impact on populations, particularly people who depend on this sector for survival. For instance, the negative impact of climate change on agriculture will reduce household income and impact food availability, influencing households' wellbeing (Weldesilassie et al. 2015).

This chapter investigates the effects of global warming on households' welfare in Africa in general and especially in Burkina Faso. Defining different climate scenarios, physical climate shocks such as temperature variation, precipitations are translated into cropland, and agriculture productivity variation using the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT). Later, these agricultural effects are introduced in the Global Trade Analysis Project (GTAP) standard model as shocks to evaluate the global impact of climate change on households' welfare in Burkina Faso. Using the welfare decomposition method integrated into the GTAP model, simulations show that the decrease of agriculture yield and the variation of cropland caused by climate change will lead to a decline of households' global wellbeing in 2050 in the considered climate scenarios in Burkina Faso. For instance, the results show that climate change will cause a minimum GDP loss estimated at 9.33% and a maximum loss estimated at 17.39% in Burkina Faso by 2050. Besides, simulations demonstrate that climate shocks will lead to an average households' welfare loss estimated as 14% in Burkina Faso by 2050. To our knowledge, it is the first time that a study precisely quantifies the climate shock effect in terms of welfare loss in Burkina Faso, and the results can be used in public policies to mitigate the climate change effect.

The rest of the chapter is structured as follows: Section I defines some theoretical concepts related to the study, and section II describes the CGE modeling. In section III, scenarios and the findings are displayed.

2.1. Theoretical concepts

Modeling the effects of climate change on households' welfare requires considering many climatic and socio-economic aspects. Indeed, it requires the conversion of climatic physical shocks into economic and social shocks. In this section, we define the theoretical concepts and summarize the previous studies related to the subject.

2.1.1. Measuring households' welfare

Household welfare is a complex concept that is difficult to make an exact definition. In the literature, many definitions are proposed. For the OECD (2013), wellbeing is the ability of a household to have the means to fulfill its essential utilities, to thrive, and to be able to live independently. Besides, it adds that welfare depends on immaterial factors such as education and social relations. For their part, Stiglitz et al. (2009) argue that defining wellbeing requires considering the following dimensions: living conditions, health, education, employment, and freedom of expression. Diener & Suh (1997), for their part, think that: "*Subjective wellbeing consists of three interrelated components: life satisfaction, pleasant affect, and unpleasant affect. Affect refers to pleasant and unpleasant moods and emotions, whereas life satisfaction refers to a cognitive sense of satisfaction with life*." While it is challenging to define wellbeing, many indicators are suggested in the literature to measure it.

Among the welfare indicators, quantitative measures such as consumption and income are widely used in the literature. Consumption per capita and total household consumption expenditure are some of the consumption indicators used to evaluate welfare. On the other hand, GDP, GNP, and GDP per capita are widely used as income indicators for evaluating welfare. In the literature, consumption is generally preferred to income for measuring welfare. Authors like Deaton & Zaidi (2002) and Moratti & Natali (2012)) think that consumption measures the wellbeing of a household better than income. Deaton & Zaidi (2002) argue that consumption is less variable and is not subject to price fluctuations.

Furthermore, consumption is a better indicator than income, especially in agricultural societies that produce their products for consumption. Besides the quantitative measures of welfare, subjective measures can be found in the literature. Kahn & Juster (2002) claim that satisfaction with life, health, and composite indexes of positive functioning are utilized in surveys for evaluating welfare.

Some specific indicators are generally used in studies related to the effects of climate change on households' wellbeing. Arslan et al. (2016) studied the effect of climate shocks on welfare in Tanzania and used household consumption and income for measuring welfare. Skoufias & Vinha (2012), in their study in Mexico, use household consumption per capita and the child height for age as wellbeing factors. Weldesilassie et al. (2015), analyzing the impact of climate change on productivity and welfare in Ethiopia, use the consumption expenditure of food and non-food per capita of households and their total expenditure to capture households' wellbeing. Indicators related to health are also used to analyze climate change impacts on human welfare. For instance, Deschênes et al., (2009), Jankowska et al. (2011), and Tagaris et al. (2009) consider the influences of climate change on children, especially on birth weight, malnutrition, stunting, and anemia problems. Finally, subjective indicators are also used to measure climate change's impact on welfare. For instance, Alem & Colmer (2013), in a study, used life satisfaction to analyze the welfare cost of climate variability.

There are many welfare indicators in the literature, and choosing among them depends on the author, the methodology employed, and data availability.

2.1.2. Channels through which climate change impacts the welfare

The environmental and biophysical effects of climate change will alter the welfare of households in many ways. Global warming can affect households' wellbeing through its impacts on the economic sectors and particularly on the agricultural sector. Indeed, the decline of agriculture production due to the decrease in crop yields and soil degradation will increase agricultural product prices and reduce food availability and accessibility. As a result, households' welfare will be impacted. In addition, household welfare can be affected by climate change's impact on health. Many studies (Deschênes et al., (2009), Jankowska et al., (2011), and Tagaris et al., (2009)) have shown that climate change will have direct effects on health of the households, and these effects may affect their wellbeing. Skoufias & Vinha

(2012) argues, for instance, that climate change, which is characterized by an increase in the temperature level, will make some pathogens much more resistant and increase the risk of such as malaria and heart diseases.

Furthermore, households' disposable income reduction due to climate change impacts on agriculture could reduce household health expenditure. The impact of climate change on households' assets will also be a channel through which climate change can affect welfare. Weldesilassie et al. (2015) point out that climate change's consequences could push households to sell their assets for adapting. Therefore, that will limit their production capacities in the future and negatively impact their welfare.

In sum, there are several channels through which climate change could affect households' wellbeing in developing countries. This chapter examines the effects of climate change on households' welfare from the agricultural sector.

2.1.3. Theoretical CGE modeling of climate change's impact

Economic modeling of climate change impact is very challenging because it requires quantitative investigation of a wide range of environmental, economic, and social issues (Stern, 2006). Many approaches have been developed for evaluating the economic and social impact of climate change, and each of them has its strength and weakness. Among those approaches, we have the Computable General Equilibrium (CGE) models, which are nowadays widely used in the literature of climate change impacts. Computable General Equilibrium models originated from Leon Walras' general theory of equilibrium developed during the nineteenth century. However, Arrow and Debreu are the first designers of the modern computable general equilibrium models formalized in the 1950s. These models consist of a detailed set of equations representing the economic sectors in aggregate production and utility functions for producers and consumers. They assume a simultaneous equilibrium in all the markets of the economy, which they call general equilibrium. According to Wing (2004), this equilibrium is assured under three conditions: the market-clearing conditions, the zero-profit, and the income equilibrium condition. In recent decades, there has been a rapid growth in the use of the CGE models with extensions to many domains.

For instance, nowadays, these models are used to solve a variety of issues ranging from the effects of exogenous shocks to the impacts of specific policies on overall welfare and income inequality. The use of CGE models has been extended to assess climate change global economic effects, considering the interactions between economic agents and activities. CGE models are also used to analyze the mitigation and adaptation policies and evaluate the agreements on reducing greenhouse gas emissions (Böhringer et al., 2012). In recent literature, many CGE-type models have been specifically designed to estimate the effects of climate change. Bellow, we review some of the CGE models used for evaluating climate change's impact on the overall economy.

The Global Trade Analysis Project (GTAP) model is a multiregional, multisectoral general equilibrium model with perfect competition and constant returns to scale assumptions, developed by a group of researchers at Purdue University in 1992. It compries a database, a standard general equilibrium framework, and software for data manipulation and model implementation (Nijkamp et al., 2005). The global database combines comprehensive data on bilateral trade, transport, and protection that determines linkages between regions and national input-output databases. GTAP models have been used widely to estimate the costs of greenhouse gases (GHG) reduction and the spillover effects resulted from this. Nowadays, many sub-models of GTAP have been designed to analyze specific sectors. For instance, GTAP-E Burniaux & Truong (2002) is designed for describing the behavior of energy consumers in the situation of high energy prices, and GTAP-W (Calzadilla et al., 2011) is is used in order to account for water use in the agriculture sector.

The Inter-Temporal Computable Equilibrium System (ICES) is another CGE model that is used to analyze climate change’s impact developed by the Fondazione Eni Enrico Mattei (FEEM). It is a recursive dynamic multiregional Computable General Equilibrium (CGE) model that is used to evaluate climate change impacts on the economic system and study mitigation and adaptation policies. The model consists of 8 regions spread across the world, 28 indicators related to the 17 Sustainable Development Goals (SDGs), and a time horizon between 1997 and 2050. It is derived from the GTAP-E model developed by Burniaux & Truong (2002), a GTAP standard model module. In the model, each country's economy is represented by n industries, a representative household, and the government. Industries are modeled as representative cost-minimizing firms, taking input prices as given. The model assumes that the average cost of production estimates output price and production functions are specified as CES function. ICES model provides a comprehensive tool for analyzing climate change impacts, mitigation, adaptation strategies, and sustainability.

Economy Projection and Policies Analysis (EPPA) is one of the two components of the Integrated Global System Modeling (IGSM) framework developed by the MIT Joint Program on Science and Policy of Global Change. EPPA is a recursive-dynamic multiregional CGE model used to project the world global economy at regional and sectoral levels. It is based on the GTAP dataset and adds complementary data on greenhouse gas emissions. The first version of the EPPA model was created in 1997 by Jacoby et al. (1996), and since 2000, it is updated recursively every five years. Nested CES production functions specify all production and final consumption sectors, but Cobb-Douglas and Leontief functions are also used in some cases. The EPPA model is used to simulate the global economy's progress, demographics, trade-in time to produce scenarios of greenhouse gases, aerosols, other air pollutants, and their antecedents. The core model contains 18 regions; however, it has been extended with an application at a vast spatial, economic sector, and household studies. This chapter uses the standard GTAP model to analyze the impact of climate change on households' welfare.

2.2. Empirical works on climate change effects on households' welfare

This section reviews the empirical studies on the influence of climate change on households' welfare. There are two types of research in the literature related to climate change's effects on households' welfare. First, quantitative studies have examined the impact of climate shocks on consumption, income, and household health. Secondly, the studies that have analyzed the effect of global warming on households' subjective welfare.

2.2.1. Quantitative studies on climate change impact on households' welfare

2.2.1.1. Impact of climate change on households' income and consumption

Household consumption and income have been the focus of many studies on climate change's impact on household welfare. Households whose production and consumption come from sectors directly affected by climate change are likely to be affected by global warming. The Ricardian model, the hedonic model, and econometric estimations are generally used to evaluate climate change's impact on productivity, production, and farm income. Skoufias & Vinha (2012), analyzing climate shocks' impacts on households' welfare in Mexico, find that the shocks affect households living in municipalities with a dry climate. When they examine all their samples together, the analysis shows a non-significant impact of climate shocks on food and non-food consumption. Therefore, they conclude that weather shocks' effects on households' welfare are a function of the regional climate characteristics. Kabubo-mariara et al. (2016) use a panel data method to examine the impact of climate change on Kenya's food production and poverty. Their study's outcomes reveal a non-linear impact of climate factors on food production and the likelihood of food insecurity. Their study also reveals a positive relation between humidity and food production until an optimal point. Furthermore, they advise that adaptation and mitigation policies such as new technology and market access can reduce the effect of climate change. Mulatu et al. (2016), using a Computable General Equilibrium (CGE), find that Green House Gases negatively impact the agriculture sector's productivity and households' wellbeing in Ethiopia. Indeed, their results show that compared to the defined baseline scenario, climate change will reduce Ethiopia's GDP by 4.5 percent. A panel data analysis (Schlenker et al., 2010) demonstrates that global warming will negatively affect agricultural production in SSA. For instance, their results reveal that crops such as maize, millet, sorghum, cassava, and groundnut production will respectively decrease with a rate of −22, −17, −18, −8%, and −17 by the mid-century. Besides, their study shows that African countries experiencing high agricultural yields will realize the significant yield losses due to climate change.

Hirvonen (2016) examines the impact of temperature change on households' consumption in Tanzania. He shows that temperature level in the growing season is negatively correlated with households' consumption per capita. For instance, his results reveal that a 1% increase in the mean monthly temperature leads to a 4.9 to 5.5% decline of per capita consumption on average in Tanzania. Marx & Espagne (2019) inspect the impact of climate variability on households' income in Vietnam using a non-linear specification. Their research demonstrates that the number of days with a temperature level above 33°c is negatively correlated with yearly income. For instance, one more day with a temperature above 33°C is associated with a decrease of 1.3% of households' annual income. Using the RCP scenario, they stimulate that global warming could lead to a 100% loss of households' income by 2099 in the Vietnam regions. For their part, Arndt et al. (2015) evaluate the implication of climate change on Ghana's economy using a CGE model. They underline that climate change adversely affects Ghana's economy, particularly the agriculture sector. Indeed, their simulations show that the climate change scenario causes a decrease in agriculture GDP with a 1.9% decline rate compared to the non-climate change scenario. However, these climate change impacts vary widely across scenarios and regions. To sum up, most previous studies analyze the impact of climate on households' wellbeing on agriculture sector production and consumption.

2.2.1.2.Impact of climate change on households' welfare in Burkina Faso

The literature on assessing the effects of climate change on Burkina Faso is very scarce. The existing studies have focused on analyzing global warming impacts on the agricultural sector and food security. For instance, Ouedraogo et al. (2006) evaluate the impact of climate shocks on agriculture production in Burkina Faso using the Ricardian method. Their research shows that a marginal increase in temperature will result in a decrease in agriculture revenue of US 19.9 dollar per hectare, while an additional growth of 1mm a month of precipitation will result in a loss of US 2.7 dollar per hectare in farming revenue. Besides, they demonstrate that irrigated crops are less sensitive to rainfall and more vulnerable to temperature than non-irrigated farms. Their findings are in line with (Siégnounou 2011). Indeed, Siégnounou (2011) points out that there is no link between water resources availability and crop production. However, there is a correlation between irrigated production, temperature, and rainfall in the Ouahigouya region located in the north of the country.

Oueresse (2009), meanwhile, estimated the effect of climate change on the cotton crop in a village in the western part of Burkina Faso. His research shows that the insufficiency of rainfall leads to a significant drop in cotton farmers' income. In the same vein, Diarra et al. (2017) examine climate change's impact on the cotton crop in Burkina Faso. They show that both temperature and precipitation variation will negatively influence the yield of cotton in

Burkina Faso. However, the effect of temperature will be relatively higher than the effect of rainfall.

Zidouemba (2017) use a CGE model to analyze the economic impact of climate change in Burkina Faso. By assuming that climate change will increase rainfall variability and decline crop yields, he finds that the total effect of global warming will be a reduction of national welfare, with rural households being the more affected. Also, he finds that the extent of climate change's impact is a function of the scenario. Another study by Zidouemba (2017b) employs a CGE model to evaluate climate shocks' impact on households' food security in Burkina Faso. The CGE model simulations reveal that rural households and urban low-income households will be the most affected by global warming in Burkina Faso.

In this chapter, we extend the literature on the effect of climate change in Burkina Faso by examining the effect of climate change on households' welfare using a combination of partial and general equilibrium models.

2.2.2. Effect of climate change on households' subjective wellbeing

Some studies examine climate change's impact on households' welfare using subjective wellbeing measures. Many approaches were developed to examine the impact of climate change on households' subjective wellbeing.

Hedonic approach and subjective life satisfaction are generally combined to analyze the effects of climate change on welfare. Life satisfaction is an indicator of wellbeing computed with survey data, where participants are generally asked to evaluate their current life situation in a range of a given interval. The hedonic approach assumes that goods' values are estimated according to utilities and characteristics (Rosen, (1974)). Therefore, in several studies (Rehdanz & Maddison, 2009; Nakic et al., 1996; Rehdanz 2006) related to climate impact on welfare, the climate variables are included as factors that influence life satisfaction. A study by Rehdanz & Maddison (2005) using cross-national data and controlling for other factors show that temperature and rainfall significantly affect subjective wellbeing.

Alem & Colmer (2013) evaluate the cost of change change in terms of welfare in Ethiopia. They combined atmospheric data with panel data collected in rural Ethiopia to demonstrate that the uncertainty related to climate variability reduces households' subjective wellbeing.

Also, they show that one standard deviation of climate change leads to a decrease in life satisfaction equivalent to a 2% consumption. Möllendorff & Hirschfeld (2016), for their part, evaluate the effect of extreme weather events on life satisfaction. Using a fixed-effect model, they find that extreme events such as flood, hail, and storm cause a small decline in life satisfaction ranging from 0.020–0.027 on a scale of 11.

Maddison & Rehdanz (2010) evaluate the impact of climate change on life satisfaction in 87 countries using the World Value survey data. They find that climate shocks negatively influence African countries, while Northern Europe will be less affected and may benefit from climate change in term of life satisfaction. Carroll et al. (2009), using a hedonic technique with a fixed effect estimation method, find that drought in springs negatively affects life satisfaction, estimated to annual income reduction of A$18,000 in Australia. Nakic et al. (1996) used the hedonic method to examine the impact of doubling CO_2 on climate amenities in the USA. The study reveals that a doubling of CO_2 will decrease climate amenities, which corresponds to 0.17% of US GDP.

2.3. Methodology framework

This section describes the theoretical framework used in this study to analyze climate change's impact on households' welfare. In the preview chapter, we have described the effects of climate change on agriculture in Burkina Faso using the IMPACT model's outcomes. In this chapter, we use these results to build scenarios for the standard GTAP model simulations.

2.3.1. GTAP standard model

The Global Trade Analysis Project (GTAP) standard model is a static General Equilibrium Model covering the whole world and assuming perfect competition, constant returns to scale, and quantity homogeneity in the production sectors. GTAP standard model is derived from the family of neo-classical theory models, which differentiate, on the one hand, real variables and relative prices, and on the other hand, price level. The model is global because it includes all the world countries, with some countries represented individually and others incorporated in regional aggregates. Countries follow the same pattern of representations with some differences in the data reference years. The model is compatible with the input-output data framework, and all the supply and uses of the different goods are included. The GTAP model resolution requires a non-linear solution methodology since its formulation is non-linear.

Figure 13 displays the graphical representation of the GTAP standard model. It defines a regional household that gathers each region's total income and distributes it through private consumption, government consumption, and savings to maximize a regional utility. The total income includes factors income and direct and indirect tax income. Model details can be found in *CORONG et al. (2017).*

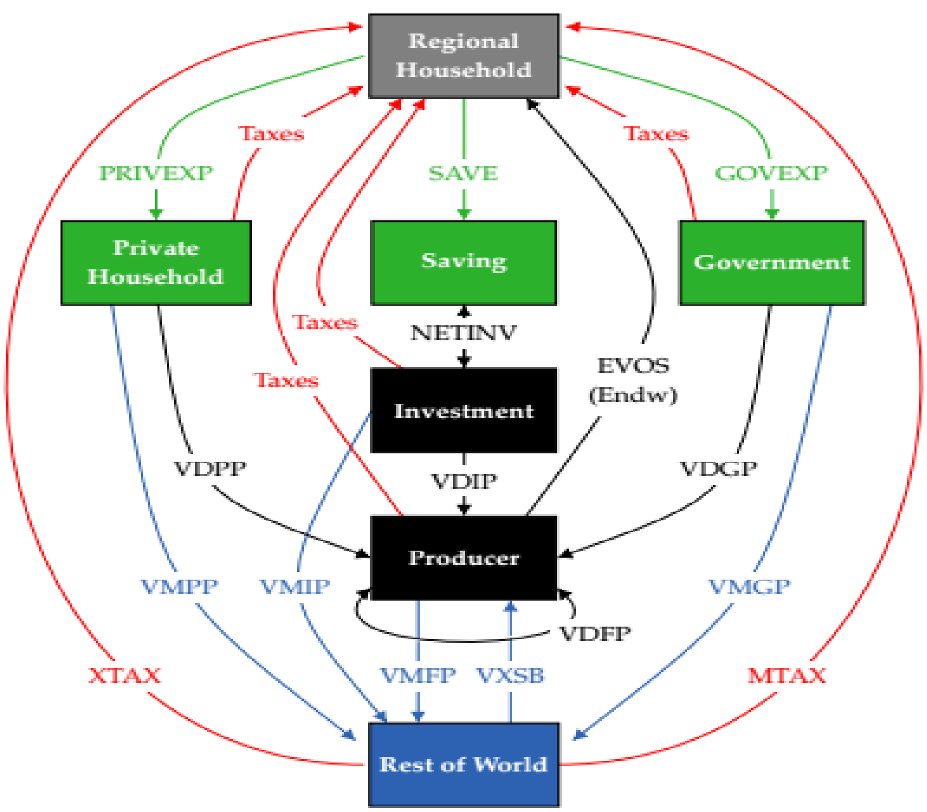

Figure 2.1. *GTAP Graphical representation*

Source: *CORONG et al., (2017)*

2.3.1.1.Firms' behavior in the model

The production activities are fulfilled by an industry that includes many identical and insignificant firms in the model. These firms adopt cost minimization behavior, and the zero-profit condition is verified for each activity. The production structure in the GTAP model is shown in Figure 14. It consists of a sequence of nested constant elasticity of substitution (CES) production functions. The production activity is carried out in three stages.

Each regional activity sector at the top-level combines value-added and intermediate inputs following a CES function to produce a composite sectoral output. Each component at this top-level production nest can be written as in equations 1 and 2. The equations are written in percentage change form, as it is a commonly used practice when using GEMPACK for running simulations.

$$\boldsymbol{qva_{a,r} = q0_{a,r} - a0_{a,r} - ava_{a,r} - ESUBT_{a,r}\left(pva_{a,r} - ava_{a,r} - p0_{a,r} - a0_{a,r}\right)} \quad (\mathbf{1})$$

$$\begin{aligned}\boldsymbol{qint_{a,r}} &\boldsymbol{= q0_{a,r} - a0_{a,r} - aint_{a,r}} \\ &\quad \boldsymbol{- ESUBT_{a,r}\left(pint_{a,r} - aint_{a,r} - p0_{a,r} - a0_{a,r}\right)} \quad (\mathbf{2})\end{aligned}$$

Where,

$\boldsymbol{qva_{a,r}}$ and $\boldsymbol{qint_{a,r}}$ are respectively change in value-added demand and intermediate demand for the production of activity a in region r.

$\boldsymbol{ESUBT_{a,r}}$ the elasticity of substitution between value-added and intermediate input

At the second level, the different components of value-added and intermediates inputs are determined using the CES function.

The value-added bundle for each activity is determined by associating primary production factors such as natural resources, land, capital, and labor using a CES production function. The demand function of each factor is displayed in equation 3.

$$\boldsymbol{qfe_{e,a,r} = qva_{a,r} - afe_{e,a,r} - ESUBVA_{a,r}\left(pfe_{e,a,r} - afe_{e,a,r} - pva_{a,r}\right)} \quad (\mathbf{3})$$

Where,

$\boldsymbol{qfe_{e,a,r}}$ change in the demand for factor $\boldsymbol{e}$ **of** activity a in region r

$\boldsymbol{ESUBVA_{a,r}}$ the substitution elasticity of factor of activity a in region r

On the other hand, different intermediates' inputs are combined in a CES structure to give the sectoral aggregate intermediate demand. The demand function for each commodity included in the composite intermediate input is written as below.

$$\boldsymbol{qfa_{c,a,r} = qint_{a,r} - afa_{c,a,r} - ESUBC_{a,r}\left(pfa_{c,a,r} - afa_{c,a,r} - pint_{a,r}\right)} \quad (\mathbf{4}),$$

where

$\boldsymbol{qfa_{c,a,r}}$ change in the intermediate demand for composite commodity c by activity a in region r

$\boldsymbol{ESUBC_{a,r}}$, substitution elasticity

Furthermore, the commodity's demand is disaggregated in domestic products and imported commodities at the final stage. The quantities of demand for domestic commodities and the demand for composites import commodities are determined using the Armington elasticity of substitution between domestic and imported goods. Equations 5 and 6 describe the demand for domestically produced commodities and the demand for imported goods.

$$\boldsymbol{qfd_{c,a,r} = qfa_{c,a,r} - ESUBD_{c,r}\left(pfd_{c,a,r} - pfa_{c,a,r}\right)} \quad (\mathbf{5})$$

$$\boldsymbol{qfm_{c,a,r} = qfa_{c,a,r} - ESUBD_{c,r}\left(pfm_{c,a,r} - pfa_{c,a,r}\right)} \quad (\mathbf{6})$$

Where,

$\boldsymbol{qfd_{c,a,r}}$ change in demand for domestically produced commodity c by activity a in region r

$\boldsymbol{qfm_{c,a,r}}$ change in demand for composite import goods

$\boldsymbol{ESUBD_{c,r}}$Armington substitution elasticity between domestic and imports goods.

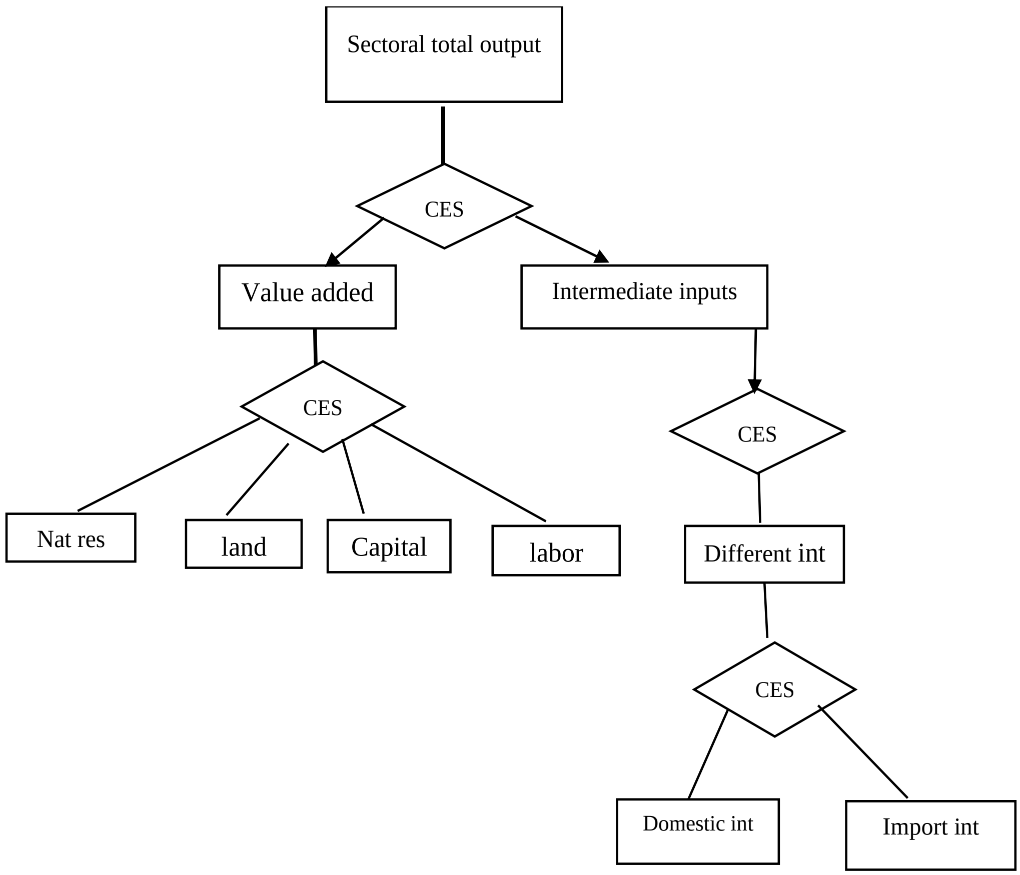

Figure 2.2. *Graphical representation of the nest production structure*

Source*: Made by the author inspired*

2.3.1.2.The supply of commodities

The current version of the GTAP standard model offers the industry sectors the possibility to supply more than one good and allows a good to be supplied by different industries. The industries use a Constant Elasticity of Transformation (CET) functions to maximize total revenue. Each industry supply function can be written as follow:

$$qca_{c,a,r} = q0_{a,r} - ETRAQ_{a,r}\left(ps_{c,a,r} - p0_{a,r}\right)$$

$qca_{c,a,r}$ the changes in the supply of commodity c produced by activity a in region r

$ETRAQ_{a,r}$ transformation elasticity

$ps_{c,a,r}$ the change in the price of commodity c produced by activity a in region r

$p0_{a,r}$ the change in the unit price of activity a in region r.

2.3.1.3.Income and expenditure

The GTAP standard model adopts the regional household representation that receives the total income and redistributes it. There are two primary sources of income, defined as total factors income and tax income.

$Y_r = FINCOME_r + INDTAX_r$, where

Y_r, total income

$FINCOME_r$, total factors income

$INDTAX_r$, total tax incomes

$$FINCOME_r = \sum_a \sum_e PEB_{e,a,r} QES_{e,ar} - \delta_r PINV_r KB_r$$

Where,

$PEB_{e,a,r} QES_{e,ar}$, total factor remuneration

$PINV_r KB_r$, depreciation

This total revenue is gathered by a regional household, which spends it on private consumption, public expenditure, and saving. The regional household maximizes a Cobb-Douglas per capita utility function, which has three sub-utilities derived from private consumption, public expenditure, and saving. The regional household’s maximization problem can be written as below.

$$\begin{cases} Max\ U_r = A_r^u U_r^{P^{\beta_r^P}} U_r^{G^{\beta_r^G}} U_r^{S^{\beta_r^S}} \\ Subject\ to, Y_r = E_r^P\left(U_r^P, P_r^p\right) + E_r^G(U_r^G, P_r^G) + E_r^S(U_r^S, P_r^S) \end{cases}$$

Where,

P, G, S represent respectively, private consumption, public expenditure, and saving.

Y_r, the total regional household's income

U_r, regional household's utility

$U_r^{P^{\beta_r^P}}$, $U_r^{G^{\beta_r^G}}$, and $U_r^{S^{\beta_r^S}}$ are respectively regional household's sub-utility of private consumption, public consumption, and saving.

E_r^P, the expenditure required to achieve each sub-utility

Private consumption follows a Constant Difference Elasticity (CDE) preferences, while public expenditure and saving function derive from CES utility functions. Private consumption and government consumption include both domestically produced goods and imported commodities. The Armington structure decomposes the different demands into domestic goods and mixtures imported commodities following a CES preference function. Therefore, domestic goods and import commodities are not perfect substitutes. Besides, the regional household's saving is the sum of domestic savings and net foreign capital flow. More details about the model's expenditure specification can be found in the paper of (Corong et al. 2017).

2.3.1.4.Model equilibrium

The GTAP model equilibrium is assured by the equilibrium in the goods and services market and the factors market.

The equilibrium in the goods and services market is written as below:

$QC_{c,r} = QDS_{c,r} + QST_{c,r} + \sum_d QXS_{c,r,d}$, where

$QC_{c,r}$ the supply of commodity c in region r

$QDS_{c,r}$ Domestic supply of commodity c in region r

$\sum_d QXS_{c,r,d}$, the total export of commodity c of region r

$QST_{c,r}$ the total trade and transport sector

The equilibrium equation in the factors markets is defined according to the type of factor. We distinguish three types of factors: mobile and partially mobile and fix factors or sector-specific factors. For instance, for mobile factors, the equilibrium equation is written as follows.

$QE_{e,r} = \sum_e QFE_{e,a,r}$, where

$QE_{e,r}$ the total stock of fix factor e in the region r

$QFE_{e,a,r}$, the demand for factor e of activity a in the region r

2.3.1.5.Model closure

In CGE modeling, the model closure consists of defining the exogenous variables and endogenous variables. GTAP standard model offers many possibilities of model closure. The global closure in GTAP standard model is a Neoclassical closure type where investments are driven by saving. For this study, the standard closure was adopted. In other words, we hold fixed the regional saving rate, which is equal to the average price of capital goods. The model closure adopted in this study can be found in Appendix A1.

2.3.2. Welfare decomposition in the model

CGE models offer many possibilities to analyze the welfare effect and the sources of variation following a shock.

In the GTAP standard model, the regional welfare is measured as the variations in the regional household utility or equivalent variation. The equivalent variation is a money-metric indicator that quantifies the change in the household's utility. Therefore, we can compute a shift in regional welfare by computing the difference between the utility level at the base scenario and the utility level after introducing a shock in the model.

The welfare decomposition technique consists of determining welfare change sources following a shock or a policy change. The welfare change can be decomposed into allocative efficiency, trade terms, technology efficiency, endowment change, and population effect. Hertel & Huff, (2000) develop a technic associated with the GTAP standard model to decompose the welfare variation into its different variation sources. For instance, the allocative efficiency effect on welfare results from the economic resources' reallocation caused by economic distortions. The terms of trade' effect on welfare change arise from a shock's impacts on exports and imports prices of a region. The variation of economic factors stocks causes the factors or endowment effect on welfare change following a shock or policy change. For example, an increase in the capital stock will increase regional welfare. Finally, the change in the population influences regional welfare. More information about this welfare decomposition is available in (Hertel & Huff, 2000).

In this thesis, we examine the effect of climate change on households' welfare using the welfare decomposition method.

2.3.3. Data

In this thesis, we use the GTAP Africa2 database. GTAP data is a global database describing the world economy in a reference year. It includes input-output tables for different countries or regions, data on bilateral trade, taxes, and transport margins data. The data are compatible with many CGE models used for policy analysis.

The GTAP Africa 2 data were released with GTAP 8 data. These data include 42 regions/countries in which 32 are African countries and 57 activity sectors. Burkina Faso is added as a single region in the data. The input-output tables of Burkina Faso for aggregating the GTAP data were supplied by Balma (2012). The data contain the Social Accounting Matrice of Burkina Faso in the year 2005. This SAM has 132 accounts of goods and services and 74 accounts of converted activities into the GTAP standard input-output table style. To fulfill this study's objectives, we aggregate the GTAP Africa 2 into eleven regions, ten sectors, and five production factors, as shown in table 3. Besides these data, we have trade elasticities and preference parameters for the model calibration.

Table 2.1: Regional, sectoral, and factors aggregation

a. Regions aggregation

Region	Description
BFA	Burkina Faso
SSA	Sub-Saharan Africa
Oceania	Australia, New Zealand
EastAsia	East Asia
SEAsia	Southeast Asia
SouthAsia	South Asia
NAmerica	North America
LatinAmer	Latin America
EU_27	European Union 25
MENA	Middle East and North Africa
RestofWorld	Rest of World

b. Sectors aggregation

Sector Code	Description
GrainsCrops	Grains and Crops
MeatLstk	Livestock and Meat Products
Extraction	Mining and Extraction
ProcFood	Processed Food
TextWapp	Textiles and Clothing
LightMnfc	Light Manufacturing
HeavyMnfc	Heavy Manufacturing
Util_Cons	Utilities and Construction
TransComm	Transport and Communication
OthServices	Other Services

c. Factors aggregation

Factor code	Comprising	Mobility
Land	Land	Nonmobile
NatRes	NatRes	Non-mobile
Capital	Capital	Mobile
Labor	UnSkLab, SkLab	Mobile

Source: GTAP Africa 2 data aggregated by author

2.3.4. Scenarios description

For analyzing the effect of climate change, we define two scenarios that represent different perspectives of the economic situation of Burkina Faso and the world economy. A scenario without climate change is named baseline scenario, and four climate change scenarios were defined.

The baseline scenario depicts the socioeconomic indicators' trend from 2005 to 2050, assuming a stable climate. Therefore, Shared Socioeconomic Pathway assuming a stable climate from 2005 (SSP2-NoCC) projections were used. Shared Socioeconomic Pathways display different possible changes in the global economy, society, and demography in the future. The SSP2, called the 'middle of the road' scenario, depicts a future world where global indicators will not significantly differ from their historical trends. In fact, in this scenario, economic growth and environmental degradation will keep their current increasing trend but slower in the future. Using the SSP2 scenario's projections provided by IFPRI, we describe the socio-economic indicators such as population, real GDP, labor force, and cropland between 2005-2050.

The results of the baseline scenario are compared to four climate change scenarios. In general, in studies, climate change impacts are estimated using the Global Climate Models (GCM) and biophysical models. Firstly, Global Climate Models (GCM) are used to simulate the physical climate change effect. Secondly, biophysical models are employed to translate these physical effects into economic shocks. However, the challenge is that different GCMs produce distinct projections of climate change effects. According to Dudu (2013), each GCM prediction is a probability distribution sample, which can be defined by a mean and a standard deviation. Therefore, using different climate scenarios is likely to give better results. In this study, we define four climate change scenarios according to different GCMs. The four GCMs include the Earth System Model of the Geophysical Fluid Dynamics Laboratory (GFDL), the Hadley Centre of Global Environment Model (HADGEM), the Institute Pierre Simon Laplace Model (IPSL-CM5A), and the Model for Interdisciplinary Research on Climate (MIROC). Using these climate change scenarios, we estimate climate change impacts on agriculture yields and arable lands. These impacts are then included in the GTAP model as climatic shocks.

Each climate change scenario's simulation outcomes are compared to the baseline scenario outputs to estimate the climate change effect on household welfare. The climate change scenarios are combined with the SSP2 as a future socioeconomic trend. The different Scenarios are summarized in table 4.

Table 2.2: Scenarios description

Scenarios	Description
SSP2_NoCC	It supposes an economic trend with a constant climate
SSP2_MIROC	Climate change scenario estimated under MICROC GCM
SSP2_IPSL	Climate change scenario estimated under GCM IPSL
SSP2_GFDL	Climate change scenario estimated under GCM GFDL
SSP2_HADGEM2	Climate change scenario estimated under GCM HADGEM

Source: Author

2.3.4.1.Baseline scenario experiment

The baseline scenario explains the different regions' socio-economic indicators during 2005-2050, assuming a stable climate. Therefore, to develop this scenario, we use projections throughout 2050 for GDP, population, arable land, capital stock, and labor. Population, GDP growth, and arable land are from the IFPRI projected data, and capital stock and labor growth rates are taken from Foure et al. (2012). In the baseline scenario, most of these variables have an increasing trend during 2005-2050 in all the regions. In Burkina Faso, the population will increase by 171.8% in 2050 (figure 15). This high population growth rate is explained by the country's annual population growth rate, estimated at 3%. The GDP will increase by more than 1000% and precisely by 1442.21% in 2050 compared to its level in 2005. Also, production factors will increase respectively, with a rate of 50.63 %, 267.80 %, and 1122.28% for land, labor, and capital stock. In the GTAP model, GDP is an endogenous variable, and to impose the projected value of real GDP, we need first to interchange GDP for total factor productivity and solve for the total factor productivity, which corresponds to projected real GDP Burfisher, (2011). After solving this total productivity, we restore the model with GDP endogenous and productivity exogenous.

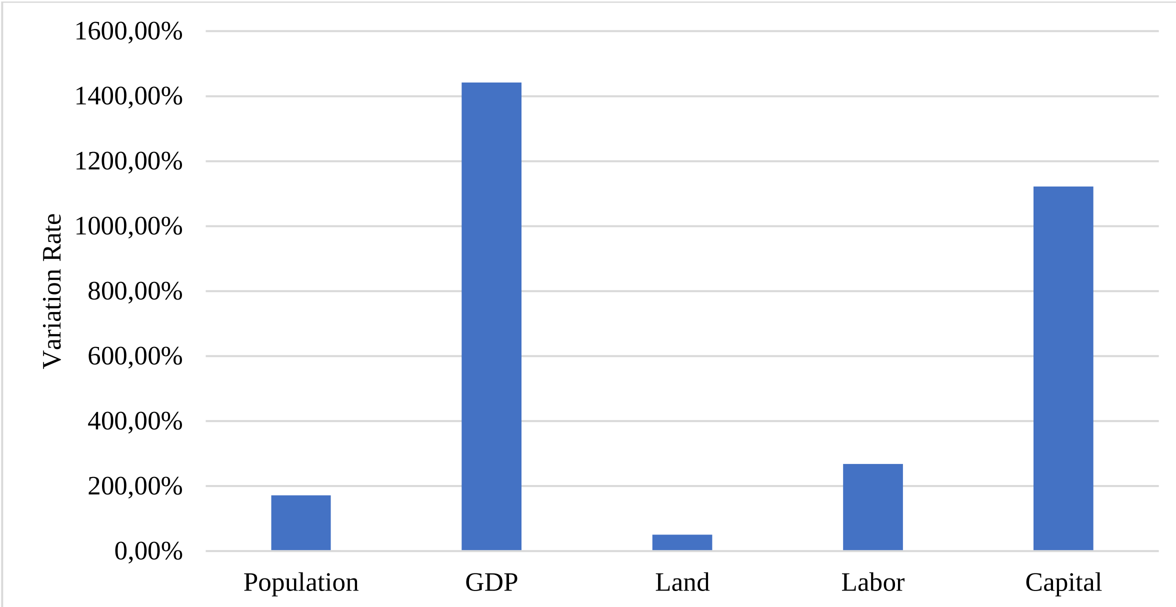

Figure 2.3. *Socioeconomic indicator in the baseline scenario in %*

Source: *Made by the author using Foure et al. (2012) and IFPRI data*

2.3.4.2.Climate change scenarios experiment

Effect of climate change on agricultural yield

Figure 16 displays climate change's effects on agriculture production yields according to different scenarios. It shows that the four climate scenarios will lead to a drop in the average agriculture yield in Burkina Faso in the 2005-2050 period. The SSP2-IPSL predicts the highest decline rate estimated as -22.94%, while the lowest decreasing rate estimated as -2.47% occurs in the SSP2-MIROC scenario. The decrease of average crop yield is also observed in most other regions and the four scenarios, except in Oceania and East Asia, where an increasing rate is observed in some scenarios. However, the yield shift is highly fluctuating according to region and scenario. The most considerable change in yield is estimated as –32.20% , which is observed in North America under the SSP2-GDFL climate change scenario.

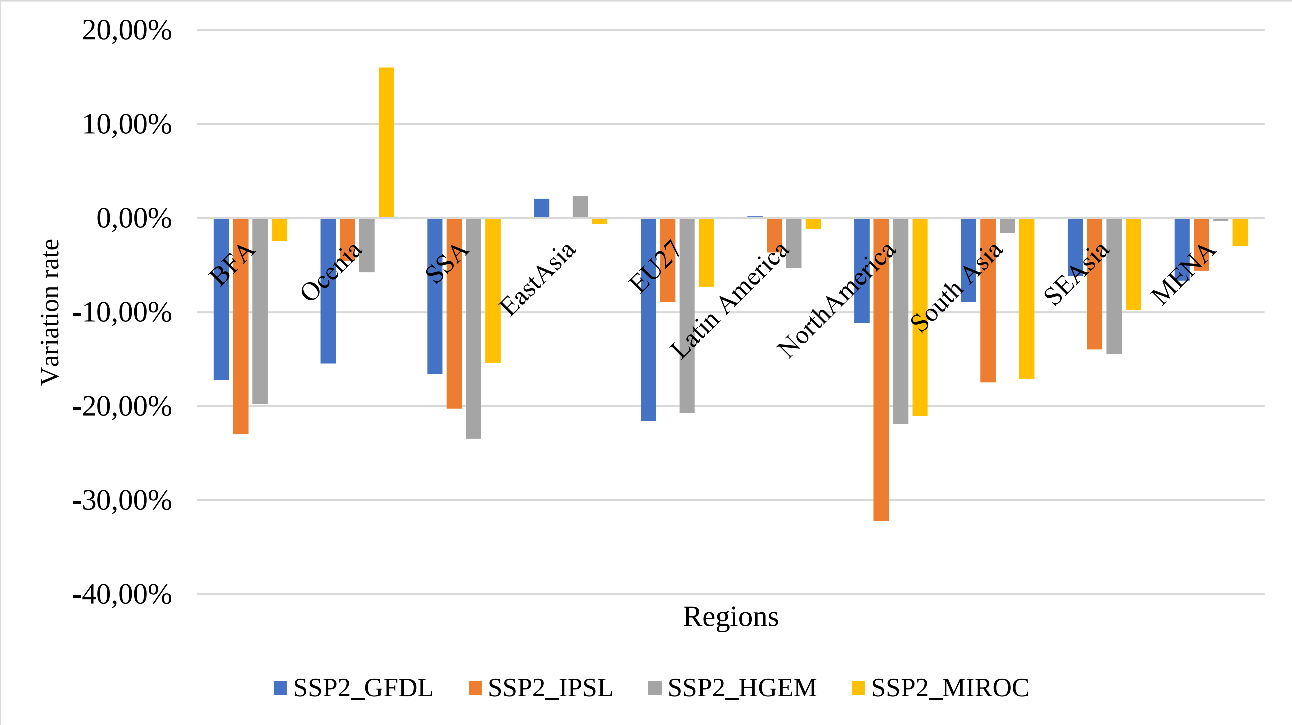

Figure 2.4. *Effect of climate change on yield during 2005-2050*

Source: *GTAP standard model simulation outcomes*

Effect of climate change on arable lands

Figure 17 displays the effect of climate change on croplands. It shows that climate change will increase harvested croplands in Burkina Faso. The highest increase will be in the SSP2-MIROC scenario, while SSP2-GFDL gives the lowest increasing rate of croplands due to climate change in Burkina Faso. Climate change will also increase lands used in the other regions, with the most massive increase observed in the MENA region. However, in Oceania, climate change leads to a decline in croplands in three scenarios. Besides, different climate change scenarios produce different variation rates of croplands in different regions.

The climate change effects on crop yields and croplands variation will be included in the GTAP model to analyze climate change's effect on welfare.

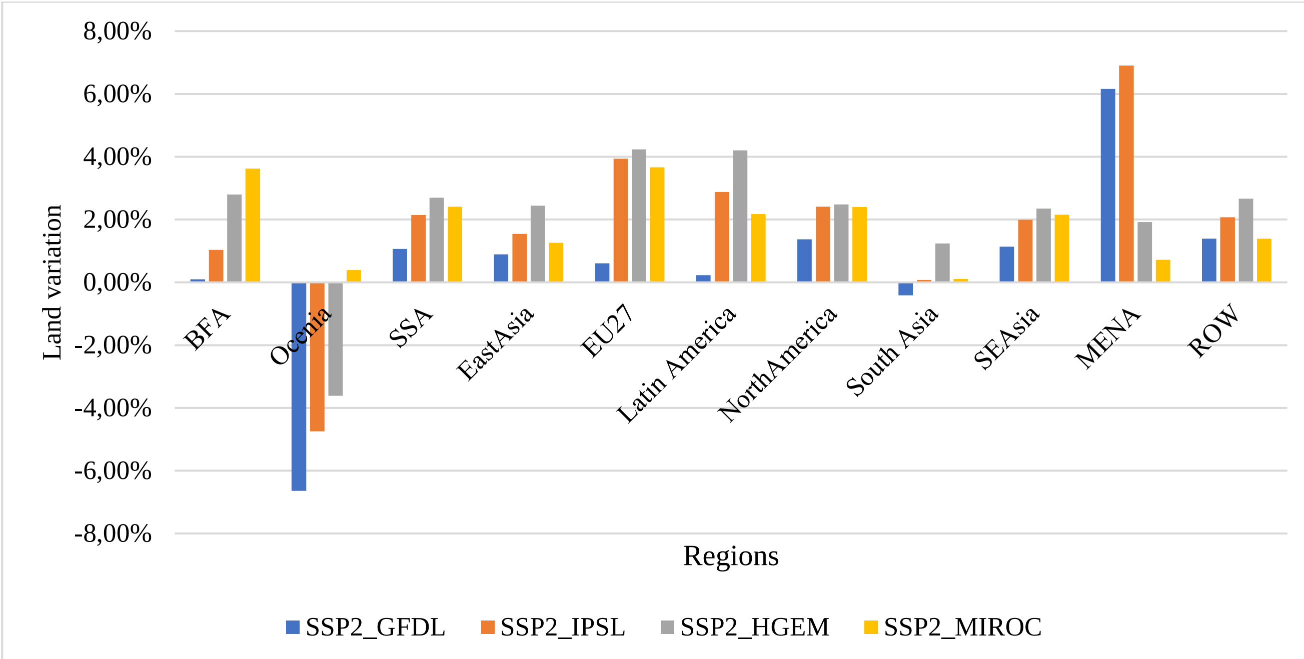

Figure 2.5. *Effect of climate change on arable land during 2005-2050*

Source: *IMPACT model simulation outcomes*

2.4. Simulations outcomes

This section presents the model simulation results of the likely effect of climate change on household welfare in Burkina Faso and the world. We present, respectively, the impact of climate change on real GDP, incomes and expenditure, and global welfare.

2.4.1. Effect of climate on GDP

The results show that climate change will lead to a loss of GDP in all the regions by 2050, as shown in Figure 18. Indeed, the median effect of climate change is negative in all countries. The extent of the losses ~~is~~, however, vary among scenarios and regions. Burkina Faso and Sub-Saharan Africa will be the most affected regions, as displayed in Figure 18. In Burkina Faso, the smallest drop in GDP is estimated by the SSP2-MIROC scenario with a GDP decreasing rate estimated at 9.33%, while the SSP2-IPSL scenario forecasts the most considerable decline rate, estimated as 17.39%. On the other hand, Oceania and MENA regions will be less affected by climate change in terms of GDP loss. However, while the scenarios predict different GDP loss levels, the forecasted signs are the same in all the regions. Therefore, we can conclude that climate change leads to decreased agriculture sector production and GDP level.

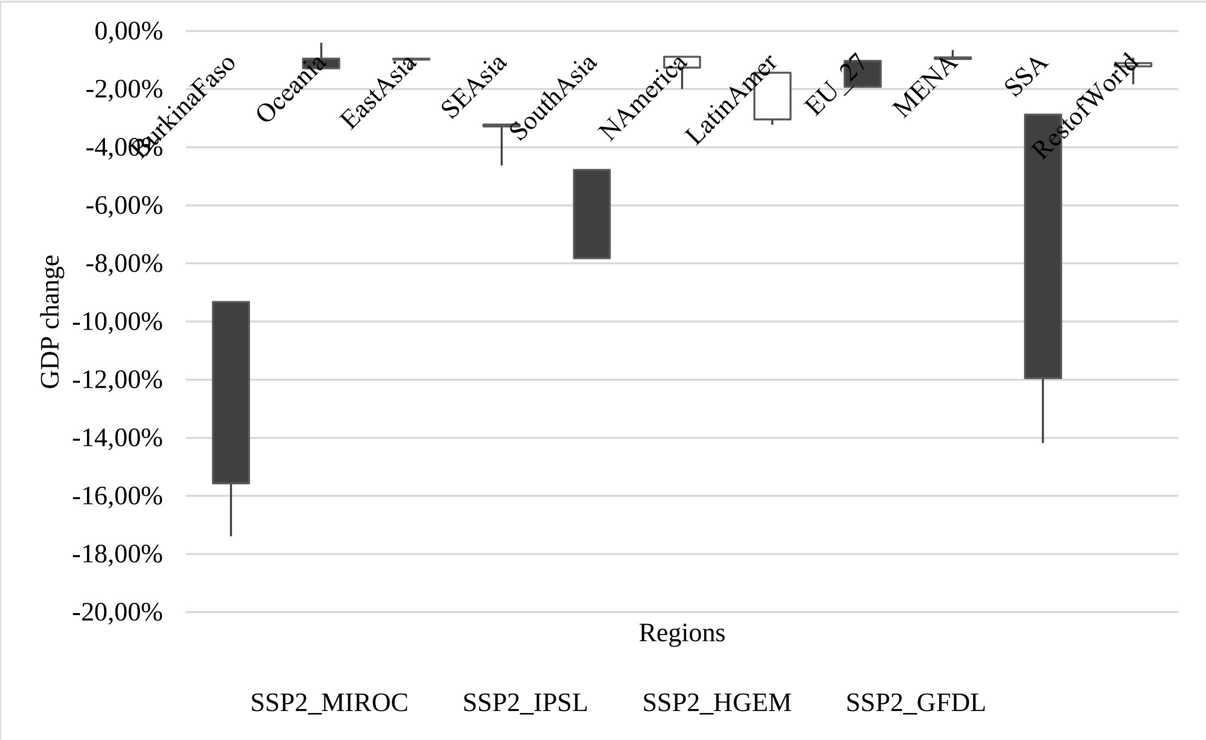

Figure 2.6. *Effect of climate change on GDP 2005-2050*

Source: *GTAP standard model simulation outcomes*

2.4.2. Impact of climate change households demand for agricultural products

The decline in crop productivity and cropland caused by climate change will impact households' demand for agricultural products. Figure 19 presents the change in the households' demands for agricultural products in Burkina Faso for four climate change scenarios. On average, climate change will drop households' demand for agricultural products by a rate of 21.04% in Burkina Faso. This drop is greater than the decrease observed in the level of GDP obtained in the previous section. The four scenarios' results do not vary very much, and the standard variation coefficient is estimated ~~at~~ as 4%. In the other regions, the change in the demand for agriculture products by households due to the change in crop productivity and arable land is negative. As in GDP, Burkina Faso and the other Sub-Saharan countries make the most critical losses in demand for agricultural products, as shown in Figure 20. Oceania and North America will be the regions with the lowest losses in household demand for agricultural products. In developing countries such as Burkina Faso, a drop in farm products' consumption will affect households' overall well-being.

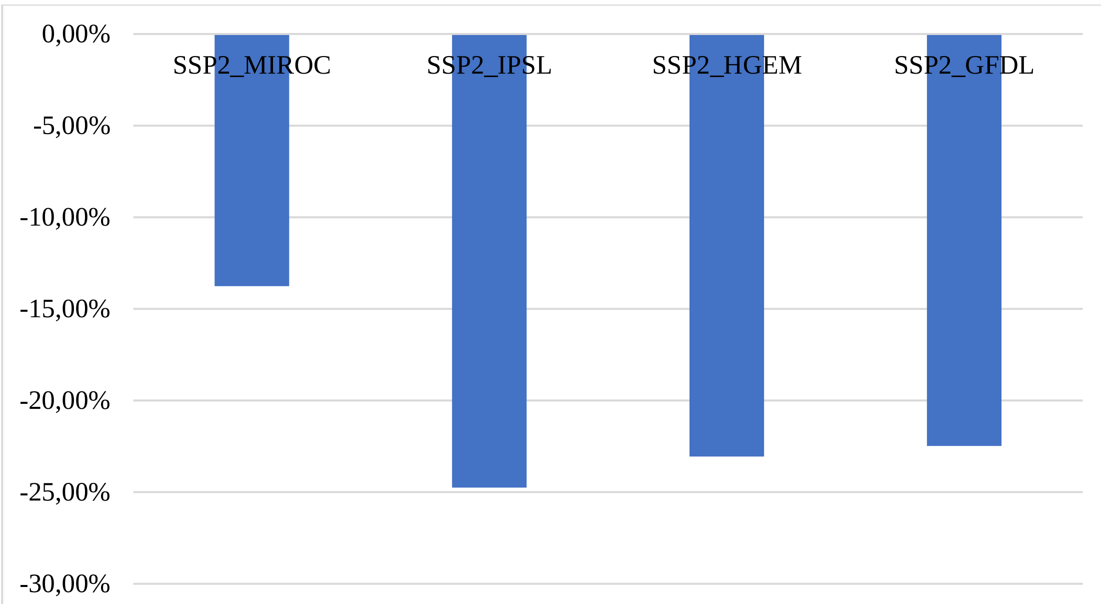

Figure 2.7*:Effect of climate change on household's agricultural products demand in Burkina Faso 2005-2050*

Source: *GTAP standard model simulation outcomes*

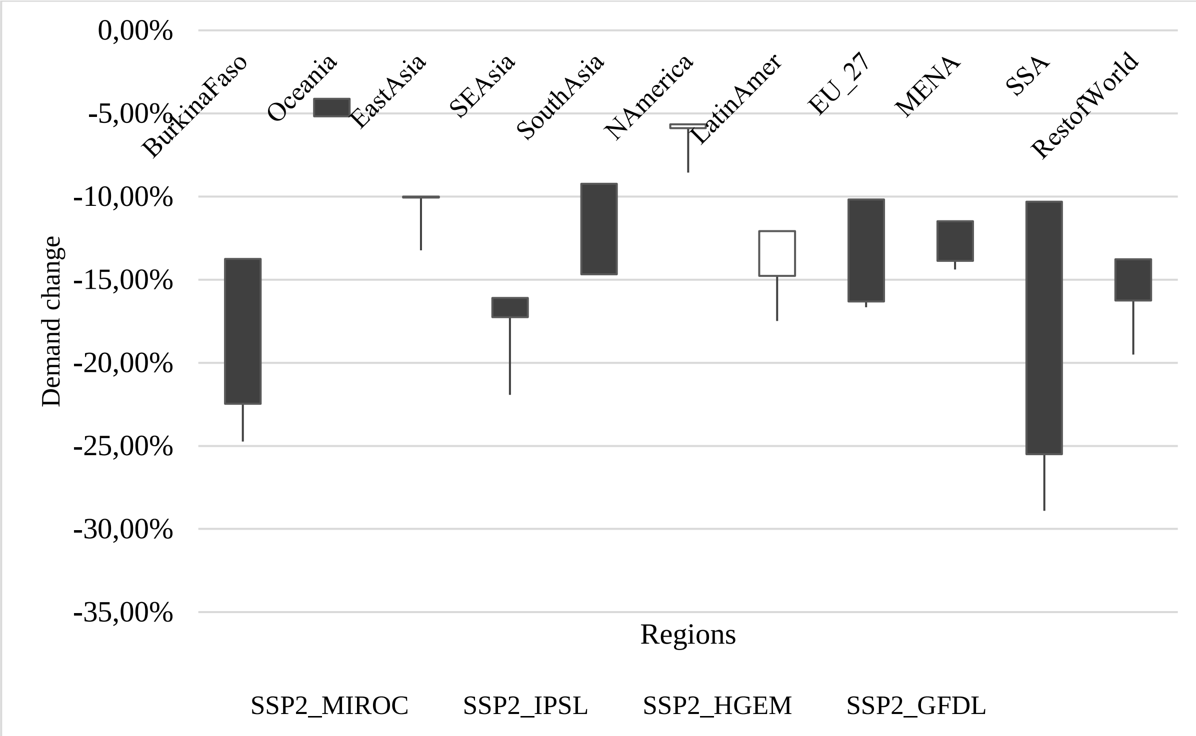

Figure 2.8: *Effect of climate change on household's agricultural products demand*

Source: *GTAP standard model simulation outcomes*

2.4.3. Impact of climate change on global welfare

2.4.3.1. Variation of the Equivalence Variation (EV)

In previous sections, we have shown that the effects of climate change on arable land and crop productivity will cause a decline in GDP and households' demand for agricultural products in Burkina Faso and other regions. These negative impacts will likely affect the overall household' wellbeing level in these regions. In fact, in countries like Burkina Faso, where the agricultural sector constitutes the main income source, a drop in agriculture production will significantly affect the household's welfare. The change in agriculture production will increase agricultural products' prices and therefore decrease their incomes. Subsequently, this reduction in incomes will decrease the demand for goods and services, and bring about a decline in households' welfare. Figure 21 presents the shift in the EV in Burkina Faso. The four climate change scenarios indicate that climate change will negatively affect households' welfare. The average welfare loss is estimated as a 14% decline of households' global welfare level relative to the baseline scenario. The minimum decline, estimated as 8%, is provided by the SSP2-MIROC scenario, while the SSP2-IPSL predicts the highest decline in households' global welfare.

In the other regions, the changes in EV are displayed in Figure 22. From this figure, we can see that the extent of climate change on EV varies highly across regions. African regions are the most affected regions, while Europe is the ~~less~~ least concerned and will benefit from climate change in the SSP2-IPSL scenario. In terms of scenarios, the predicted changes in EV are very diverse. For instance, while in Burkina Faso, SSP2-IPSL is the scenario with the highest loss, in Subsaharan Africa, SSP2-HGEM is the scenario with the highest loss.

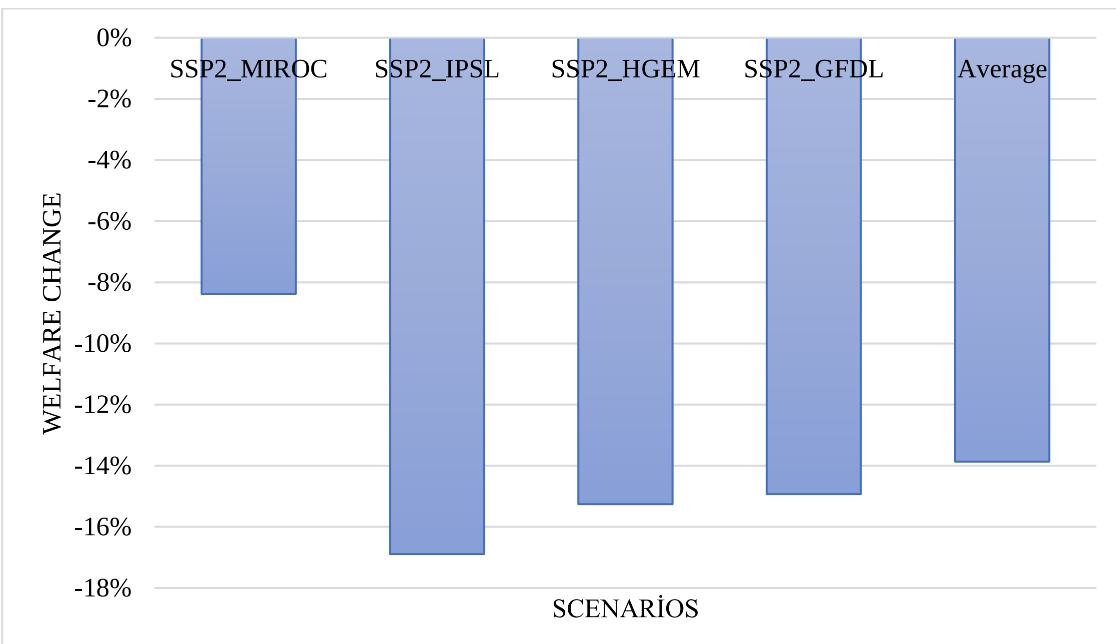

Figure 2.9: *Effect of change in welfare in climate change scenarios in Burkina Faso 2005-2050*

Source: *GTAP standard model simulation outcomes*

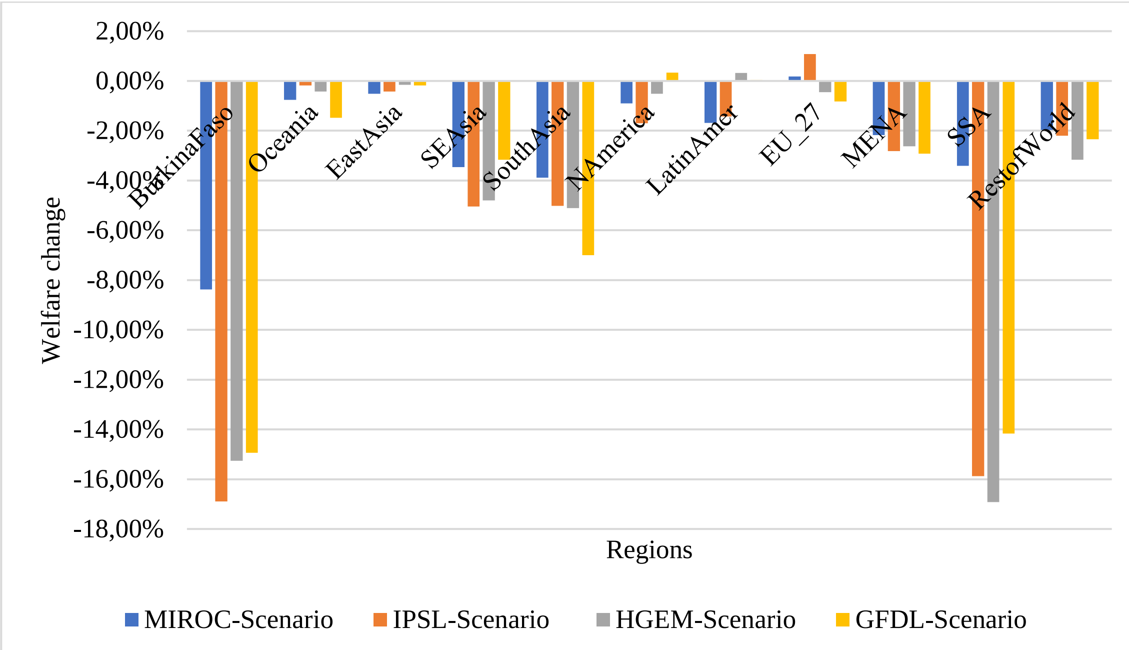

Figure 2.10:*Effect of change in EV in climate change scenarios in different regions 2005-2050*

Source: *GTAP standard model simulation outcomes*

2.4.3.2.Welfare decomposition

The welfare decomposition aims to explain the source of welfare change due to climate change shocks. These welfare variation sources include allocative efficiency, factors endowment, technology change, population, terms of trade, and investment/savings. Figure 23 displays the contribution of each factor to welfare variation in the different climate scenarios. This figure shows that only investment and saving contribute positively to welfare change under climate change scenarios. However, this positive contribution is small on average compared to the other negative contributors.

On the other hand, for Burkina Faso, the two major welfare change drivers are capital endowment and technology efficiency in the four climate change scenarios. Each of these two sources contributes negatively to more than 30% of EV change. This result is explained by the fact that climate shock introduces a negative technology shock in the agriculture sector and leads to a decline in the economy's production factors. The other welfare loss sources in Burkina Faso are population effects, allocative effect, and terms of trade effect.

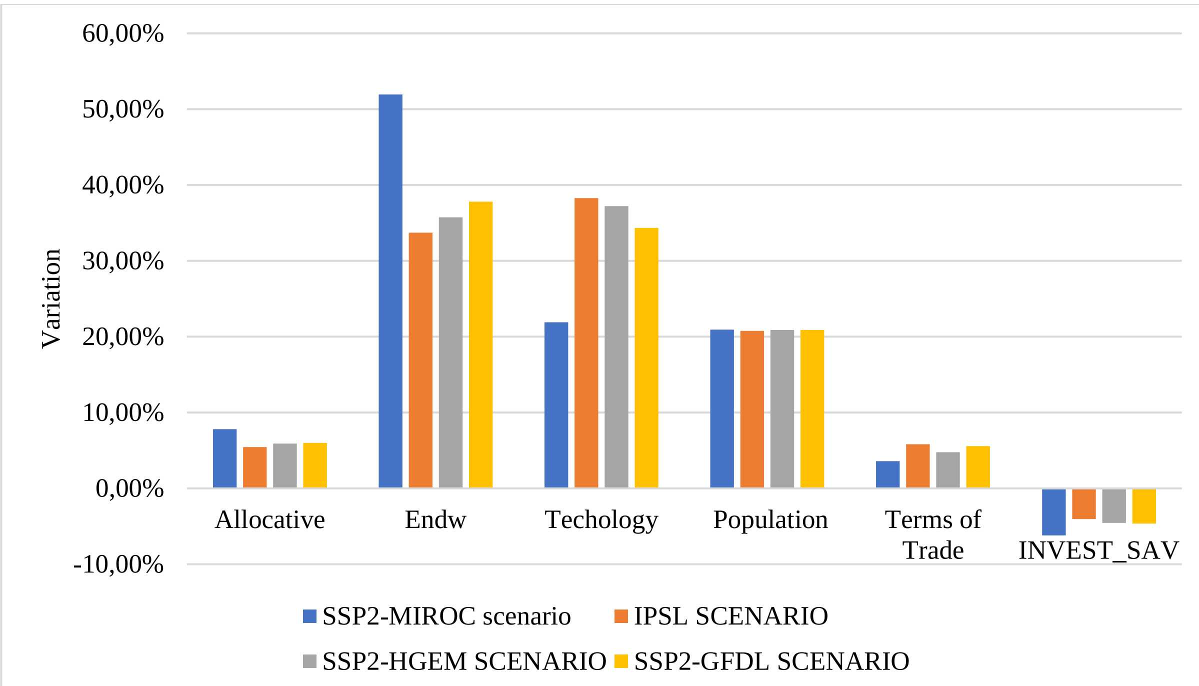

Figure 2.11: *Welfare decomposition in Burkina Faso for different climate scenarios*

Source*: GTAP standard model simulation outcomes*

2.4.4. Discussion and conclusion

This chapter analyzes climate change's impacts on households' welfare in Burkina Faso using the GTAP model. The simulation outcomes show that climate changes will negatively impact global household welfare in Burkina Faso. For instance, the results show that climate change will result in a loss in regional GDP, a decline in households' demand for agricultural products, and global welfare. The results also indicate that Sub-Saharan African regions will be the most affected regions in welfare loss. On average, global warming will cause a loss estimated at 14% of Burkina Faso households' welfare. To our knowledge, it is the first time that a study precisely quantifies the climate change effect on households' welfare in Burkina Faso. The study findings present some similarities with previous studies conducted on the

African continent. They are in line with (Zidouemba, (2017)) findings on climate change impacts in Burkina Faso.

On the other hand, the results differ from some SSA studies. Dudu's (2013) research shows that climate change will increase EV in SSA, while our study finds the opposite results. These differences in the results are probably due to the many uncertainties in Africa's climate data prediction.

CHAPTER 3

IMPACT OF TRADE LIBERALIZATION ON CLIMATE CHANGE EFFECTS: ROLE OF THE AFRICA CONTINENTAL FREE TRADE AREA (AFCFTA)

Introduction

The African continent will be severely affected by climate change. Numerous studies show that climate change will have many physical impacts, such as increased temperature levels, precipitation changes, and many natural disasters. These environmental effects will result in adverse socio-economic effects, as demonstrated in the previous chapter. For example, the overall effect on crop yields on the African continent is expected to be negative, with a decline ranging from 2% to 35%, according to the (IPCC 2014). However, the magnitude of these effects varies considerably across countries and regions. For example, while Moore et al. (2012) show that climate change will positively affect maize production in East Africa, Zinyengere et al. (2013) find that climate change will negatively affect maize production in South Africa. These effects on agricultural production are likely to exacerbate the risk of food insecurity and undernourishment, which already affects more than 200 million people on the continent FAO, (2015). Therefore, it is necessary to identify adaptation strategies to cope with these adverse effects. Trade is identified as one of the effective regional strategies for adapting to climate change impacts as trade can play a crucial role in sharing and reducing the risks associated with climate change. However, the African continent has the lowest intracontinental trade rate in the world. In 2017, Intra-African trade was estimated at 2% between 2015 and 2017, according to (UNCTAD 2019). This low rate is due to numerous trade restrictions such as trade tariffs and non-tariff barriers on the continent. The African Continental Free Trade Area was recently established to eliminate trade barriers and improve intra-continental trade. This free trade area has also the potential to contribute to adapting to the impacts of climate change on the continent through the increase of intra-continental trade. Therefore, there is a need to analyze the role that this free trade area can play in adapting to the effects of climate change. However, there are limited studies in the literature analyzing the impact of this Free Trade Area on climate change adaptation in Africa. This chapter aims to fill these gaps by examining the effect of AfCFTA on climate change adaptation in Africa. The rest of the chapter is organized as follows. In Section I, the notion of climate change adaptation is described. Section II explains the role of trade liberalization in the adaptation to climate change effects. Section III presents the empirical findings on the impact of African trade liberalization on adaptation to the effects of climate change.

3.1. Climate change adaptation

3.1.1. Definition and typology

In its fifth report, the (IPCC 2014) defines adaptation as a process to address current and future climate change and its consequences. This report states that adaptation aims to reduce or prevent the adverse effects of climate change or take advantage of climate change opportunities. Therefore, adaptation to climate change includes measures taken to reduce current and future climate change effects. These actions aim to increase people's and natural systems' capacities to cope with climate variability impacts Wilbanks et al., (2007b). Although adaptation is not well documented as mitigation of climate change in the literature, many adaptation typologies exist.

IPCC (2014) distinguish three groups of adaptations: ~~as~~ structural and physical adaptation, social adaptation and institutional adaptation. The structural and physical type of adaptation distinguishes discrete adaptation actions, which have a noticeable result. The social adaptation strategies are actions toward vulnerable people to improve their situation and reduce social inequalities. The institutional adaptation strategies include legal frameworks that range from economic and social policies to regulations. The European Climate Adaptation Platform (Climate-ADAPT), for its part, defines grey, green, and soft adaptation types. The grey strategies are defined as the structural adaptation option defined by IPCC (2014). These strategies include engineering and technological actions for territory, infrastructures, and people adaptation. The green adaptation strategies are based on ecosystem protection, and the soft strategies include social, financial, and legal policies taken to increase ecosystem and people capacities for facing climate change impacts. As can be seen, there are many similarities between these two classifications.

In the literature, several authors have determined other climate change adaptation classifications. For instance, Eakin et al. (2009) describe three distinct adaptation strategies: resilience strategies that designate actions focusing on improving the resilience system; targeted approaches that are developing toward the specific risk of climate change; and social vulnerability approaches. Ford et al. (2013) distinguish groundwork, recognition, and adaptation categories of adaptation typology. Dupuis & Biesbroek's (2013) study defines four climate change adaptation typologies: contiguous policies, contributive policies, symbolic and concrete adaptation policies. Many other typologies of climate change adaptation actions exist in the literature. Adaptation strategies are composed of many activities that aim to strengthen human and ecosystem capacities against climate change effects and exploit the opportunities that come with it. Some of these actions take place in the African continent to adapt to climate change impacts that are already occurring in the continent.

3.1.2. Climate change adaptation strategies in Africa

In Africa, where negative climate change impacts are already occurring, various adaptation approaches are being adopted and implemented to address them. These strategies are planned at local, sub-national, national, and regional levels.

At the regional level, few climate change adaptation measures are being taken to strengthen the continent's capacity to deal with climate change. A few actions are being undertaken by African regional organizations such as the Permanent Interstate Committee for Drought Control in the Sahel (CILSS), the Southern African Development Community, and the Lake Victoria Basin Committee. For example, CILSS has established an early warning system as a strategy for adaptation to climate change. It also collects climate data regularly and trains people to cope with the consequences of climate change. National strategies for adaptation to global warming in Africa are found in their National Adaptation Programs of Action (NAPAs) developed by many African countries. These national documents describe each African country's national priorities for adaptation to climate change. In these programs, the primary adaptation priorities of each country are described. Climate change adaptation programs in Africa are mainly dominated by sectoral actions in the areas of agriculture and food, forestry, and water resources. For instance, in the agriculture and food sectors, improving irrigation, planting different crop species, increasing water and soil conservation techniques, and using shade and shelter techniques are some of the most widely used adaptation strategies on the continent (Dinar et al., 2009). In access to water, increasing groundwater use, seawater desalination, and increasing rainwater harvesting are some of Africa's climate change adaptation strategies. The promotion of renewable energies such as solar energy, biogas, and wind power are the adaptation policies adopted in the NAPAs of Benin and Lesotho (Schaeffer et al., 2013).

Besides regional and national adaptation strategies, some local and community actions are being taken against global warming's negative impacts. Actions at the community level aim to strengthen populations' resilience to climate variability impacts (Petersen & al, (2018)). For example, in three communes in Mali (Sandaré, Massantola, Cinzana, and M'Pèssoba), certain resistant agricultural practices and drought-tolerant cereals were implemented in 2012 and 2013 as climate change adaptation strategies. Among the strategies for adaptation to climate change in Africa, trade is absent, despite the expected positive effect on adaptation to climate change impacts. For instance, increasing the intra-African trade level will improve the continent's economy and contribute to adaptation to Africa's climate change.

3.1.3. Trade liberalization and Climate change effect adaptation

3.1.3.1.Impact of trade opening on climate change

The overall impact of trade liberalization on pollution is not yet clearly established in the literature. While some studies have found a positive effect (i.e., a reduction in pollution) of trade liberalization, others have shown a negative impact of trade liberalization on pollution. In the literature, we distinguish two main channels through which trade openness influences GHG emissions. Firstly, it is shown that trade openness affects CO2 emission through scale, composition, and technology effects. The scale effect of trade liberalization occurs when trade liberalization leads to economic growth, which, in turn, harms the quality of the environment due to the increased use of fossil fuels. The technology effect of trade comes from the efficiency gain thanks to trade liberalization that allows the transfer of environmentally friendly technologies. This technology transfer enables the production of environmentally friendly goods and services that can reduce pollution and improve environmental quality. Trade liberalization will lead countries to specialize in producing the goods and services for which they have a comparative advantage.

Consequently, in the case where trade liberalization leads to an expansion of highly polluting sectors, it will increase CO2 emissions. Otherwise, trade openness will improve the quality of the environment. The unlikely composite effect for the other two may have a positive or negative effect on GHG emissions. The sum of these three effects provides the overall impact of trade opening on climate change. Secondly, trade liberalization influences environment quality through the pollution haven effect and pollution haven hypothesis (Copeland & Taylor, 2003). The pollution haven hypothesis assumes that removing trade limits will shift big polluter companies from countries with strong environmental regulation policies to weak regulation rules. On the other hand, the pollution haven effect occurs when the strict environmental regulations impact companies' location (Copeland & Taylor, 2003).

Empirical studies on the impact of trade opening on pollution have found controversial results. Three types of results can be found in the literature. To start with, some studies (Yu et al., 2011; Ertugrul et al., 2016 ; Mahmood et al., 2019 ; CHEBBI et al., 2011; Cole & Elliott, 2003) show that trade openness increases the level of pollution. For these studies, the total effect of trade openness on carbon emission is positive. The second type of findings supports that the global effect of trade openness on environment quality is positive. In other words, trade openness leads to a reduction of GHG emissions (Antweiler et al., 1998; Fan et al., 2019; Blandford et al., 2015). Finally, the last group of findings supports that trade openness impact on CO2 emission is dependent of countries level of income. This fact is defined as the Environmental Kuznets Curve (EKC) (Ho & Iyke, 2019; Fang et al., 2018; Zhang et al. 2017; Frankel & Rose, 2002 ; Mccarney & Adamowicz, 2005). These authors think that trade openness leads to an increase in pollution until a turning point of the country income level, where trade openness will start to improve the environment quality.

Therefore, the debate on the effect of trade liberalization on climate change is still ongoing, and findings differ from one study to another. However, trade openness can contribute to climate change impacts adaptation since countries will be affected differently by global warming.

3.1.3.2.Trade liberalization and Climate change adaptation

Beyond the effects of trade liberalization on GHG emissions, trade can contribute to adapting to climate change impacts. The impacts of climate change in general and specifically, its influences on some sectors are geographically variant, and countries will not be affected at the same level. Besides, climate change will affect national comparative and competitive advantages, which may lead regions to specialization. Therefore, trade can balance the supply and demand of goods between countries by allowing global production to shift from countries not affected by climate change to extensively affected countries. Studies show that increasing international trade through liberalization reduces the risks (food shortages, famine) of global warming. Rosenzweig et al. (1993), using different climate change scenarios, estimate the impact of climate change on crop yields and the role of trade in adapting to these effects. They find that trade liberalization contributes positively to the reduction global negative impacts of climate change. For instance, they show that agricultural products' prices will increase moderately in a full trade liberalization scenario compared to the scenario without trade liberalization. In the same sense, Reilly et al. (1994) find that agricultural trade will moderate climate change effects by relocating agricultural products from less-affected regions to more severely affected regions by climate change.

Moreover, recent literature supports the idea that trade liberalization constitutes an essential factor contributing to reducing climate change risks. A study by Stephan & Schenker (2012) demonstrates that trade contributes to climate change adaptation by reducing climate change's negative effect on global welfare. They also demonstrate that trade will be higher if the number of less affected countries and rich countries increases since that will mean affected countries will have many sources from which they can import products through trade. Research by Dudu & Cakmak (2013) finds that a trade liberalization between Turkey and the European Union will marginally reduce the negative impacts of climate change in Turkey. Stevanović et al. (2016), a study shows that free trade will significantly reduce the loss of welfare caused by climate change. They argue that trade openness will help address the consequences of extreme weather conditions by allowing a reallocation of agricultural products from temperate zones to lower altitude areas, which will be heavily affected by climate change. Gouel & Laborde (2018) show that trade terms will play a significant role in climate change adaptation in a recent paper. Their results reveal that many countries affected by climate change will be compensated for their loss by favorable trade terms. Besides, they show that trade adjustment can reduce 43% of global welfare loss due to climate change.

In summary, many studies show that trade can play a crucial role in climate change adaptation. Africa is the continent with the lowest intra-continent trade volume, and strategies to improve the intracontinental trade exist. It is with this objective that the African Continental Free Trade Area was born in 2018. This free trade area will also contribute to the adaptation to the effects of climate change on the continent. However, few studies have been carried out to analyze the impact of trade on climate change adaptation in Africa. Therefore, this chapter examines this question to provide empirical findings on free trade's impact on climate change adaptation.

3.3. African Continental Free Trade Area

Africa is the continent with the lowest level of intra-continental trade. Intra-African trade represents less than 10% over the period 2015-2017. This rate is meager compared to the European, Asian, and American continents, whose intra-continental trade is estimated at 67%, 61%, and 47%, respectively (UNCTAD, 2019). This low intra-African trade rate is a source of vulnerability for the continent to internal and external shocks of all kinds. To address this situation, discussions on creating an African free trade area have been underway for decades. The African Continental Free Trade Area was born in March 2018 during an extraordinary summit of the African Union, where the agreement establishing the area was proposed to African leaders for signature. This free trade zone will cover the 55 states of the

African Union and thus be the largest free trade area since the World Trade Organization. This common market will also include a population estimated at more than one billion people and generate a combined gross domestic product estimated at nearly 3.5 billion US dollars. It has the following main objectives(Abrego et al. 2019):

- Create a single continental market for goods and services with free movement of people and capital.
- Improve the economic integration in the continent.
- Promote and increase intra-continental trade among African countries.
- Encourage competitiveness and support the economic revolution.
- Contribute to the mobility of capital and natural persons and facilitating investment.
- Promoting industrialization

AfCFTA will include numerous legal instruments to regulate trade in goods and services and property rights. The implementation process of the African continental free trade area is being carried out in two major phases. In the first phase of implementation, negotiations focus on the agreement and protocol on trade in goods and services and dispute settlement. In the second phase, discussions will focus on investment, competition policy, and intellectual property. In July 2019, at the 12th Extraordinary Assembly of the African Union, the operational phase of AfCFTA was launched, and 54 countries signed the agreement. Trade under the free trade area was expected to begin by July 2020, but it was postponed due to the CORONA virus's global pandemic. AfCFTA includes four institutions: The Assembly, the Council of Ministers, the Committee of Senior Trade Officials, and the Secretariat. Its General Secretariat is in Accra, Ghana. The organization will use many instruments to eliminate trade tariffs and non-trade measures to promote intra-continental trade on the continent. This trade openness will help reduce the continent's dependence on international trade and reduce the risk of external shocks such as global warming.

Many studies show that AfCFTA will generate significant positive effects. For instance, according to the Economic Commission for Africa (ECA) estimates, AfCFTA will increase intra-African trade by 52 % thanks to trade barriers removal. Abrego et al. (2019) report that removing trade tariffs and non-tariff barriers will increase global welfare in the continent by a rate of 2.1%. Besides, Masunda (2020) shows in a study that AfCFTA will have positive trade effects on some countries and negative impacts on other countries such as COMESA countries.

In the following section, we examine the potential impact of AfCFTA on climate change adaptation using a GTAP model simulation.

3.4. AfCFTA role in climate change adaptation

We use the GTAP standard model developed in the previous chapter to simulate the expected effect of the AfCFTA on climate change adaptation in the continent. Therefore, we re-aggregate the Africa2 GTAP database and define new scenarios.

3.4.1. Aggregation and scenarios

3.4.1.1.Data aggregation

This chapter uses the GTAP Africa 2 database to simulate trade liberalization's impact on Africa's climate change adaptation. Hence, we aggregate this database in 12 regions, three sectors, and three production factors. Six regions form the African continent. This aggregation is done according to the existing regional African communities. Therefore, we distinguish the Western African region, including the Economic Community of West African States (ECOWAS) countries. East Africa region is forming with the East African Community (EAC) countries, and the central Africa region contains the Economic Community of Central African States (ECCAS). North African region includes Egypt, Libya, Morocco, Algeria, and Tunisia. The southeast African region includes the Common Market for Eastern and Southern Africa (COMESA) countries. Finally, the Southern Africa region is exclusively covering by South Africa. The other regions in the model contain America, Europe, Oceania, Asia, the MENA region without North African countries, and the Rest of the World. The three defined sectors consist of agriculture, manufacture, and services sectors. On the other hand, we defined three production factors: land, labor, and capital. The full description of the aggregation can be found in Appendix A3.

3.4.1.2.Scenarios

In this chapter, using the GTAP standard model calibrated with Africa2 data, we examine the African Continental Free Trade Area's potential effects on climate change adaptation in Africa. Hence, we define two scenarios: a benchmark scenario and a trade liberalization scenario.

Baseline scenario

In this scenario, we use the business as a usual trend of the countries' economies, and we introduce a climate change shock in the period 2005-2050. The climate change shock is introduced thanks to IFPRI simulation outcomes of climate change impact using three climate change scenarios[4]. The variation in crop yields caused by climate change is displayed as a boxplot distribution in Figure 24 for different climate change scenarios. This figure shows that all climate scenarios reveal an adverse effect of climate change on African regions' crop yields. Indeed, the distribution for all regions except East Africa is below zero. West African region will experience the largest crop decline with a maximum yield loss exceeding 30% by 2050. On the other hand, East Africa will be the least affected region with an estimated maximum yield loss of 23%.

Similarly, figure 25 displays the distribution of cropland changes due to climate change. This figure shows that climate change will lead to an increase in cultivated land in most African regions. The figure shows that the distribution for each region is very significant. However, the levels of variation are very heterogeneous from one region to another. COMESA will be the region with the highest variation in cropland, and North Africa will be the region with the lowest variation in cropland.

[4] SSP2-GFDL, SSP2-IPSL, SSP2-GDFL

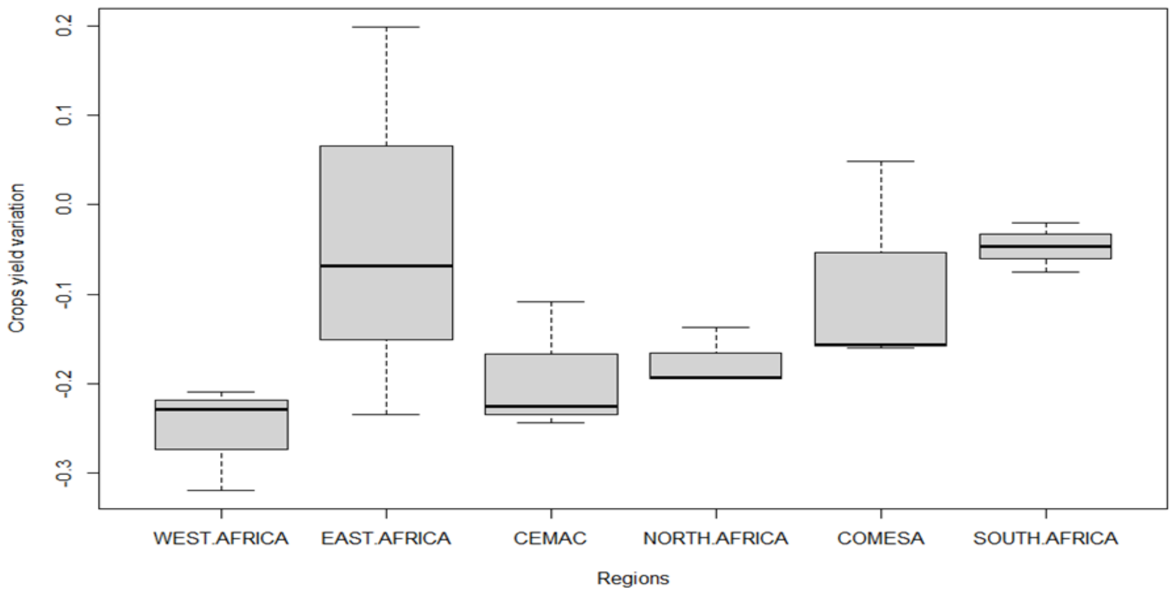

Figure 3.1: *climate change effect on regional crop yields.*

Source: *GTAP standard model simulation outcomes*

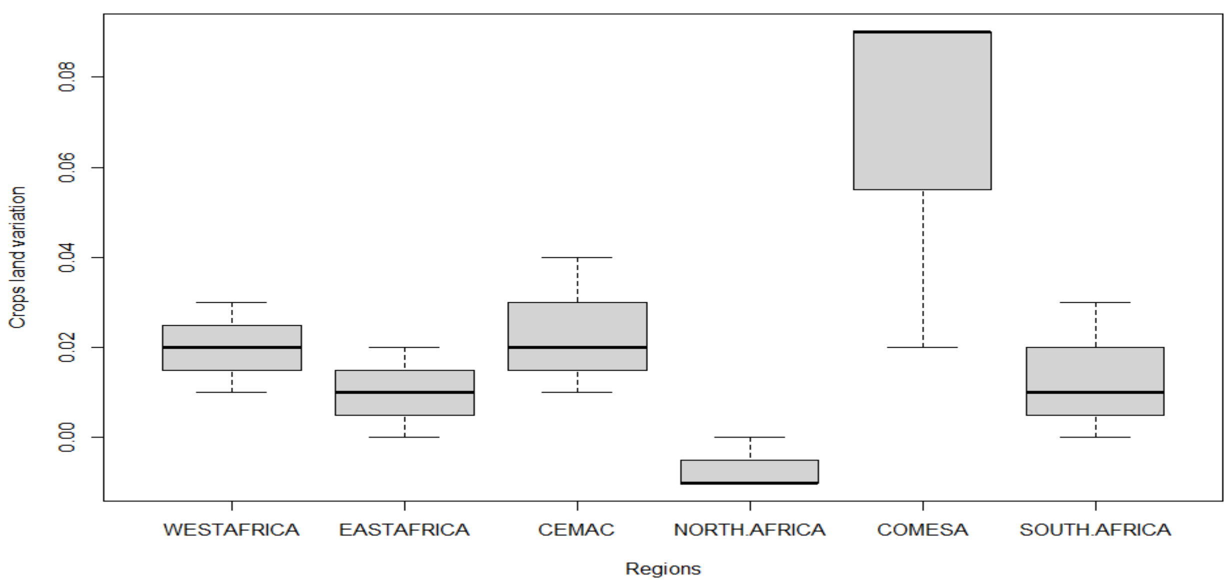

Figure 3.2: *climate change effect on regional agricultural lands*

Source: *GTAP standard model simulation outcomes*

For the simulation, we compute the mean variation of crop yields and land for each distribution. Afterward, these average variations will be introduced as a climate change shock for the simulations. Alongside the climate change shock, the variations of other economic indicators, such as labor, population, capital change, are included in the model to reflect the economic situation in 2050.

Trade liberalization scenario

The Trade liberalization scenarios consist of adding to the baseline scenario the elimination of 90% of trade tariffs among the AfCFTA State Parties. AfCFTA aims to progressively reduce trade tariffs on non-sensitive goods by 90% in 5, 10, and 15 years respectively for Non-Least Developed Countries (N-LDC), Least Developed Countries (LDC)[5] , and the Group 6 countries (G6)[6]. Also, non-trade barriers will be significantly reduced over the same periods. These trade measures will be implemented in two phases. Phase I of the AfCFTA will address trade in goods and services and dispute settlement, while Phase II will focus on competition rules, investment, and intellectual property rights. The trade scenario results will be compared with those of the baseline scenario to determine the effect of trade liberalization on climate change effects. The scenarios are summarized in the table below:

Table 3.1: *Climate change adaptation scenarios*

Scenario	Definition
BASELINE	Business as usual + Average Climate change
TRADE LIBERALIZATION	Business as usual + Climate change + 90% trade tariffs removal

Source: built by the author

3.4.2. Simulations results and discussion.

3.4.2.1 Baseline scenario

3.4.2.1.1. Climate change impact on African Regional GDP

[5] Angola, Benin, Burkina Faso, Burundi, Central African Republic, Chad, Comoros, Democratic Republic of Congo, Djibouti, Eritrea, Ethiopia, Gambia, Guinea, Guinea-Bissau, Lesotho, Madagascar, Malawi, Mali, Mauritania, Mozambique, Niger, Rwanda, Sao Tome and Principe, Senegal, Sierra Leone, Somalia, South Sudan, Sudan, Togo, Uganda, Tanzania, Zambia

[6] G6 includes Ethiopia, Madagascar, Malawi, Sudan, Zambia, Zimbabwe

Figure 3.3. displays the percentage variation of regional GDP caused by climate change in Africa. It shows that by 2050, climate change will lead to a decline in GDP in all African regions. On average, climate change will lead to a GDP decline rate of 4.56 % in Africa. However, this rate varies from region to region. West Africa will experience the most significant GDP loss caused by climate change with a decrease of 8.82%, while East Africa will be the least affected region, with a decrease rate estimated at 1.29%. The other African regions will be heterogeneously affected, with decrease rates ranging from 1.94 % to 5.94%.

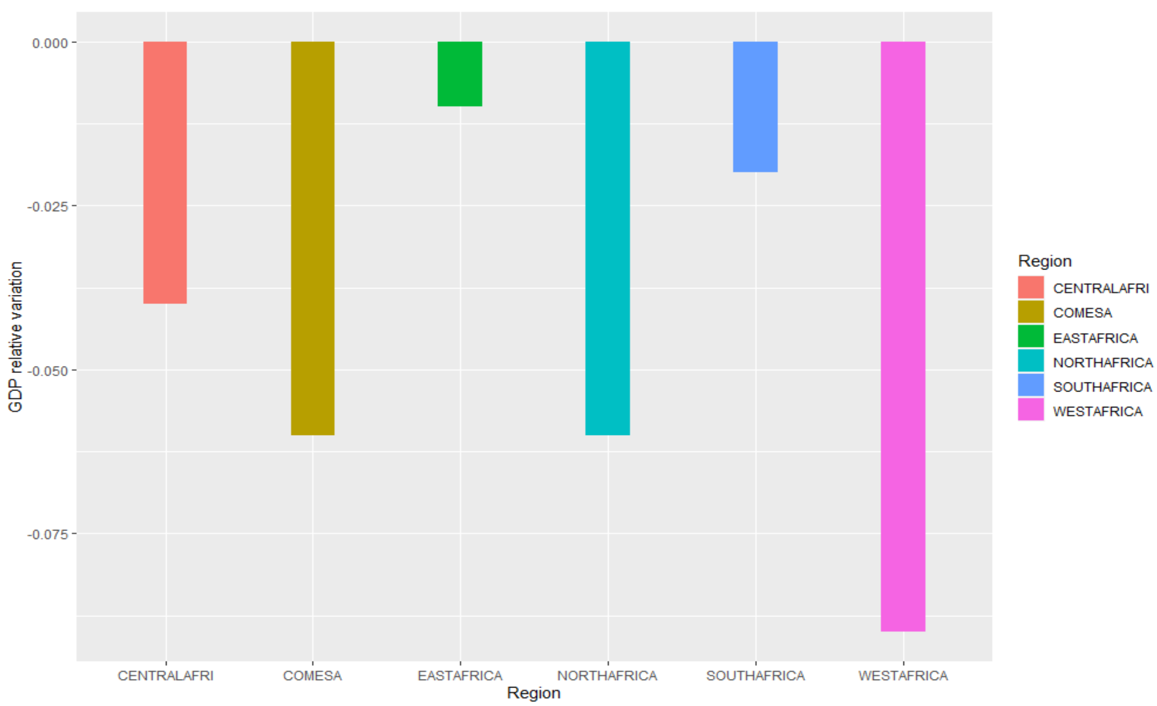

Figure 3.3: *Change in GDP rate from climate change.*

Source: *Built by the author using GTAP standard model simulation outcomes*

3.4.2.1.2. Climate change effect on regional households Welfares

The effect of climate on household welfare in Africa is obtained using the equivalence variation (EV) as previously defined in the last chapter. The level of EV expressed in millions of US dollars of consumption is presented in figure 3.4. This figure shows the level of EV under the situation of business as usual (without climate change) and in the context of climate change. This figure illustrates the difference in the level of EV in the two economic scenarios.

Compared to the level of EV in the business as a usual economic trend, the EV level decreases in all regions under the climate change scenario. Therefore, climate change will cause a decline in welfare for all African regions. At the continental level, climate change will lead to an estimated welfare loss of 1214463.75 million US dollars, which is very significant for a continent already facing poverty. As in the GDP analysis, West Africa will experience the largest welfare decline due to climate change. Indeed, by 2050, climate change will decrease the level of global welfare estimated at 833,179 million US dollars, which represents a 7.16 % decline rate.

On the other hand, South Africa will be the least affected region with only 0.45% welfare loss. Given these very significant adverse effects, it is urgent to find strategies to adapt to these climate changes. In the following section, we examine the impact of trade liberalization on climate change impacts in Africa.

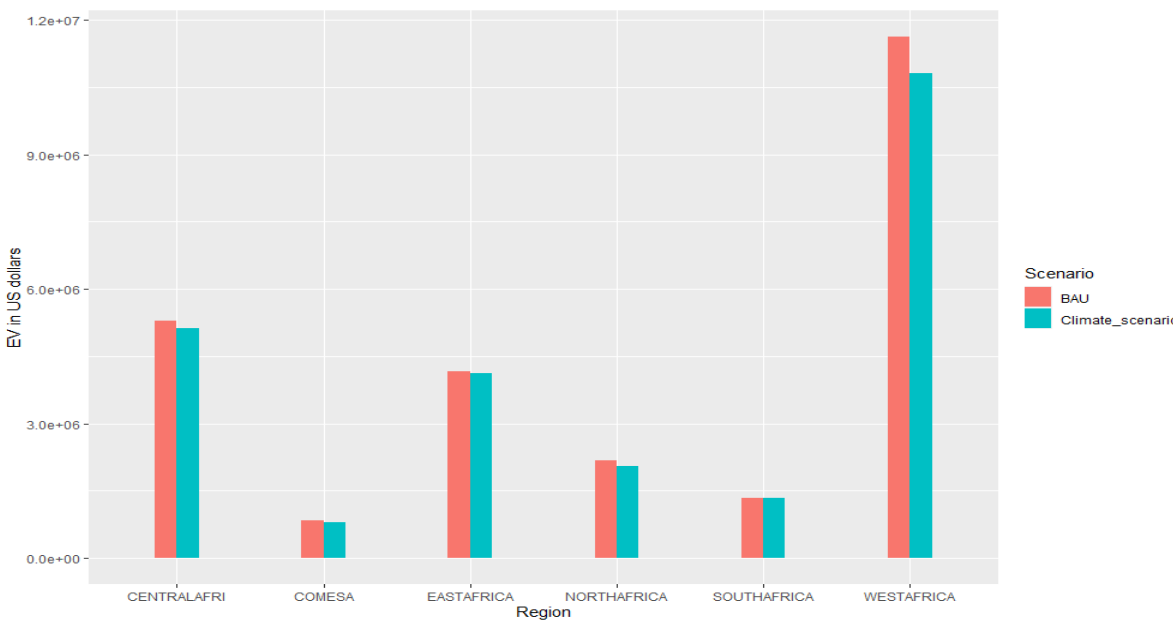

Figure 3.4: *Regional Households' welfare level under Business as usual (BAU) and in climate change scenarios*

Source: *Built by the author using GTAP standard model simulation outcomes*

3.4.2.2. Effect of trade liberalization on climate change

Impacts of trade tariff removal on regional GDP

The results presented below in figure 4.5 show that the removal of 90% of trade tariffs in the context of climate change will have varying effects on GDP in African regions. While in some regions, the removal of tariffs will lead to GDP gains, in others, trade tariffs elimination will result in a GDP loss relative to its level in the climate change scenario. For instance, in regions such as West Africa, COMESA, South Africa, and North Africa, the removal of trade tariffs will increase GDP, with the highest increase in South Africa. Moreover, in some of these regions, trade liberalization gains are sufficient to offset the GDP loss caused by climate change. However, the removal of tariffs will exacerbate the adverse effects of climate change on GDP in East and Central Africa, with East Africa being the most adversely affected region.

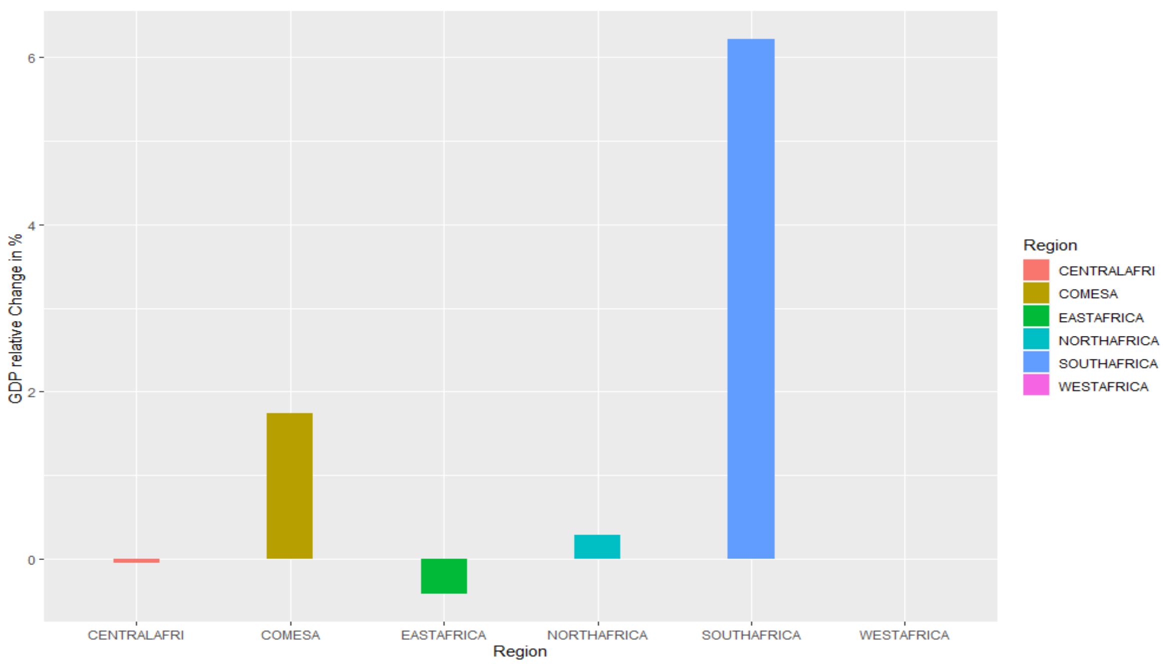

Figure 3.5: *GDP change from trade liberalization under climate change*

Source: *Built by the author using GTAP standard model simulation outcomes*

3.4.2.2. Impact of trade liberalization on welfare effect of climate change

The simulation results show that the elimination of 90% of trade tariffs between African countries in the context of climate change will generate sufficient gains to offset the adverse effects of climate change. Indeed, the results suggest that trade liberalization will lead to an overall increase in the level of welfare of the African continent estimated as 6323840.25 US dollars. This welfare gain represents a growth rate of more than 26% relative to its quantity under the climate change scenario. However, regions will benefit differently from this trade tariffs removal under climate change. The level of welfare represented by the EV and its variation under the scenarios of climate change and trade liberalization are displayed respectively in figures 3.6 and 3.7. Figure 3.6 shows that welfare is higher in the trade liberalization scenario for North Africa, COMESA, and South Africa regions relative to welfare under the climate change scenario and lower for the West, East, and Central Africa regions. In South Africa, North Africa, and COMESA regions, the welfare gains from trade liberalization will offset the loss caused by climate change and generate a net gain of welfare. For instance, these three regions will realize net welfare earnings from trade liberalization estimated respectively as 686,182.5 million US dollars, 75,963,336.5 million US dollars, and 126,116 million US dollars for North Africa, South Africa, and COMESA. However, for West Africa, East Africa, and Central Africa, trade liberalization will result in a net loss of 820939.5 million US dollars, and 1720673.25 million US dollars respectively in West Africa, Central Africa, and East Africa.

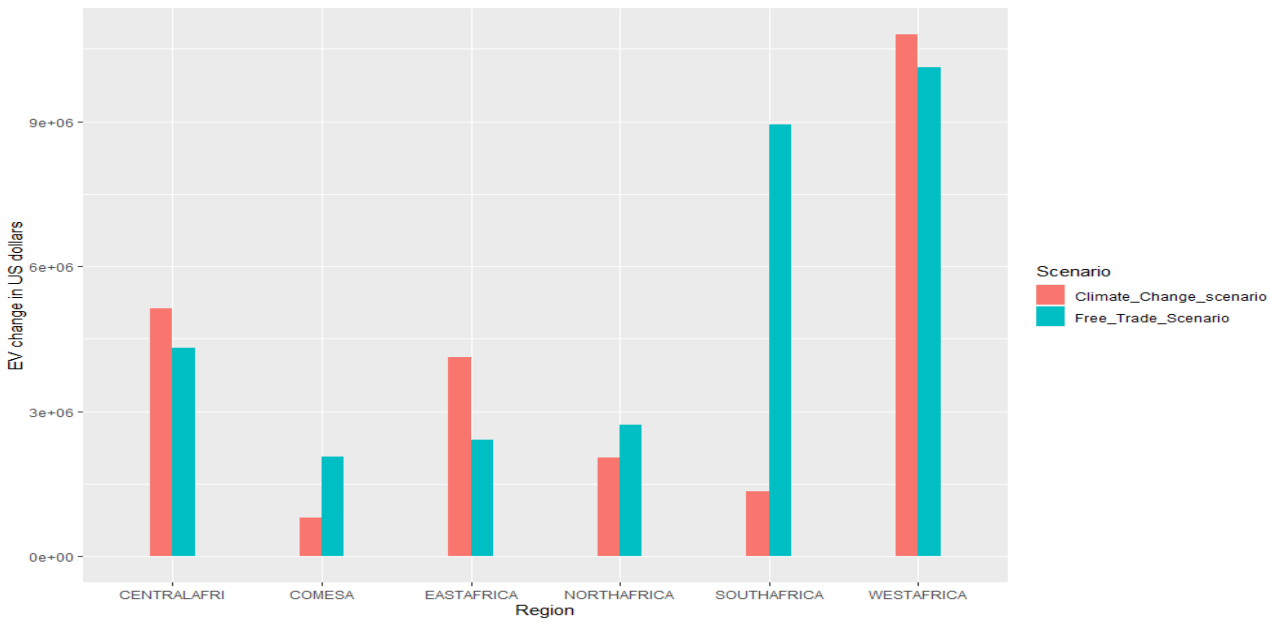

Figure 3.6*: Regional welfare level under different scenarios*

Source: *Built by the author using GTAP standard model simulation outcomes*

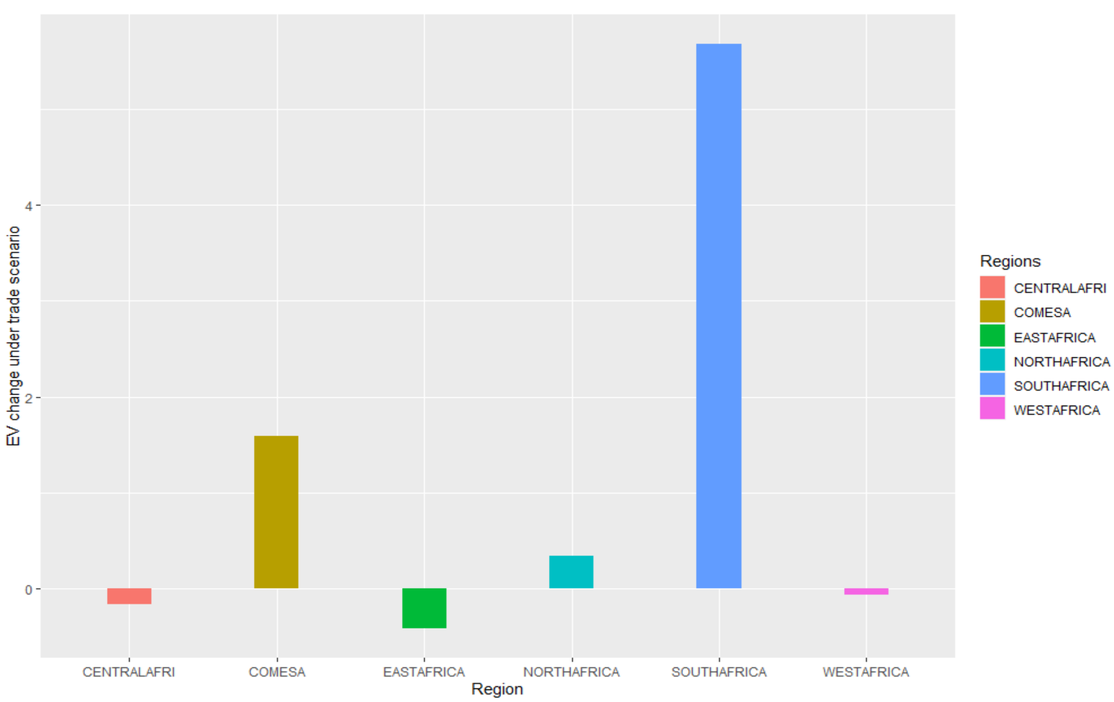

Figure 3.7: *Change in welfare under trade liberalization scenario relative to baseline.*

Source: *Built by the author using GTAP standard model simulation outcomes*

3.4.2.4.Welfare decomposition

Table 6 provides the decomposition of welfare variation generated by trade liberalization. As we mentioned above, trade tariffs removal in the context of climate change will result in a welfare increase in three regions and a welfare loss in three others. The welfare decomposition breaks down the welfare change into its different components. Table 6 demonstrates that technological progress, which is defined as the change in productivity due to a shock, is the principal factor of welfare variation (positively or negatively) for all the regions. For example, in South Africa, which realizes the highest welfare gain from trade liberalization, technology progress contributes to 57% to its welfare change. East African region that is the biggest loser from trade tariffs elimination, technology progress backs 47% of its total welfare change. The terms of trade effect, which evaluate the impact of price variation after the trade tariffs elimination, are the second source of welfare change. For instance, trade contributes positively and significantly to EV variation for regions such as North Africa, West Africa, Central Africa, and East Africa. On the other hand, it contributes negatively to welfare variation in South Africa and COMESA regions.

Table 3.2: *Decomposition of welfare change relative to climate change scenario under trade liberalization scenario.*

REGION	Welfare change	Allocative efficiency	Endowment effect	Technical effect	Population effect	Terms of Trade effect	I/S effect
NORTHAFRICA	33.60%	-8469	-35368	486225	226923	15033	1839
WESTAFRICA	-6.28%	-320995	-1285531	-446104	1478123	-5975	-97701
SOUTHAFRICA	568.27%	341869	624545	4383154	2537901	-89224	-201909
COMESA	158.51%	19143	123807	843729	328409	-33121	-20851
CENTRALAFRI	-16.00%	-66515	-114810	-540364	116352	37188	-252792
EASTAFRICA	-41.72%	-112131	-252890	-822764	-514505	47684	-66066

Source: Built by the author using GTAP standard model simulation outcomes

3.4.2.5. Impact of trade liberalization on trade volume

The impact of tariff elimination on the volume of imports and exports is illustrated in Figure 3.8. The removal of trade tariffs increases the volume of imports for all African regions except East Africa. South Africa will experience the most considerable rise in imports as a result of tariff elimination. In terms of exports, trade liberalization will increase their volume in three regions and a decrease in the other regions. Indeed, trade liberalization will positively affect exports for West Africa, COMESA, and South Africa regions. South Africa will benefit the most from the elimination of tariffs in terms of exports. South African exports will increase by more than 500% of the quantity projected in climate change. This result is justified as South Africa is one of the most industrialized countries in Africa and therefore the removal of the tariffs will increase its export sales in the continent.

However, East Africa will experience the largest decline in export volume due to trade liberalization. Furthermore, in regions where trade liberalization positively affects both imports and exports, there is a welfare gain from tariff removal. Therefore, trade liberalization as a climate change adaptation strategy will impact global welfare through trade volume variation.

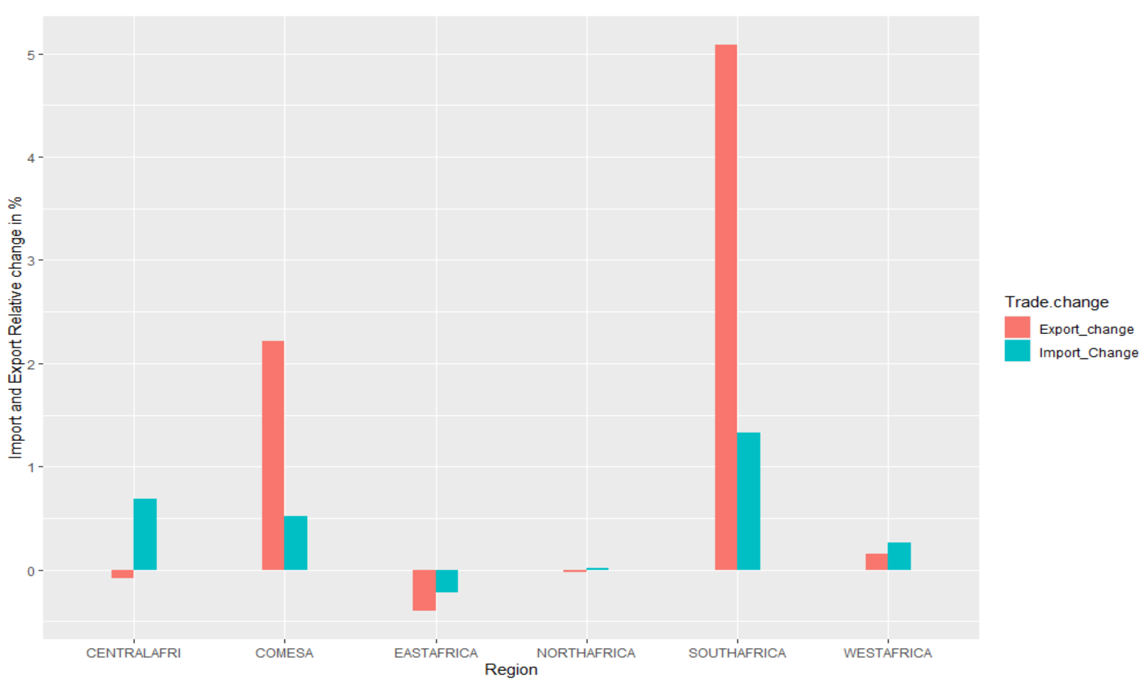

Figure 3.8: *Change in import and export volume under trade liberalization scenario relative to baseline.*

Source: *Built by the author using GTAP standard model simulation outcomes*

3.4.3. Discussion and conclusion

This chapter uses the GTAP standard model to assess the impact of trade tariffs' elimination on Africa's climate change adaptation. The simulations reveal that climate change could decrease 15% of continental welfare and 10% of Africa's GDP by 2050. However, the study demonstrates that liberalizing the intra-continental trade will contribute to lessening these impacts. Indeed, the findings prove that the elimination of continental trade tariffs in the context of climate change will generate a sufficient welfare surplus to offset the welfare loss caused by climate change in the continent. For instance, removing 90% of trade tariffs among African countries will result in a 26% increase in global welfare than the level achieved under climate change. This welfare gain compensates for the welfare loss caused by climate change. However, it is disproportionately distributed across the regions in the continent. Some regions, such as South Africa, North Africa, and COMESA, will benefit from trade tariffs removal, while other regions, namely East Africa, West Africa, and Central Africa, will see their welfare levels deteriorate after trade liberalization. Moreover, the study shows that technological progress is the main factor that affects welfare change resulting from trade tariffs reduction. Therefore, countries with better technical progress will benefit from tariff elimination in the continent.

Despite being one of the few such studies conducted for the continent, this research is part of the vast literature on the effect of trade liberalization on the consequences of climate change. The results found are consistent in many aspects with some recent research findings on the subject.

CONCLUSION

Climate change is one of the most significant threats of the 21st century for humanity, and its effects are already occurring worldwide. Developing countries in general and African countries are expected to be the most affected because of their geographical location and lack of resources for adaptation and mitigation. Therefore, it is necessary to estimate the potential effect of climate change on these countries and find adaptation strategies. This thesis analyzes climate change's impact on household welfare and trade liberalization's impact on climate change adaptation in Burkina Faso and Africa in general. Therefore, we combine the outputs of a partial equilibrium model and simulations of a CGE model. The partial equilibrium model is the IMPACT model developed by IFPRI and used for simulating the impact of climate change on cropland and agriculture yields according to different climate change scenarios. These croplands and agriculture yield change are then included in the GTAP standard model to simulate climate change's effect on households' welfare. GTAP standard model is a multi-countries and static general equilibrium model and compatible with the GTAP database.

The descriptive analysis in chapter II reveals that climate change will negatively affect cereals' yield and production in three climate change scenarios. For instance, it demonstrates that the average cereal production decline rate in Burkina Faso is estimated at 5.4% in these three scenarios. Maize crop production is expected to be the most affected cereal in Burkina Faso by climate change. Also, this descriptive chapter shows that crops harvested lands will increase due to climate change. Indeed, as the crop yields decrease, farmers will increase the cultivated are to maintain their production level. However, this increase in croplands will not compensate for the production loss caused by yields decline. The yield and cropland variations due to climate change are introduced as shocks in the GTAP standard model to analyze households' welfare impact of climate change in chapter III.

The finding of chapter III indicates a significant and negative impact of climate change on Burkina Faso's economy, particularly on GDP and household welfare. For instance, it is revealed that Burkina Faso households' welfare will decline by 14% due to climate change. Furthermore, the welfare decomposition shows that capital endowment and technology efficiency are the two major welfare change drivers of welfare change caused by climate change in Burkina Faso in all the scenarios. This result is explained by the fact that climate shock introduces a negative technology shock in the agriculture sector and leads to a decline in the economy's production factors. Climate change will affect GDP and welfare at different extents in the different regions.

Chapter IV examines the African Continental Free Trade Area on climate change adaptation in Africa. The findings in this chapter reveal that removing 90% of trade tariffs among African countries will result in a 26% increase in global welfare than the level achieved under climate change. This gain of welfare generated by trade liberalization can compensate for the loss of welfare at the continent level. Nevertheless, the trade liberalization impacts will be disproportionally distributed across African regions. Some regions, such as South Africa, North Africa, and COMESA, will benefit from trade tariffs removal, while other regions, namely East Africa, West Africa, and Central Africa, will see their welfare levels deteriorate after trade liberalization. Besides, technological progress is the primary factor of welfare change caused by trade liberalization in Africa in climate change. The launch of the AfCFTA in early January 2021 is an excellent opportunity for Burkina Faso and the African countries to adapt to climate change’s effects. The increase in the intra-African trade volume will help balance the supply and demand of agricultural products on the continent.

Given these significant adverse impacts of climate change on African countries, adaptation and mitigation strategies should be found to face them. In this thesis, we identify trade liberalization as an effective climate change adaptation strategy in Africa. However, countries need to improve technology progress and develop the local industry to benefit from AfCFTA.

The analysis presented in this study is a starting point for other extended literature on climate change effects and adaptation strategies studies in Burkina Faso and Africa. For estimating climate change impact, we could combine chapters II and III by using an integrated model that includes the climate and economic variables. The regional household used for welfare effect analysis can be disaggregated to different household categories for a more precise estimation of climate change impacts. Finally, the analysis can be extended to consider the impact of non-tariffs removal in the context of AfCFTA on climate change adaptation.

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APPENDICES

A1: Model closure

Exogenous

pop

psaveslack

pfactwld

profitslack incomeslack endwslack

cgdslack tradslack

ams atm atf ats atd

aosec aoreg avasec avareg

afcom afsec afreg afecom afesec afereg

aoall afall afeall

au dppriv dpgov dpsave

to tp tm tms tx txs

qo (ENDW_COMM, REG)

atall avaall tf tfd tfm tgd tpd tgm tpm;

Rest Endogenous;

A2. Regional Aggregation for adaptation analysis

REGIONS	Description
OCEANIA	Oceania
ASIA	EAsia , SEAsia, South Asia
AMERICA	North America, Latin America
EUROPE	EU27, Rest Europe

MENA	Middle East
NORTHAFRICA	Egypt, Morocco, Tunisia, Rest of North Africa
	Benin, Burkina Faso, Ghana, Cote d'Ivoire, Guinea, Nigeria, Senegal, Togo,
WESTAFRICA	Rest of Western Africa
CENTRALAFRI	Cameroon, Central Africa, South Central Africa
COMESA	Ethiopia, Kenya, Madagascar, Malawi, Mauritius, Zambia, Zimbabwe
	Mozambique, Botswana, Namibia, South Africa , Rest of South African
SOUTHAFRICA	Customs & SOUTHAFRICA
EASTAFRICA	Rwanda, Tanzania, Uganda, Rest of Eastern Africa
RestofWorld	Rest of the World

A3. AfCFTA countries agreement signature status