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## MASTER THESIS

**Subject:**

# Projection of socio-economic and climate scenarios impacts on food security: case of Mali and Burkina Faso

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# DEDICATION

I dedicate this master thesis to my dear cousin, the late Marian DIARISSO, may her soul rest in peace.

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## ABSTRACT

Variation in cropping areas' size and food security is a major problem facing Mali and Burkina Faso. The growth of agricultural production, especially of staple crops, is a key element of food security. Maize, millet, sorghum are among the most widely grown cereal crops in West Africa(Serba et al., 2019). Specifically, global statistics from FAOSTAT, show that more and more land is being taken up for cereal crops production to meet food demands. From 1999 to 2019, the area allocated to grow maize, millet and sorghum increased by **0.12%, 0.06%, 0.05%** in Mali, and by **0.08%, 0%, 0.03%** in Burkina Faso respectively. Based on the available literature, this paper investigated on one hand in how the cultivated areas per capita are supposed to evolve in the future under two climate scenarios (RCP4.5 and RCP8.5). on the other hand, what impact this evolution might have on agricultural yields. The results show some average decreases of **3%** in Mali and a constant state of harvested area per capita in Burkina Faso, in the area of each selected crops under the RCP4.5 scenario. In addition, under RCP8.5 scenario, the results show an average decrease of **1%** in both Mali and Burkina Faso in the area of each selected crop. Attributed areas per capita are averagely **0.31 ha**, **0.45 ha** respectively under RCP4.5 and RCP8.5 in Mali. Average area per capita of **0.46 ha**, **0.38 ha** respectively under RCP4.5 and RCP8.5 in Burkina Faso. Average yield per capita are about **442.44 kg, 384.04 kg** respectively under RCP4.5 and RCP8.5 in Mali, and **330.40 ka, 276.07 kg** respectively under RCP4.5 and RCP8.5 in Burkina Faso**.** Some **4%** decreases in each crop yield are likely to occur in both countries under RCP4.5. While, some decreases of **6%** are expected in each crop yield under RCP8.5 regardless the country. Moreover, this thesis studied the future daily intake from each of the three main crops, in both countries. Although producing enough is not the only aspect of food security in a region, it is important to know how this might change over time.

**Key words:**

cropland; food security; climate change; climate scenarios; maize; millet; sorghum; West Africa.

## RESUME

La variation des superficies des aires culturales, la sécurité alimentaire, constituent un enjeu majeur pour le Mali et le Burkina Faso. La croissance de la production Agricole notamment celle des cultures de base, est un élément clé de la sécurité alimentaire. Le maïs, le mil, le sorgho font partie des cultures céréalières les plus cultivées en Afrique de l'Ouest. Plus précisément, les statistiques mondiales de la FAO, montrent que de plus en plus de terres sont accaparées par la production de cultures céréalières pour répondre à la demande alimentaire. De 1999 à 2019, la superficie allouée au maïs, au mil et au sorgho a augmenté respectivement de **0.12%, 0.06%, 0.05%** au Mali, et de **0.08%, 0%, 0.03%** au Burkina Faso. Sur la base de la littérature disponible, cette étude a consisté à évaluer dans un premier temps, comment les zones cultivées sont censées évoluer dans le futur sous deux scénarios climatiques (RCP4.5 et RCP8.5). Dans un second temps, elle a consisté à examiner l'impact que pourrait avoir cette évolution sur les rendements agricoles. Les résultats montrent des diminutions moyennes de **3%** au Mali et un état constant de la surface récoltée par habitant au Burkina Faso, de la surface de chacune des cultures sélectionnnées, sous le scenario RCP4.5. En outre, dans le cadre du scenario RCP8.5, les resultats montrent une diminution moyenne de **1%** au Mali et au Burkina Faso, de la superficie de chaque culture sélectionnée. Les superficies attribuées par habitant sont en moyenne de **0,31 ha, 0,45 ha** respectivement sous les scenarios RCP4.5 et RCP8.5 au Mali. Ells sont de **0,46 ha, 0,38 ha** en moyenne, respectivement sous les scenarios RCP4.5 et RCP8.5 au Burkina Faso. Le rendement moyen par habitant est d'environ **442,44 kg, 384,04 kg** respectivement sous l'effet des scenarios RCP4.5 et RCP8.5 au Mali, et **330,40 kg, 276,07 kg** respectivement sous l'effet des scenarios RCP4.5 et RCP8.5 au Burkina Faso. Des diminutions de **4%** du rendement de chaque culture sont susceptible de se produire dans les deux pays sous l'effet du scenario RCP4.5. Alors que des reductions de **6%** du rendement de chaque culture sont attendue avec le RCP8.5 quelque soit le pays. Cette étude a aussi consisté à définir l'apport quotidien future de chacune des trois cultures principales dans les deux pays. Bien que produire suffisamment ne soit pas le seul aspect de la sécurité alimentaire d'une région, il est important de savoir comment cela pourrait évoluer dans le temps.

**Mots clés :**

Terres cultivées ; la sécurité alimentaire ; changement climatique ; scénarios climatiques ; maïs ; mil ; sorgho ; Afrique de l'Ouest.

## ACRONYM AND ABBREVIATION

| | |
|---|---|
| **AR** | **A**ssessment **R**eport |
| **DBMS** | **D**ata**B**ase **M**anagement **S**ystem |
| **ED- ICC** | **E**cole **D**octorale **I**nformatique et **C**hangements **C**limatiques |
| **ENSO** | **E**l **N**ino **S**outhern **O**scillation |
| **FAO** | **F**ood and **A**griculture **O**rganization |
| **GDP** | **G**ross **D**omestic **P**roduct |
| **GHG** | **G**reen **H**ouse **G**as |
| **GIS** | **G**eographic **I**nformation **S**ystem |
| **ICC** | **I**nformatics for **C**limate **C**hange / **I**nformatiques et **C**hangements **C**limatiques |
| **IPCC** | **I**ntergovernmental **P**anel on **C**limate **C**hange. |
| **OECD** | **O**rganization for **E**conomic **C**o-operation and **D**evelopment |
| **ORM** | **O**ffice **R**iz **M**opti |
| **RCP** | **R**epresentative **C**oncentration **P**athways |
| **SAR** | **S**econd **A**ssessment **R**eport |
| **SRES** | **S**ix **S**pecial **R**eport on **E**mission **S**cenarios |
| **SSP** | **S**hared **S**ocioeconomic **P**athways |
| **TAR** | **T**hird **A**ssessment **R**eport |
| **WCC** | **W**ASCAL **C**ompetence **C**entre |
| **WHO** | **W**orld **H**ealth **O**rganization |

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## 1.1. INTRODUCTION

### 1.1.1. context

Climate change is actually one of the major prerogatives of the whole word. It is obvious to see that this is a threat for any continent, country and individual that are aware of it. West Africa is one of the regions that are more impacted by its changes. Hence it has been stated that the West African Sahel, between 10N and 20N, was experiencing a 25 years drought which began in the late 1960s and is still in progress (Nicholson et al., 1988, Le Houerou et al., 1993). This long period of drought could be ascribed to the El Nino Southern Oscillation (ENSO). Other studies had shown that the region has experienced one of the most striking shifts in climate known globally since instrumental records began to kept-from anomalously abundant rains in 1950's and 1960's to progressively drier conditions in the 1970's and 1980's (Giannini et al., 2008). Moreover, the changes in the mean of climate over years are affecting lot of sectors. Such sectors could be the forestry, the economy, the health, and the agriculture. It has been stated in the IPCC report that when rainfall regimes change, it is expected to drive changes in vegetation cover and composition, which may be a cause of land degradation (IPCC, 2017).

In one hand, the continent's economy is mostly based on the primary sectors such as agriculture, fishery, animal breeding etc. Moreover, the Agricultural sector is playing an important role in the economy of West-African countries. Thereby, the agriculture sector is the main provider of employment in this region. About 175 million people are working in the smallholder farms (OECD & FAO, 2016). in the other hand, on average, this sector contributes about 15% of the GDP of the region (OECD & FAO, 2016). Moreover, eradicating hunger and improving food security relies on agriculture.

Despite its importance in the regional economy, agriculture faces several huge constraints: Global warming impacts are yet to be clearly determined in terms of rainfall levels. However, rainfall high variability seems to be already settled as a future increased uncertainty (Mougin et al., 2009). This situation induces structural water stresses, production losses dues to shocking droughts at crucial growth periods and uneven spatial distribution of the productions and hampers expectations over agricultural activities from farmers and policy makers with thereby a lower investment in capital in these activities. Therefore, investigating in how croplands are changing over the years under climate scenarios and how these changings are impacting crop production constitute a major stake in terms of development and food security over the region. That is the problem we would like to address in this study.

### 1.1.2 Problem

**Literature review**

The distribution of agricultural resources is a function of demographic growth. Around 1920, manual agricultural activity on smaller land areas were able to ensure food security. This was due to the soil's richness in agricultural nutrients and also to the abundance of rains. This performance of arable lands has been reduced on the one hand due to overexploitation of croplands to meet the needs of an exponentially growing population. And on the other hand, due to climatic conditions causing variations in cultivable areas.er; the sources of these changes are diverse. Some studies have been done in the past to establish the link between demography, cropland changes and food security. Some have been on a global scale and others taking into account different aspects. Zehadul Karim assessed the impact of population growth on agricultural resources in the world (Karim, 2013) and concluded that the rapid population growth has been identified as the single most important factor of environmental degradation. Kees Klein Goldwijk and Peter H Verburg showed that there is a relationship between population growth and land use(Klein Goldewijk & Verburg, 2013). Navin Ramankutty et al. studied the global distribution of croplands (Ramankutty, Navin, Foley, Jonathan A., Norman, John, McSweeney, 2002) and showed that there is a large reserve of croplands, mainly in tropical South America and Africa. In addition, Juan Antonio Duro et al. stated that, the world population will probably be raised to 9.7 billion by 2050 and to approximatively 11 billion by 2100 and securing its healthy nutrition is a key concern (Duro et al., 2020). They therefore analyzed the international inequalities between food supply, land-use efficiency and cropland demand from 1990-2013 at country level using an integrated approach.

Mechiche-Alami & Abdi(2020) made a research on Agricultural productivity in relation to climate and cropland management over West Africa. They used among others the datasets about, downwards solar radiation to quantify optimum conditions for vegetation growth, the land temperature from the ECMWF to evaluate the exchange of energy between the vegetation canopy and the atmosphere, ERA5 reanalysis data product with a spatial resolution of 10km X 10km from January 2000 to December 2018, the rainfall dataset from CHIPRS, the vegetation data from MODIS. As conclusion, they highlighted that some areas are undergoing land degradation that leads to decreased crop production in southern Mali, Niger and Kano in Nigeria. The limitations of this study were pointed out: the use of annual rainfall, and the mean land surface temperature restricted to the growing season(Mechiche-Alami & Abdi, 2020). Other studies related to land use showed some trends at the regional level using the west Africa land cover time series (1975, 2000, and 2013). Those studies mapped only the southern parts of the countries. The aim of this study is then to define how the cultivable areas have evolved in the past and to simulate an estimate of the possible changes in the future under the different climatic scenarios established by the IPCC (e.g., RCP4.5, RCP8.5) and assessing the consequences that they could have an impact on crop grain and thereby on food security in Mali and Burkina Faso.

**Population**

According to the world bank, the definition of population includes all residents regardless of their legal status or citizenship, with the exception of refugees who are not permanently established in their adopted country. These are generally considered as part of their country of origin. According to the world bank data, population growth is positive in Mali and Burkina Faso. The population has increased by 56 5296 in Mali and by 558251 habitants in Burkina Faso in 2017. These growths are likely to impact on cultivated areas and will certainly increase the countries' food needs.

**Food security**

Although food security is generally defined as a dichotomy, it can also be defined as a set of elements. The FAO defines food security as a situation in which, all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life(Connolly-Boutin & Smit, 2016). From this definition of food security, one can identify three major pillars such as food availability, food access and food use. The availability could refer to the production and could be understood as the quantity of food available for the consumption. This points out the fact that sufficient grain production in a country, can often be considered as a precursor to food security. A country's food availability often remains the predominant aspect used in food security analysis and measurement(Connolly-Boutin & Smit, 2016). The primary vulnerability of a family in rural area of sub-Saharan Africa in terms of food security is more often identified by the availability of grain stocks. Organizations such as FAO derive their estimates of undernourishment from estimated food balance at the national level. These partly productivity-based estimates are categorized into global, regional and national levels.

**Cropland changes current situation**

The majority of the population in West African countries, and more specifically in the Sahel, derive their livelihoods from agriculture. Consequently, their vulnerability to food security is increasing with the degradation of farmland caused by unfavorable environmental and climatic conditions. However, few studies have examined how this degradation affects agricultural productivity and household food security in the Sahel region, particularly in Mali and Burkina

Faso. We analyze changes in the area allocated to staple crops (maize, millet, sorghum) and how these changes affect the productivity of these crops and food security in Mali and Burkina Faso.

**Impact of climate change in, Burkina Faso, and Mali**

Gumma et al.(2014) in their journal entitled “Mapping seasonal rice cropland extend area in the high cropping intensity environment of Bangladeshi using MODIS”, stated that, the Soudano sahelian zone which is characterize by a monsoon season stretching between May and September, is one of the most vulnerable regions in the world to climate hazards. Given that the population of the Sahel depends agriculture, there is a concern about the future land use and the climate of the region(Lewis & Buontempo, 2016). As global warming may alter the availability of arable land, understanding that this threat is real for human security that could impact food, water, energy and assets require looking beyond the current situation in some patterns such as food demand in the future, the likely yield grain in years to come and the population growth over time. In addition, Burkina Faso and Mali are among the West African countries that are sensitive to climate variability and change. Mali’s landlocked geography and climate-sensitive economy render the country among the most vulnerable to climate stress. Social and economic insecurity are rised by political instability, flooding and recurrent droughts(World Bank, 2010). Characterized by chronic food insecurity, Burkina Faso is chocked by droughts which reduces local production and increase demand throughout the region. Moreover, fluctuations in rainfall also lead to erratic cereal production(Anderson et al., 2012).

### 1.1.3. Research questions

In order to contribute solving the problem stated above, this study aims at defining how cropland areas have evolved in the past, and simulate an estimate of the possible changes in the future, under Representative Concentration Pathways (RCPs) and socio-economic scenarios, and assessing the fact that they could have an impact on food security in West Africa particularly in Burkina Faso and Mali. Investigating such a study rises some questions to which answers will be provided in details.

- ✓ What is the current state of cultivated areas in Mali and Burkina Faso, and How will they look like in the future under the different climate and socio-economic scenarios?
- ✓ How will the evolution of cropland impact the future food security under climate and socio-economic scenarios?

- ✓ What alternative agricultural policies for Burkina Faso and Mali to face climate change?

**1.1.4. Hypotheses**

From the questions above, the following hypotheses may be useful to address the challenges related to cropland changes in Mali and Burkina Faso under the two main climate scenarios:

The main hypothesis could be formulated as follows:

The changes in cultivated areas could be examined for the past years, and estimated for the years to come likely by 2100.

Specifically, the following hypotheses could be derived too:

- ✓ The current state of cultivated areas at a country level may be experiencing considerable changes in the future under the effects of climate scenarios.
- ✓ Changes in crop yield and cultivated areas may have significant impacts on food security in West Africa specially in Burkina Faso and Mali.
- ✓ An adaptive policy in the field of agriculture could be a point to rise to policy makers.

**1.1.5. Objectives**

The main objective of this study is to assess the future climate change and demographic growth impacts on the evolution of cultivated areas and its implication on food security in West-Africa (Mali and Burkina Faso) under various socio-economic and climate scenarios.

Specifically, it aims to:

- ✓ analyze global changes in cultivated areas in Burkina Faso Mali and under various climate scenarios.
- ✓ point out the likely changes in crop yield in Mali and Burkina Faso according to the state of the changes in cultivated areas under climate scenarios.
- ✓ Assessing the impacts of evolution of cultivated areas and changes in crop yield on food security in Mali and Burkina Faso.
- ✓ assessing Developing recommendation for policy makers in Mali and Burkina Faso.

# CHAPTER I:

## 2.1. METHODOLOGY

As any research project is conducted in a specific study area, we began by identifying the area in which we intend to conduct our study. This was two countries in West Africa, Mali and Burkina Faso. Once the study area was chosen, we began to gather the data needed for our study. After collecting the data, defining the methods and data analysis tools, was the next step in our research. thus, our master plan is as follows:

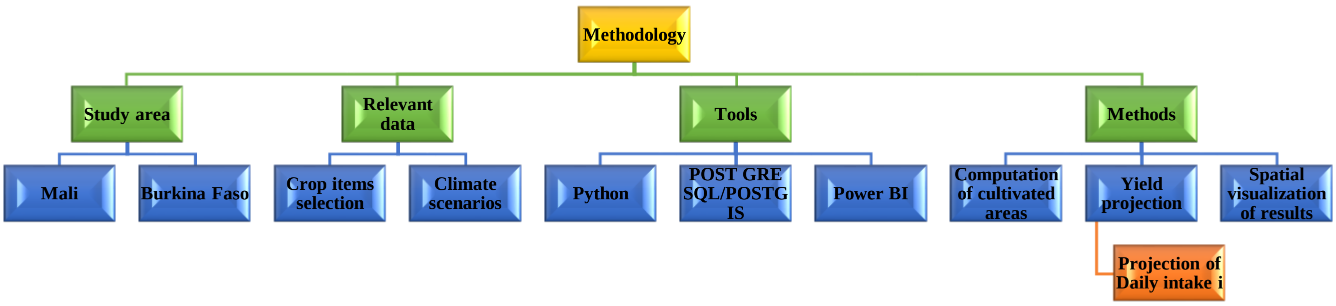



*Figure 1: Methodology*

## 2.2. STUDY AREA

This study aims at assessing the impact of climate and socio-economic scenarios on cropland change and food production in West Africa. We concerned also by the spatial variability of the climate change impacts. For that, this study concerns two sahelian countries such as Burkina Faso and Mali.

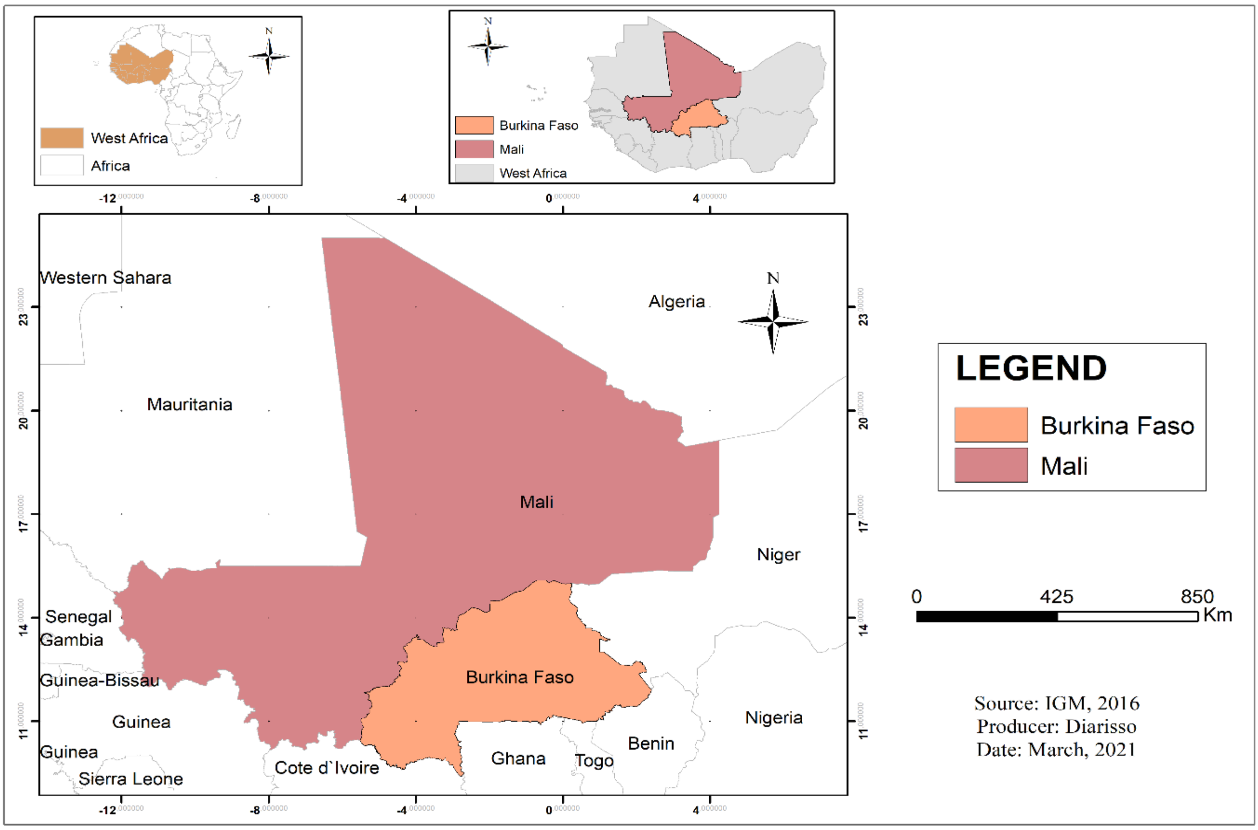



*Figure 2:Location map of Mali and Burkina Faso*

Located between -12° W, 4° E, 9° S and 30°N, these countries are part of West African region where rural population draw most of their resources from agricultural activities. The land use over west Africa has been experiencing changes. According to USGS, in Mauritania, Mali, Niger and the northern Sahel, the droughts of 1970s and 1980s degraded or reduced some of the savannas and steppes and led to 47% increase in sandy soils.

### 2.2.1. Mali

#### 2.2.1.1. Size and geographical location

Mali is a landlocked country in West Africa covering approximately 1.241 million km2 which is constitute of desert land in about 51 percent. It shares its borders with seven countries such as Algeria to the north, Niger to the east, Burkina Faso and Côte d'Ivoire to the south, Guinea to the southwest, Senegal to the west, and Mauritania to the northwest.

#### 2.2.1.2. Climate

Mali's climate is Soudano-sahelian, characterized by average temperatures very high and by the alternation of wet and rainy season from June to September and dry season lasting between five and nine months from October or November to May or June. The country is divided into four agroclimatic zones with an average rainfall of about 1280 mm/year decreasing from south to north. Firstly, The Soudano Guinean zone covering about 6 % of the country's total area the north. This is characterized by wooded savana and forest, with about 1200mm year -1. Secondly, the Sudanian zone extending over 17% of the national territory to the center. It is characterized by a more or less dense plant cover with a variable precipitation between 600 and 1200 mm year-1. In addition, the sahelian zone which is covering about 26% of the county's total area in the north, has rainfall varying from 200 to 600 mm year-1. It occupies a great part of the delta of Niger which is partially flooded areas within the year with rainfed agriculture. Moreover, the Saharan zone covering 51% of the country's total area in the northernmost region with less precipitation of about 200 mm year-1.

**2.2.1.3. Population**

Mali's population is estimated to over 20 million of people in 2019 with a density of about 16 inhabitants km-2 characterized by great heterogeneity specially within northern region where the density is less than 2 inhabitants $km^{-2}$. The population growth rate is estimated at 2.2 %.

**2.2.1.4. Economy**

In one hand, the county's economic system is mostly based on the primary sector such as agriculture, fisheries, animal breeding etc.…, that uses 83,4 % of the active people. Moreover, the agriculture that is ensuring the food security is one of the most important sectors with a total of cultivable area of 14% of the county's (Ministère de l'équipement et des transports, 2007)

**2.2.2. Burkina Faso**

**2.2.2.1. Area and geographical location**

Burkina Faso located in the middle of west Africa, is landlocked country in west Africa, bordering Mali, Niger, Cote d'Ivoire, Togo, Benin and Ghana. Essentially flat, only a few low reliefs mark its western part. It nevertheless has a fairly large hydrographic network in the south. It has three main courses such as Mouhou, Nakambé and Nazinon. It covers an area of 270764 $km^2$

**2.2.2.2. Climate**

A part from the north, Sahelian, the country belongs to the so-called Sudanese zone, which is tropical. A dry season from mid-October to mid-June and a rainy season which peaks in August. The harmattan, a dry wind blows from November to February, the temperatures are varying between 25° and 30°. March, April and May are scorching hot. Depending on the rainfall, the vegetation cover takes various forms; from the most watered to the least watered: wooded savana, shrub, dry forest, gallery forest, grassy or wooded savana, shrub, grassy steppe.

#### 2.2.2.3. Population

The population of Burkina Faso is estimated at about 21 million of inhabitants in 2019 according to National Institute of statistics and Demography. About 51% of the population is constitute of women with an estimate of youth under 20 years old at 59% with a growth rate of 3.1%.

#### 2.2.2.4. Economy

Burkina Faso is classified among the poor countries with few natural resources in terms of gold, iron and copper. The agricultural sector employs, around 80% of the workforce. Its economy is dominated by the cotton cultivation, thereby, sensitive to price fluctuations on international markets. This changes in market price have sometimes savior consequences on the livelihood, and may even lead to emigration in sectors where the population live below the poverty line.

## 2.3. RELEVANT DATA

### 2.3.1. Crop items' selection (FAOSTAT)

As the objective of this study is to assess climate change impacts on food security, we identified three main crops to be taken into account: Maize, millet, and sorghum. These constitute the sources of nutrient in diets of people in semi-arid regions of Africa. We investigated and found in several studies that the three major crops grown in Mali and Burkina Faso are maize, millet and sorghum. According to Yarnell(2008) maze constitutes the highest percentage of calories intake in the national diet in 22 in the world among them 16 African countries. In sub-Saharan Africa, maize accounts for almost half of calorie and protein consumed, and one-fifth of the calories and protein consumed in West Africa. (Santpoort, 2020) stated maize provides 19% of average calorie intake per capita in the southern and eastern Africa. Moreover, Burkina Faso and Mali are among the top 20 countries that account for 96% of the total maize production in Sub-Saharan Africa (FAOSTAT, 2015). In addition, sorghum and millet are also part of the most important consumed food in Africa. In a recent study, it has been stated that sorghum and millet constitute a main source of nutrition in diets of people in the semi-arid regions of Africa (Cisse et al., 2018). According to Yarnell, Sorghum and millet are the most important cereals in West Africa after maize (Yarnell, 2008). In addition, millet, sorghum, maize, and occasionally rice are the main crops in most of provinces in Burkina Faso(Anderson et al., 2012). For the reasons mentioned above, maize, millet and sorghum were selected for this study. Consequently, we make hypotheses that assess climate change impacts on maize, millet and sorghum production to help us have good perspectives of climate change impacts on food security in Burkina Faso and Mali.

### 2.3.2. Data Collection

Different data sources are used in this study (table 1). The socio-economic data were extracted from the Global Food Demand projections based on the IPCC Special Report on Emission Scenarios (SRES) storylines for the period 2005 until the year 2100(Bodirsky, Rolinski, et al., 2015). The dataset includes national population and per capita food demand at country level. The land use (cropland areas) data were extracted from Land-Use Harmonization (LUH1) project database (Hurtt et al., 2020). The LUH provide harmonized land use data for the years 1500-2100 at 0.5°x5° resolution under four Representative Concentration Pathways (RCPs) for different countries (table 2). The four RCPs have been simulated using four Integrated Assessment Model (IAM) such as MESSAGE, IMAGE, MiniCam and AIM. These RCPs scenarios have their correspondent socio-economic scenarios. The SRES and RCPs scenarios that are closed are RCP4.5 and SRES B1, RCP8.5 and SRES A2(Draft et al., 2011). Additional data have been extracted from FAO database and from the literature review. These data concern the yields of main cereal produced in Burkina Faso and Mali.

*Tableau 1: Data sources*

| Data used | Data sources |
|---|---|
| Predicted Population data under socio-economic scenarios | Bodirsky et al., 2015 |
| Food demand data under socio-economic scenarios | Bodirsky et al., 2015 |
| Predicted Cropland data under RCP scenarios | Hurt et al, 2019 |
| Current cultivated area under maize, millet and sorghum | Fao stat |
| Current yields of maize, millet and sorghum | Fao stat |
| Predicted maize yields under RCP 4.5 and RCP 8.5 | Freduah et al., 2019 |

*Tableau 2: correspondence table between RCPs and SRES*

| Integrated Assessment Model | RCPs | Land-Use Data |
|---|---|---|
| MESSAGE | 8.5 $W/m^2$ | Gridded |
| AIM | 6 $W/m^2$ | Gridded |
| GCAM (minicam) | 4.5 $W/m^2$ | Regional (14 regions) |
| IMAGE | 2.6 $W/m^2$ | Gridded |

### 2.3.3. Climate scenarios and socio-economic scenarios (RCPs and SRES)

It is important to assess some uncertainties while projecting climate change patterns. Such uncertainties might be how the climate might be sensitive to some increased concentration of

Greenhouse gas in the atmosphere on one hand. On the over hand, the quantity of energy emission is involved to simulate different scenarios of the future emission. According to IPCC scientists, scenarios provide a framework by which the process of building experiments can be streamlined. Scientists then use the results of different scenarios to run complex models to project possible changes in the state of climate in the future.

Enormous number of scenarios are nowadays available to simulate climate sensitivity and parameters in the future. Indeed, the most used to drive climate model runs are among other:

- ✓ Six IPCC 1992 (IS92) used in the IPCC second assessment report (SAR)
- ✓ Six Special Report on Emission Scenarios (SRES) used in the IPCC third (TAR) and fourth (AR4) assessment report
- ✓ Four RCP scenarios used in the IPCC fifth assessment report (AR5)
- ✓ Nine forcing scenarios developed the sixth assessment report (AR6) based on the Shared Socioeconomic Pathways (SSPs).

**2.3.3.1. RCPs**

The RCPs were developed after the publication of AR4 in 2007 to fit the needs of climate scientists in a relatively short time in which an update of the old SRES could not be ready for them to use it and run simulations for the following report (AR5) supposed to come out by 2013. The following four pathways were developed: RCP2.6 which indicates 2.6 watts per meter squared increase relative to pre-industrial conditions; RCP4.5, RCP6.0, RCP8.5. these are useful tools for modelling potential climate outcomes.

**2.3.3.1.1. RCP4.5**

RCP4.5 is a stabilization scenario of radiative forcing at 4.5 Watts/m2 in the year 2100 including long term global emission of Green House Gases (GHG), short lived species and land-use-land-cover in a global economic framework (Thomson et al., 2011). This scenario is based on the mininCAM level3 with incorporating updated land use modeling. It assumes that climate policies are invoked to achieve the global goal of limiting emissions, concentrations and radiative forcing. In addition, it employed an updated historical data series, and a sophistical land-use-land-cover model.

**2.3.3.1.2. RCP8.5**

The RCP8.5 which corresponds to a considerable increase of GHG emission and concentration is supposed to lead to a radiative forcing of 8.5 W/m2. It also combines assumptions about high population and relatively slow growth with technological development which causes high demand of energy consumption with consequently high emissions of GHG. It was developed considering air pollution and the enhancement of land-use-land-cover change projections and do not include any specific climate mitigation target (Riahi et al., 2011). Establishing correspondences between RCPs and specially the RCP8.5 and SRES is a process of underlying assumptions about the main scenario drivers and assumptions about technological change. Thereby, the RCP8.5 drivers such as demography and economy work with the IPCC A2 scenario published in Riahi et al. (2007). In addition, this RCP brought improvement in the categorization of land-use, and facilitate the spatial representation of land-transformation.

**2.3.3.1.3. RCP2.6**

According to IPCC scientists, the RCP2.6 is a pathway where radiative forcing peaks at approximately $3Wm^{-2}$ before 2100.

**2.3.3.1.3. RCP6.0**

According to IPCC scientists, the RCP6.0 is one of the intermediate stabilization pathways in in which radiative forcing is stabilized at approximately 6.0 $Wm^{-2}$ after 2100.

**2.3.3.2. SRES**

According to IPCC. the development of SRES took into account various possible future changes of the world's development in the 21st century. This includes the socioeconomic factors such as economic development and technological development, energy use and population growth. Four main storylines (A1, A2, B1, B2) describe the relationship between the forces driving GHG and aerosol emission and their global evolution.

**2.3.3.2.1 A2**

It describes an heterogenous world with self-resilience and preservation of local identities. According to the NARCCAP this scenario is useful for all simulations. It is preferred to the others because of its possible adaption measure to a lager climate change. On One side, this scenario, the world's population is supposed to reach 10 billion people by 2050. On the other side, it shows a slow regionally distributions of technology development.

**2.3.3.2.2 B2**

Based on sustainability and equity, the B2 scenario describes a world that considers local solutions to the economic, social and environmental development. In this scenario, the population growth is slower than in the A2 and it present a moderated technological change. Here the focus is both, regional and local solutions.

**2.3.3.2.3 A1**

In this scenario, it is assumed that the world's economy, population, and new technologies will be rapidly growing.

**2.3.3.2.4 B1**

According to the IPCC scientist, this is a scenario with rapid changes in economy, population with reduction in resource-efficient technology.

**2.3.3.2. Selection of climate and socio-economic scenarios**

Our focus in terms of RCP is on RCP4.5 and RCP8.5. The RCP4.5 and RCP8.5 are the most representatives of West African context. For each of these RCPs, we used the corresponding socio-economic data. It has been stated that, SRES and RCPs scenarios that are closed are RCP4.5 and SRES B1, RCP8.5 and SRES A2(Draft et al., 2011). Population data from SRES B1 was used to estimate the impact of population growth on per capita cultivated area in RCP4.5. The estimate of population growth impacts on per capita cultivated area in RCP8.5 has been done using population data in SRES A2. This correspondence has been established in the table of similarities between RCP and SRES.

*Tableau 3: Similarities between RCPs and SRES*

| RCP | SRES |
|---|---|
| RCP 2.6 | None |
| RCP4.5 | B1 |
| RCP 6.0 | B2 |
| RCP 8.5 | A2 |

## 2.4. DATA ANALYSIS

The analysis of data has been achieved in two steps:

1. Estimation of cropland evolution: the objective was to estimate cropland evolution from 2005 to 2100 under RCP4.5 and RCP8.5;
2. Assessment of climate change and population growth impacts on food security: the objective was to assess climate change and population growth impacts on cultivated land under socio-economic and climate scenarios;

**Step1:** Cropland trends assessment

Firstly, cropland trends in different RCPs were assessed at two levels: grid and national levels. This assessment has been done in order to estimate the spatio-temporal impact of cropland trends from 2005 to 2100 in Burkina Faso and Mali.

As stated earlier, there is a relationship between population and cropland evolution. For that, the impacts the impacts of population growth on per capita cropland variability were estimated based on the national food demand in the selected RCPs and SRES scenarios.

Based on this estimation, the per capita cropland cereal has been predicted from 2020 to 2100 in the selected RCPs and SRES scenarios and taking into account the share of cereal in cultivated areas in the both countries (Burkina Faso and Mali) in the past 20 years.

**Step 2:** Assessment of population growth and climate change impacts on food security. For this assessment, per capita food demand was projected for Burkina Faso and Mali under the different SRES scenarios. After, we estimated the food production per capita. This assessment has been achieved using the projected cultivated areas.

**2.4.1. Computation of the cultivated crops areas per capita**

FAOSTAT provide a dataset about cultivated areas on almost all the crops in most of the countries. Projecting changes in cropland over the years to come need to considere the changes in the past. Thereby, the dataset of the last 20 years about the cropland areas all crop included was used to compute the percentage of cultivated areas of maize, millet, sorghum. Accordingly, the mean values of these percentages were used to compute the areas attributed to respectively each crop type under the climatic scenarios considered in this study. Below is the formula used to compute the mean values of the percentage of cropland attributed to each selected crop item:

$$\mu = \Sigma\ \kappa\gamma i\ /\beta * 1/\ \eta$$

Where:

**μ** is the mean value in percentage of cropland attributed to a crop;

**κ** is the area of the crop item;

**γ** is the year;

**i** is the crop item;

**β** is the total crop area all crops included;

**η** is the number of years.

Once the mean values of percentage per cropland areas are known, the areas are computed using the following formula:

$$A_{\gamma i} = \delta * \mu_i$$

where:

$A\gamma i$ is the area of the selected item;

δ is the projected cropland areas all crops included (global model output under RCP4.5)

$\mu i$ is the mean value of percentage cropland attributed to each crop.

Moreover, to assess the food security aspect of the study, a dataset from HYDE database grouping together the population data, the global projected cropland area data, the food demand, was used. These are stored in the SRES scenarios accordingly as stated in the section above.

### 2.4.2. Yield Projection under climate scenarios

Yield projection in this study requires the changing rates that have been estimated in previous studies using simulation of crop yields under climate scenarios. These rates concern the values to which the crop yields may be changing in the future (e.g., 30 years to come). In our case we considered the projected changing rate estimated in 2019 by (Freduah et al., 2019). Where they estimate a decrease in yield of -0.13%, -0,15% respectively under RCP4.5 and RCP8.5 in Burkina Faso. And respectively a decrease in yield of -0.13 and -0.1 under RCP4.5 and RCP8.5 in Mali. The formula below is used to compute the likely changes in crop yield under both of the scenarios.

$$Y_{n+1} = (1+r) * Y_n$$

Were

Y is the yield;

n is the year;

r is the changing rate.

2.4.3. Yield projection per capita

In one hand, assessing food security require the amount of yield and the population. Thereby, dividing the yield by the population will give insights on the quantity of grain per individual. The formula below is used for that.

$$\sigma = Y\gamma / \varepsilon$$

Were

$\sigma$ is the production per capita;

Y is the Yield computed in the section above;

$\gamma$ is the year;

and $\varepsilon$ is the population.

### 2.4.3. Spatial visualization of the results

#### 2.4.3.1 Spatial database:

**a) Definitions and types**

- ❖ **Definition**
  - ✓ **Database**

A database is a collection of information that is organized in a such way that it can be easily accessed, managed and updated. Computer databases typically contain aggregation of data records or files, containing information about a company's business such as billing and payment transaction with customers. Building a database either spatial or not, require data in one hand, and a DBMS on the other hand. Thereby the different results of our computation are used as input of our database. Of course, they are converted into SQL format to meet the DBMS requirements. In addition, a database is made up of tables which are organized into rows and columns. Computer databases typically contain aggregation of data records or files, containing information about a company's business such as billing and payment transaction with customers. Moreover, a relational database which is targeted in this study is organized into tables and they are more often linked each other. These links are called relations.

- ✓ **Database management system (DBMS)**

A DBMS is a software package which is designed to define, access, retrieve and manage data in a database. It contains all the features such as tables and their relations. There are many kinds of DBMS, among others we have MySQL, PostgreSQL, MariaDB etc.… The used DBMS in this study is PostgreSQL. It is a DBMS with spatial functionalities and have a huge range of users.

- ✓ **Table :**

In database management, tables refer to major entities or subjects of the system. A table is made of columns and rows. A column lists the different elements of an occurrence or a record and each row contain a record of the entity.

- ✓ **Relation :**

Once the tables are ready, one can now think of how to link them in a meaningful way. Thereby, the established links refer to relations. One table can therefore be linked one or more other tables.

Making data more attractive and decision driven is nowadays one of the main purposes of data science. One could see nice plots in a thesis report but, it could be more interesting to see in an interactive way the charts and graphs built from a dataset. Here is where the visualization tools come in.

**2.4.3.2 Data visualization tools:**

Data visualization is the graphical representation of information and data by using charts, graphs, and maps. Thereby, data visualization tools make it easy to understand trends, outliers and patterns in the data. Like the databases, there are numerous data visualization tools such as tableau public, Power BI, visme, infogram, whatagraph, Sisense, DataBox, ChartBlocks etc.…. Unlike most of the rest, the first two tools (Tableau public and Power BI) are free and suitable for nice visualization. Thereby a description of each of them will make it easy to understand our choice.

**a) Tableau public**

It is a free platform where anyone can create charts, graphs, reports, dashboards etc. though they provide great possibilities with tableau public, some of the options cannot be freely accessed. In addition, tableau public can handle only excel sheets and text files.

**b) Power BI**

Like tableau public, Power BI, considered as the most preferred tool, is also free to use and download. Among its peculiarities, it can use DBMS as source of data, the data can be published in different views (mobile and desktop views). Thereby, this is our choice in terms of visualization tool.

## 2.5. TOOLS

The analysis in this study, we used a range of tools particularly for data analysis, data storage, and data visualization. For data analysis, we used python, PostgreSQL for data storage and PowerBI data visualization.

### 2.5.1. Python

Python is an object-oriented, high-level, and interpreted programming language. Its dynamic typing and dynamic bidding combined with its high-level built-in data structures make it easy to manipulate datasets having numerous lines of information. In addition, its interpreter and extended standard library are freely available for all major platforms and can be freely distributed. Python provides an increased productivity because of its fastness in debugging and its ability to save time by scaping the compilation step, therefore programmers love it. Moreover, it is easy to manipulate various types of data with python by just importing the right library at the right place and at the right time. It has several text notebooks that give users an extremely flexible choice in what to use while writing their code. Jupiter-notebook is the one that is chosen in this study. Dealing with, csv and excel files in this study, the corresponding libraries are always imported in the computation steps. The libraries to be mostly used are pandas and NumPy for data manipulation and matplotlib for the plotting stuffs.

### 2.5.2. PostgreSQL / POSTGIS

PostgreSQL often called just Postgres, is an object-relational database management system with more flexibility that safely store and scale the most complicated data workloads. It has a strong reputation for its best architecture in structuring data to ensure data integrity, reliability. It has more features with a wide community which consistently deliver performant and innovative solutions. In addition, one of its major flexibilities is its spatial features which allow users to build spatial databases dedicated to store georeferenced data. That is what guided our choice on it.

### 2.5.3. PowerBI


PowerBI is a collection of software services, apps and connectors that work in synergy to turn unrelated sources of data into coherent, visually immersive and interactive insights. Considered as the most preferred tool, power BI is used for different purposes based on one's need. But mostly, it is used to make report and dashboards. It also allows nontechnical business users with tools for their data analysis. Among its peculiarities, DBMS can be used as source of data and the reports can be published in different views (mobile and desktop views). Thereby, this is our choice in terms of visualization tool. Though it has some great advantages, one should be linked to an organization in order to use it efficiently.

# CHAPTER II:

## 3.1. RESULTS AND DISCUSSION

This study aims to assess the capacity of Burkina Faso and Mali to feed their own population in the future. It includes the historical, and the projection under two rcps (RCP4.5, RCP8.5), of the cultivated areas, the projection of yield and crop production, and the projection of daily needed energy in calori, under the two rcps (RCP4.5, RCP8.5).

### 3.1.1. Past cultivated areas (historical)

#### 3.1.1.1. Mali

The historical data in terms of areas dedicated to the different crops selected in this study are presented in the stacked histogram below. It is important to note that each of the items in the histogram starts at the zero level of the x-axis. In addition, the data units are in millions of hectares.

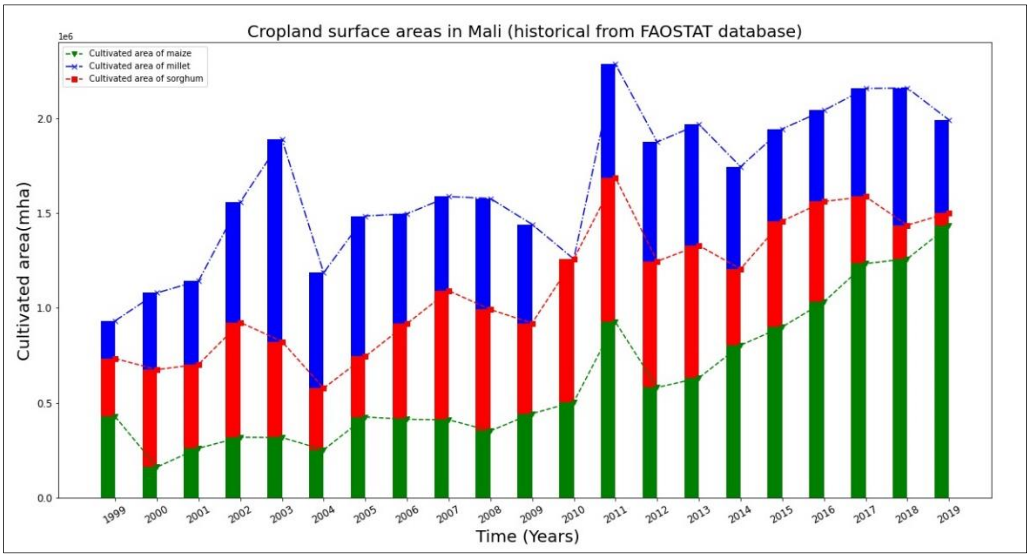



*Figure 3: Cultivated areas of maize, millet, and sorghum in Mali from 1999 to 2019*

Figure 3 shows an almost uniform decrease in cultivable land for different crops around 2000. From 2001 until 2002, millet crops have seen a considerable increase while those of the other two crops have not experienced significant changes. From 2002 going towards 2004, a considerable decrease in cultivated areas of millet appeared. However, a small decrease was also found in the areas cultivated with maize and sorghum. Between the periods 2004 and 2010, the cultivated areas evolved almost uniformly and resumed their peaks around 2010, 2011. Then they start to increase for a few years before showing a shallow change. In addition, the total change in cropland surface in Mali has been gradually increasing from 2000 to 2019 with continuous increases between the years 2000-2002, 2010-2011 and 2013-2017, and negative trends appearing between the years 2002-2003, 2011-2012. Almost constant evolutions appeared between 2005-2010 and 2012-2013. The dataset used is summarized in table1.

#### 3.1.1.2. Burkina Faso

Like in the section above, this stacked histogram is about the historical of cropland areas of the three main crop items in Burkina Faso. Once again note that each histogram starts on the x-axis of the graph.

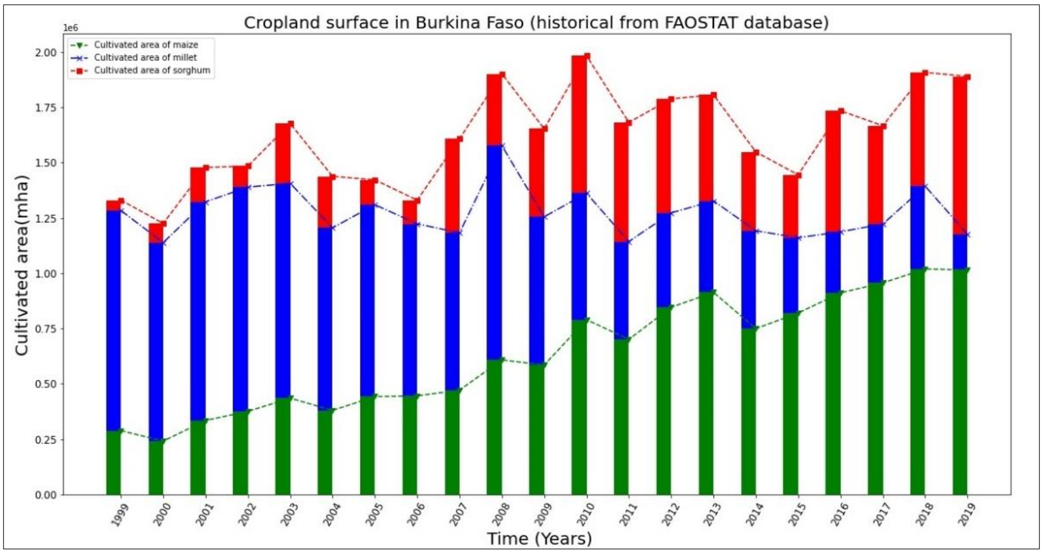



*Figure 4: Cultivated areas of maize, millet, and sorghum in Burkina Faso from 1999 to 2019 use the same color as Mali*

On Figure 4, the evolution of maize cultivated areas seems to not change as much as such between 2000 and 2007 while the cultivated areas of the two other crops increased upwards between 2000 and 2003, then experienced decreases during the period between 2003 and 2006. From 2006 going towards 2013, the fluctuations are a little more significant in the areas cultivated with sorghum and millet. The cultivated surface areas of these crops then recorded more or less constant decreases until 2019. However, the corn has recorded an evolutionary growth over the years in terms of cultivated area. In general, the total surface area allocated to the three crops in Burkina Faso is evolving in an increasing way with some decreases observed during the years 2000, 2004, 2006, 2007, 2009, 2011, 2014 and 2015. The relevant data is summarized in Table 1.

*Table 1 : Summary of the cultivated area of maize, millet, sorghum within the past 20 year in Mali and Burkina Faso.*

| **Year** | **Total crop Area** | | **Area dedicated to maize** | | **Area dedicated to millet** | | **Area dedicated to sorghum** | |
|---|---|---|---|---|---|---|---|---|
| | **Ha** | **%** | **Ha** | **%** | **Ha** | **%** | **Ha** | **%** |
| 2000 | 3 275 637 | 100% | 161 053 | 5% | 1 078 624 | 33% | 674 768 | 21% |
| 2005 | 4 543 764 | 100% | 424 861 | 9% | 1 484 190 | 33% | 744 172 | 16% |
| 2010 | 4 945 975 | 100% | 504 362 | 10% | 1 257 043 | 25% | 1 257 011 | 25% |
| 2015 | 6 924 048 | 100% | 899 640 | 13% | 1 943 002 | 28% | 1 457 267 | 21% |
| 2019 | 8 252 849 | 100% | 1 432 151 | 17% | 1 989 953 | 24% | 1 500 778 | 18% |
| **Average rate of changes from 2000-2019** | | | | **11%** | | **30%** | | **20%** |
| **Burkina Faso** | | | | | | | | |
| 2000 | 3 564 099 | 100% | 241 401 | 7% | 1 138 581 | 32% | 1 225 223 | 0,34 |
| 2005 | 5 318 103 | 100% | 442 497 | 8% | 1 309 710 | 25% | 1 422 272 | 0,27 |
| 2010 | 6 864 172 | 100% | 790 321 | 12% | 1 361 835 | 20% | 1 983 122 | 0,29 |
| 2015 | 6 496 083 | 100% | 820 117 | 13% | 1 160 718 | 18% | 1 444 937 | 0,22 |
| 2019 | 7 786 945 | 100% | 1 014 907 | 13% | 1 176 512 | 15% | 1 890 172 | 0,24 |
| **Average rate of changes from 2000-2019** | | | | **10%** | | **22%** | | **28%** |

The following values were obtained: **11%, 30%** and **20%** respectively for maize, millet and sorghum as mean of dedicated crop area to these items in Mali.

Similarly, the changes were computed over Burkina Faso and occurred to be **10%, 22%** and **28%** respectively for maize, millet and sorghum.

### 3.1.2 Projection of cultivated areas

#### 3.1.2.1. Projected cultivated areas of the selected crop items under RCP4.5 climate scenarios

Projecting changes over the years requires some statistics based on the past. Thus, we first of all, computed the mean of changes in cultivated areas. This mean value was then used to compute the likely changes in the future considering that all the conditions (climatic and socioeconomic) remain the same. The projection is made using a multiplier based on the fact that we considere a minimum threshold of variation of the cultivated areas in the future. The figure below is an illustration of these changes.

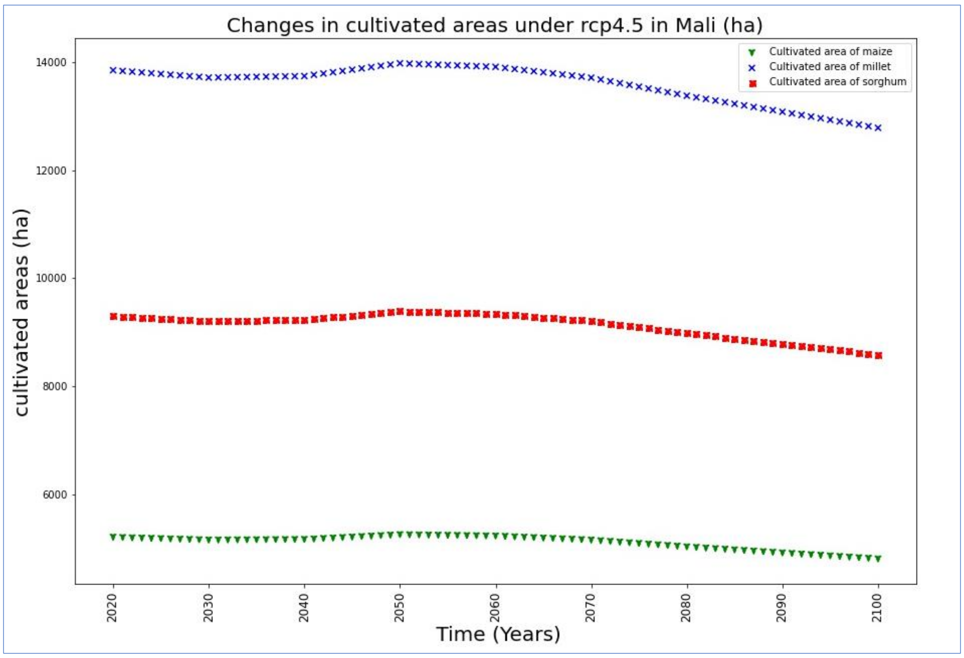



*Figure 5: changes in cultivated areas under RCP4.5 in Mali*

Figure 5 shows that, the cultivated surface areas are globally reducing under the climate scenario RCP4.5. though some increases could be noticed between 2040 and 2070, the actual state of cropland will not remain statable and will likely be decreasing from the current day up to 2100 in Mali.

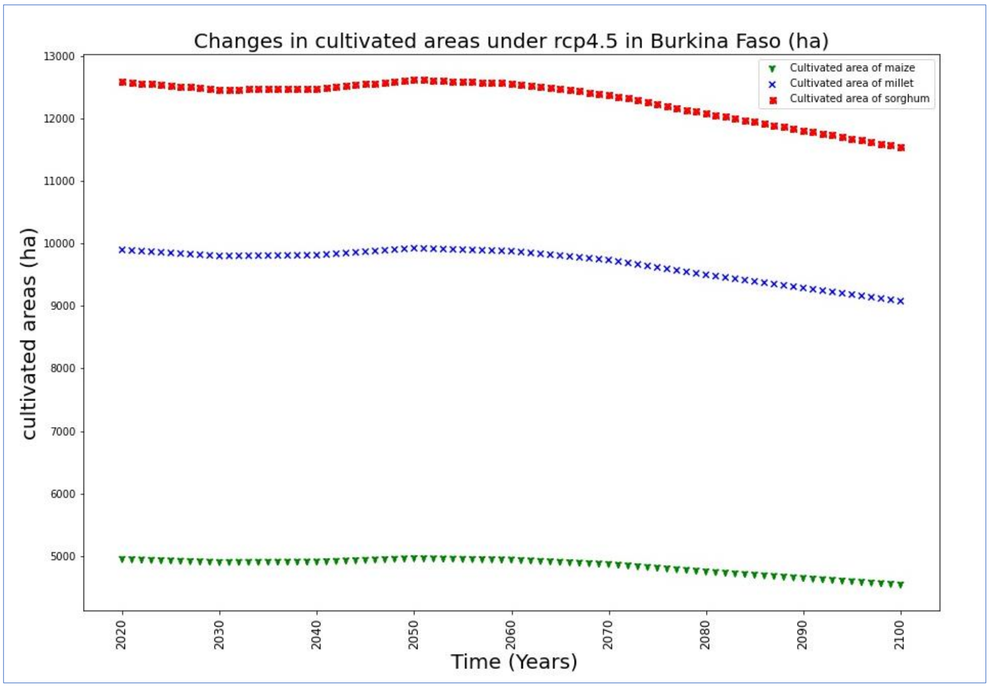



*Figure 6: changes in cultivated areas under RCP4.5 in Burkina Faso*

Like in Mali, the Figure 6 highlights that the cropland areas are mostly decreasing from the current day all the way to the future. The relevant dataset used in both of the countries is summarized in Table 1Table 2.

*Table 2 : summary of the projected crop areas in Mali and Burkina Faso under RCP4.5*

| Mali | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Year** | **Total area** | **Area dedicated to maize** | | **Area dedicated to millet** | | **Area dedicated to sorghum** | |
| | **Ha** | **Ha** | **%** | **Ha** | **%** | **Ha** | **%** |
| **2020** | 46440 | 5417 | | 13771 | | 9552 | |
| **2025** | 46212 | 5390 | 0% | 13704 | 0% | 9505 | 0% |
| **2030** | 45985 | 5363 | -1% | 13636 | 0% | 9459 | 0% |
| **2035** | 46031 | 5369 | 0% | 13650 | 0% | 9468 | 0% |
| **2040** | 46078 | 5374 | 0% | 13664 | 0% | 9478 | 0% |
| **2045** | 46474 | 5420 | 1% | 13781 | 1% | 9559 | 1% |
| **2050** | 46871 | 5467 | 1% | 13899 | 1% | 9641 | 1% |
| **2055** | 46760 | 5454 | 0% | 13866 | 0% | 9618 | 0% |
| **2060** | 46649 | 5441 | 0% | 13833 | 0% | 9595 | 0% |
| **2065** | 46314 | 5402 | -1% | 13734 | -1% | 9526 | -1% |
| **2070** | 45978 | 5363 | -1% | 13634 | -1% | 9457 | -1% |
| **2075** | 45417 | 5297 | -1% | 13468 | -1% | 9342 | -1% |
| **2080** | 44857 | 5232 | -1% | 13302 | -1% | 9227 | -1% |
| **2085** | 44359 | 5174 | -1% | 13154 | -1% | 9124 | -1% |
| **2090** | 43861 | 5116 | -1% | 13006 | -1% | 9022 | -1% |
| **2095** | 43364 | 5058 | -1% | 12859 | -1% | 8920 | -1% |
| **2100** | 42866 | 5000 | -1% | 12711 | -1% | 8817 | -1% |
| **Average rate of changes from 2005-2100** | | | **0%** | | **0%** | | **0%** |
| **Burkina Faso** | | | | | | | |
| **2020** | 57 106 | 6 535 | | 11 374 | | 15 069 | |
| **2025** | 59 234 | 6 779 | 4% | 11 798 | 4% | 15 630 | 4% |
| **2030** | 61 361 | 7 022 | 4% | 12 222 | 4% | 16 192 | 4% |
| **2035** | 63 692 | 7 289 | 4% | 12 686 | 4% | 16 807 | 4% |
| **2040** | 66 023 | 7 556 | 4% | 13 151 | 4% | 17 422 | 4% |
| **2045** | 68 076 | 7 791 | 3% | 13 559 | 3% | 17 964 | 3% |
| **2050** | 70 130 | 8 026 | 3% | 13 969 | 3% | 18 506 | 3% |
| **2055** | 72 148 | 8 257 | 3% | 14 371 | 3% | 19 038 | 3% |
| **2060** | 74 166 | 8 488 | 3% | 14 773 | 3% | 19 571 | 3% |
| **2065** | 75 955 | 8 692 | 2% | 15 129 | 2% | 20 043 | 2% |
| **2070** | 77 744 | 8 897 | 2% | 15 485 | 2% | 20 515 | 2% |
| **2075** | 79 000 | 9 041 | 2% | 15 735 | 2% | 20 846 | 2% |
| **2080** | 80 256 | 9 185 | 2% | 15 986 | 2% | 21 178 | 2% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **2085** | 82 715 | 9 466 | 3% | 16 475 | 3% | 21 827 | 3% |
| **2090** | 85 173 | 9 747 | 3% | 16 965 | 3% | 22 475 | 3% |
| **2095** | 87 013 | 9 958 | 2% | 17 331 | 2% | 22 961 | 2% |
| **2100** | 88 852 | 10 168 | 2% | 17 698 | 2% | 23 446 | 2% |
| **Average rate of changes from 2005-2100** | | | **3%** | | **3%** | | **3%** |

The average changes projected in each crop area are about **0%** between 2020 and 2100 in Mali and **3%** in Burkina Faso.

In addition, the expected changes in cultivated land areas per capita were also computed under RCP4.5. The results are shown in the section below.

#### 3.1.2.2. Projected cultivated areas per capita of the selected crop items under RCP4.5 climate scenarios

After computing how the cropland areas could be evolving in a general way, it will be more interesting to see their evolution per capita. Thereby, the outputs of the projected cultivated areas in each scenario are divided by the corresponding population estimate. The figures below illustrate the possible changes.

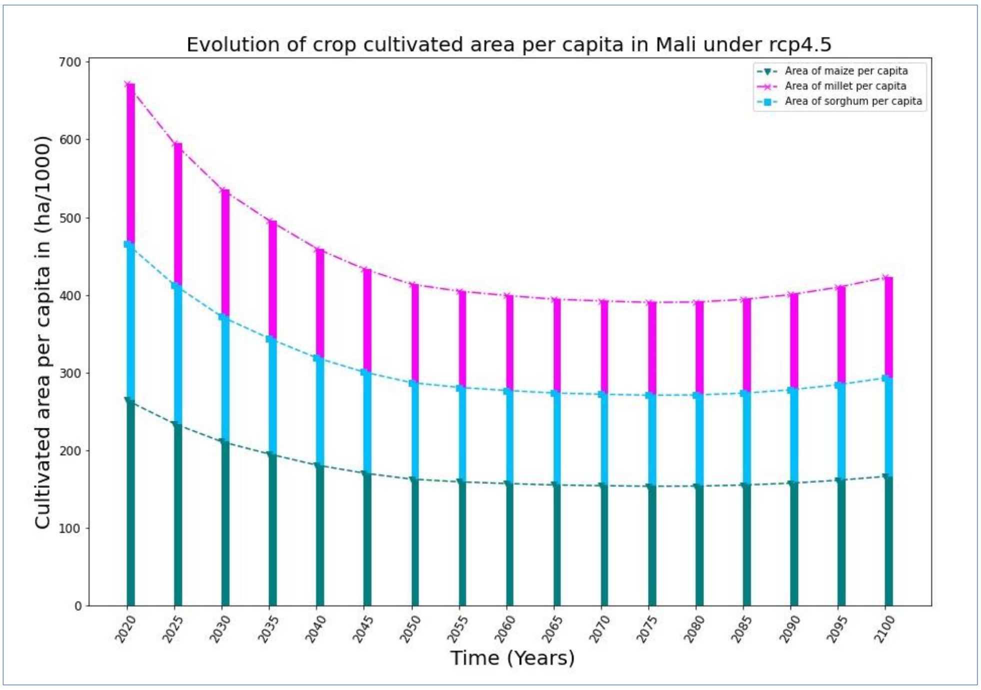



*Figure 7: cultivated area per capita in Mali under RCP4.5*

Figure 7 shows a global decrease in cultivated area per capita though the changes seem to be stable from 2045 all the way to 2100. The used dataset is summarized in Table 9.

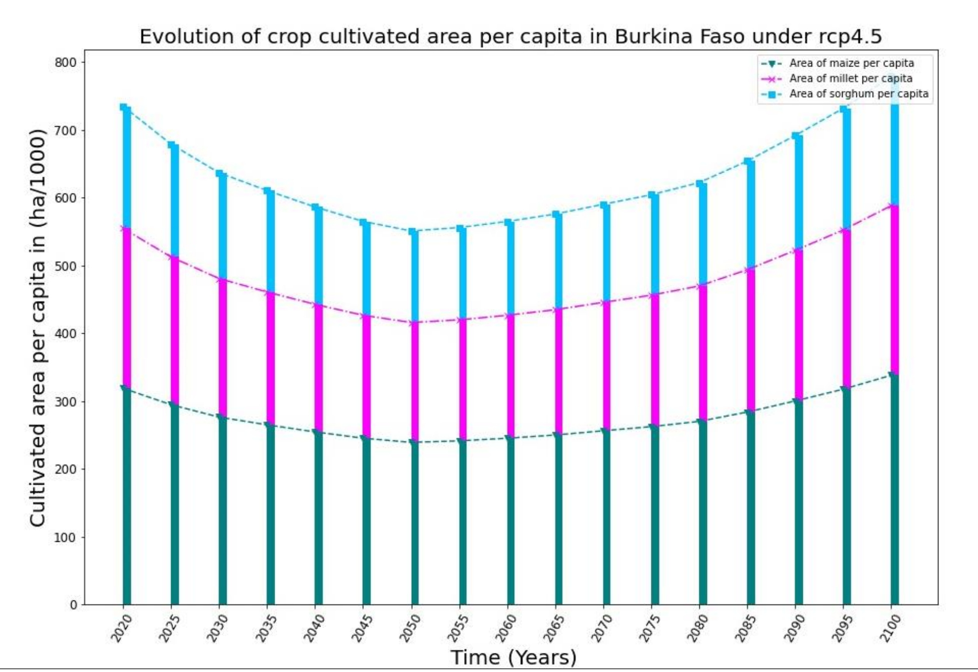



*Figure 8:cultivated area per capita in Burkina Faso under RCP4.5*

Unlike the distribution in Mali, the cultivated areas per capita are undergoing some decrease from 2005 to 2050, then starts increasing until 2100. The dataset is summarized in Table 3.

*Table 3: summary of cultivated area per capita in Mali and Burkina Faso under RCP4.5*

| Mali | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Year** | **Total area per capita** | **area per capita in maize** | | **Area per capita in millet** | | **Area per capita in sorghum** | |
| | **ha** | **$Ha10^{-3}$** | **%** | **$Ha10^{-3}$** | **%** | **$Ha10^{-3}$** | **%** |
| **2020** | 2264,55 | 264,15 | | 671,51 | | 465,78 | |
| **2025** | 2006,86 | 234,07 | -11% | 595,13 | -11% | 412,78 | -11% |
| **2030** | 1807,76 | 210,83 | -10% | 536,06 | -10% | 371,85 | -10% |
| **2035** | 1671,57 | 194,97 | -8% | 495,69 | -8% | 343,82 | -8% |
| **2040** | 1550,14 | 180,79 | -7% | 459,68 | -7% | 318,86 | -7% |
| **2045** | 1461,13 | 170,40 | -6% | 433,27 | -6% | 300,53 | -6% |
| **2050** | 1394,68 | 162,67 | -5% | 413,57 | -5% | 286,87 | -5% |
| **2055** | 1364,80 | 159,19 | -2% | 404,71 | -2% | 280,72 | -2% |
| **2060** | 1345,79 | 156,97 | -1% | 399,07 | -1% | 276,81 | -1% |
| **2065** | 1329,88 | 155,12 | -1% | 394,36 | -1% | 273,53 | -1% |
| **2070** | 1322,09 | 154,21 | -1% | 392,04 | -1% | 271,93 | -1% |
| **2075** | 1315,90 | 153,47 | 0% | 390,22 | 0% | 270,67 | 0% |
| **2080** | 1317,23 | 153,64 | 0% | 390,61 | 0% | 270,95 | 0% |
| **2085** | 1328,41 | 154,94 | 1% | 393,92 | 1% | 273,23 | 1% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **2090** | 1349,49 | 157,41 | 2% | 400,16 | 2% | 277,58 | 2% |
| **2095** | 1381,23 | 161,11 | 2% | 409,59 | 2% | 284,12 | 2% |
| **2100** | 1423,85 | 166,08 | 0% | 422,21 | 3% | 292,87 | 3% |
| **Average rate of changes from 2005-2100** | | | 0% | | -3% | | -3% |
| **Burkina Faso** | | | | | | | |
| **2020** | 2784,65 | 318,67 | | 554,63 | | 734,81 | |
| **2025** | 2572,36 | 294,39 | -8% | 512,35 | -8% | 678,77 | -8% |
| **2030** | 2412,22 | 276,05 | -6% | 480,47 | -6% | 636,54 | -6% |
| **2035** | 2312,91 | 264,69 | -4% | 460,68 | -4% | 610,33 | -4% |
| **2040** | 2221,12 | 254,20 | -4% | 442,42 | -4% | 586,11 | -4% |
| **2045** | 2140,28 | 244,95 | -4% | 426,29 | -4% | 564,78 | -4% |
| **2050** | 2086,76 | 238,82 | -3% | 415,66 | -2% | 550,66 | -3% |
| **2055** | 2105,81 | 241,00 | 1% | 419,45 | 1% | 555,67 | 1% |
| **2060** | 2139,64 | 244,87 | 2% | 426,19 | 2% | 564,61 | 2% |
| **2065** | 2181,00 | 249,59 | 2% | 434,42 | 2% | 575,52 | 2% |
| **2070** | 2235,51 | 255,83 | 3% | 445,27 | 2% | 589,90 | 2% |
| **2075** | 2288,93 | 261,95 | 2% | 455,90 | 2% | 603,99 | 2% |
| **2080** | 2356,72 | 269,72 | 3% | 469,43 | 3% | 621,89 | 3% |
| **2085** | 2477,05 | 283,48 | 5% | 493,37 | 5% | 653,65 | 5% |
| **2090** | 2620,56 | 299,89 | 6% | 521,97 | 6% | 691,50 | 6% |
| **2095** | 2771,55 | 317,18 | 6% | 552,03 | 6% | 731,36 | 6% |
| **2100** | 2951,34 | 337,74 | 6% | 587,86 | 6% | 778,79 | 6% |
| **Average rate of changes from 2005-2100** | | | **0%** | | **0%** | | **0%** |

The average changes projected in millet and sorghum crops area are about **-3%** between 2020 and 2100 in Mali and **0%** for each crop in Burkina Faso.

### 3.1.2.3. Cultivated areas of the selected crop items under RCP8.5 climate scenarios

As changes in areas were computed under RCP4.5, the same process was used to compute the likely changes under RCP8.5. the results are shown in the figures below.

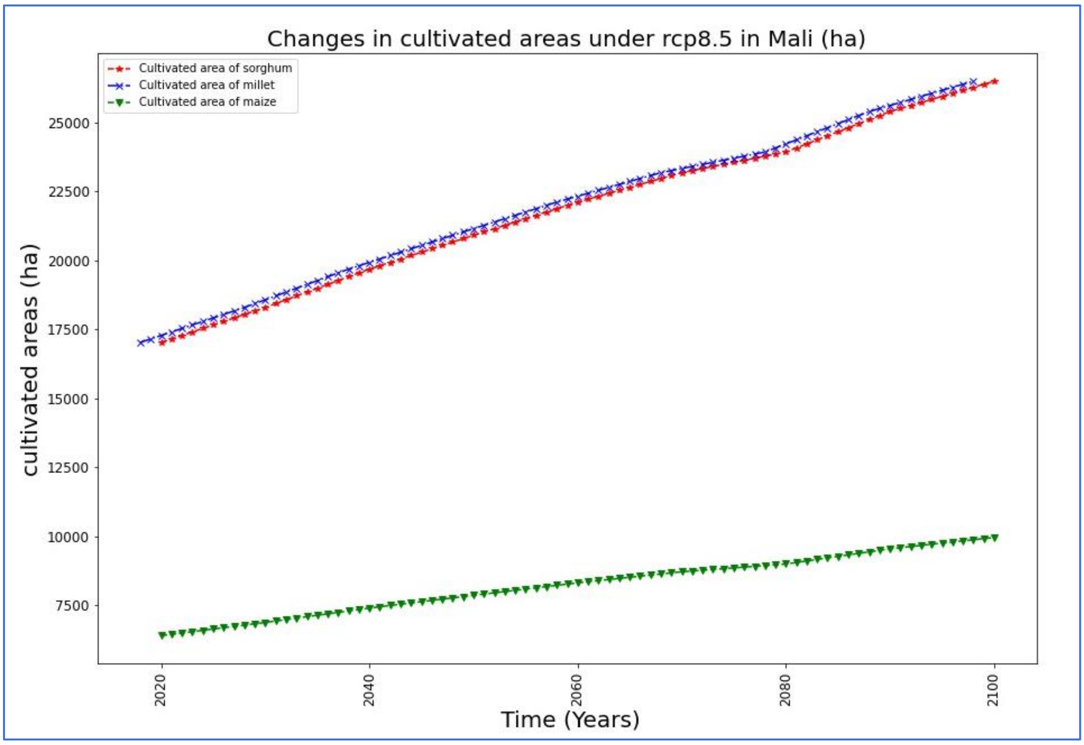



*Figure 9: projected changes in cultivated areas under RCP8.5 in Mali.*

Unlike under the RCP4.5 scenarios, where the cultivated areas are decreasing, they are increasingly changing under RCP8.5 in Mali. This expansion may be due to a growing population which could lead to certain increases in food demands.

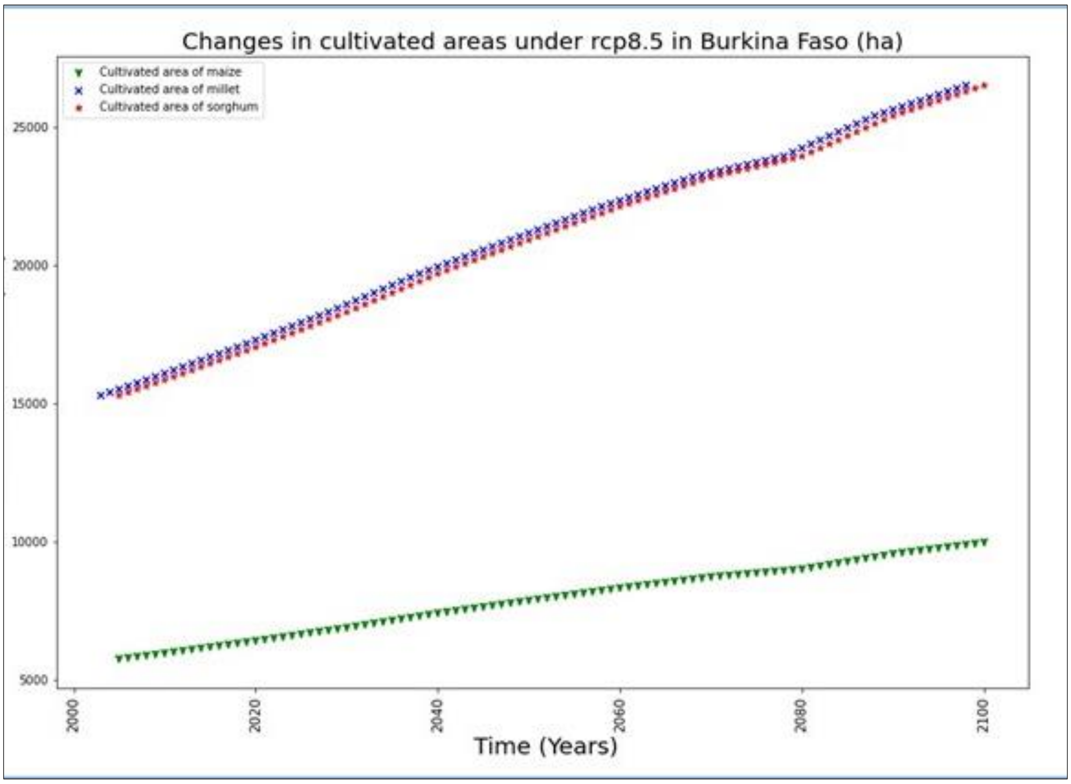



*Figure 10 : projected changes in cultivated areas under RCP8.5 in Burkina Faso.*

Like in Mali, the cropland areas are changing in an increasing way in Burkina Faso. The Table 4 summarizes the used dataset.

*Table 4: Summary of the projected crop areas in Mali and Burkina Faso under RCP8.5*

| Mali | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Year** | **Total area** | **Area dedicated to maize** | | **Area dedicated to millet** | | **Area dedicated to sorghum** | |
| | **Ha** | **Ha** | **%** | **Ha** | **%** | **Ha** | **%** |
| **2020** | 59 114 | 6 895 | | 17 529 | | 12 159 | |
| **2025** | 60 797 | 7 222 | 5% | 18 361 | 5% | 12 736 | 5% |
| **2030** | 61 919 | 7 549 | 5% | 19 193 | 5% | 13 313 | 5% |
| **2035** | 64 725 | 7 907 | 5% | 20 102 | 5% | 13 944 | 5% |
| **2040** | 67 789 | 8 264 | 5% | 21 010 | 5% | 14 574 | 5% |
| **2045** | 70 853 | 8 577 | 4% | 21 806 | 4% | 15 126 | 4% |
| **2050** | 73 535 | 8 890 | 4% | 22 601 | 4% | 15 677 | 4% |
| **2055** | 76 217 | 9 195 | 3% | 23 377 | 3% | 16 215 | 3% |
| **2060** | 78 832 | 9 499 | 3% | 24 152 | 3% | 16 753 | 3% |
| **2065** | 81 446 | 9 780 | 3% | 24 866 | 3% | 17 248 | 3% |
| **2070** | 83 854 | 10 061 | 3% | 25 580 | 3% | 17 744 | 3% |
| **2075** | 86 263 | 10 254 | 2% | 26 069 | 2% | 18 083 | 2% |
| **2080** | 89 562 | 10 446 | 2% | 26 558 | 2% | 18 422 | 2% |
| **2085** | 92 656 | 10 807 | 3% | 27 476 | 3% | 19 059 | 3% |
| **2090** | 95 749 | 11 168 | 3% | 28 393 | 3% | 19 695 | 3% |
| **2095** | 98 174 | 11 451 | 3% | 29 112 | 3% | 20 194 | 3% |
| **2100** | 100 599 | 11 733 | 2% | 29 831 | 2% | 20 692 | 2% |
| **Average rate of changes from 2005-2100** | | | **3%** | | **3%** | | **3%** |
| **Burkina Faso** | | | | | | | |
| **2020** | 57 106 | 6 535 | | 11 374 | | 15 069 | |
| **2025** | 59 234 | 6 779 | 4% | 11 798 | 4% | 15 630 | 4% |
| **2030** | 61 361 | 7 022 | 4% | 12 222 | 4% | 16 192 | 4% |
| **2035** | 63 692 | 7 289 | 4% | 12 686 | 4% | 16 807 | 4% |
| **2040** | 66 023 | 7 556 | 4% | 13 151 | 4% | 17 422 | 4% |
| **2045** | 68 076 | 7 791 | 3% | 13 559 | 3% | 17 964 | 3% |
| **2050** | 70 130 | 8 026 | 3% | 13 969 | 3% | 18 506 | 3% |
| **2055** | 72 148 | 8 257 | 3% | 14 371 | 3% | 19 038 | 3% |
| **2060** | 74 166 | 8 488 | 3% | 14 773 | 3% | 19 571 | 3% |
| **2065** | 75 955 | 8 692 | 2% | 15 129 | 2% | 20 043 | 2% |
| **2070** | 77 744 | 8 897 | 2% | 15 485 | 2% | 20 515 | 2% |
| **2075** | 79 000 | 9 041 | 2% | 15 735 | 2% | 20 846 | 2% |
| **2080** | 80 256 | 9 185 | 2% | 15 986 | 2% | 21 178 | 2% |
| **2085** | 82 715 | 9 466 | 3% | 16 475 | 3% | 21 827 | 3% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **2090** | 85 173 | 9 747 | 3% | 16 965 | 3% | 22 475 | 3% |
| **2095** | 87 013 | 9 958 | 2% | 17 331 | 2% | 22 961 | 2% |
| **2100** | 88 852 | 10 168 | 2% | 17 698 | 2% | 23 446 | 2% |
| **Average rate of changes from 2005-2100** | | | **3%** | | **3%** | | **3%** |

The average changes projected in each crop area are expected to be about 3% between 2020 and 2100 in Burkina Faso and Mali.

### 3.1.2.4. Projected cultivated areas per capita of the selected crop items under RCP8.5 climate scenarios

In one hand, the projected areas per capita could be different from a scenario to the other, one scenario may be predicting in an optimist way while the other predicts otherwise. Thereby, the possible changes in cropland areas per capita are computed under the RCP8.5 scenario and the figures are shown below.

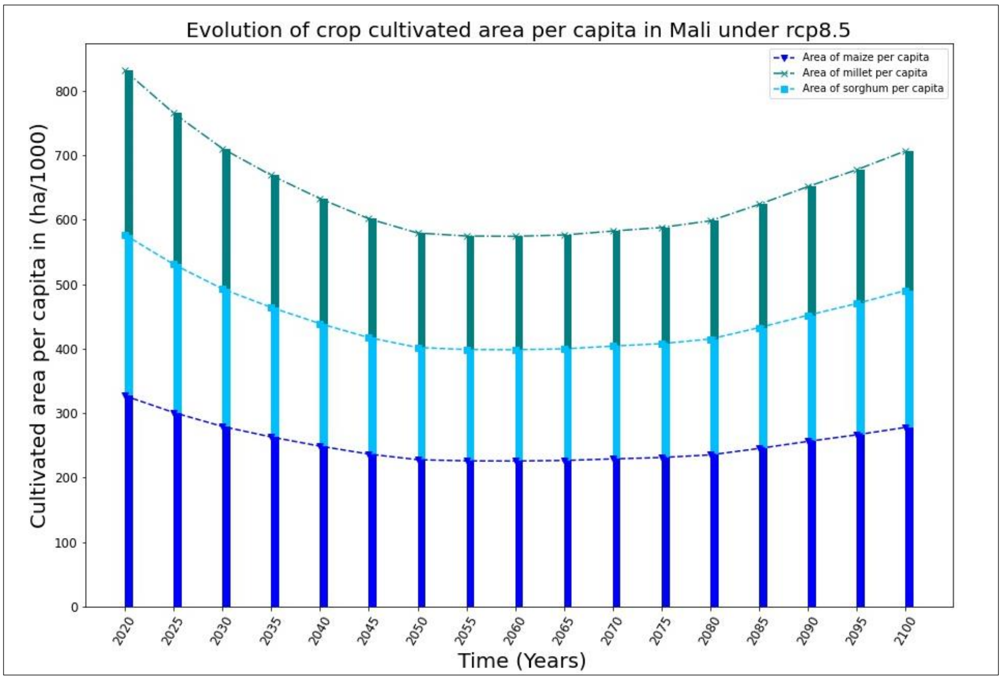



*Figure 11: cultivated areas per capita in Mali under RCP8.5 scenario*

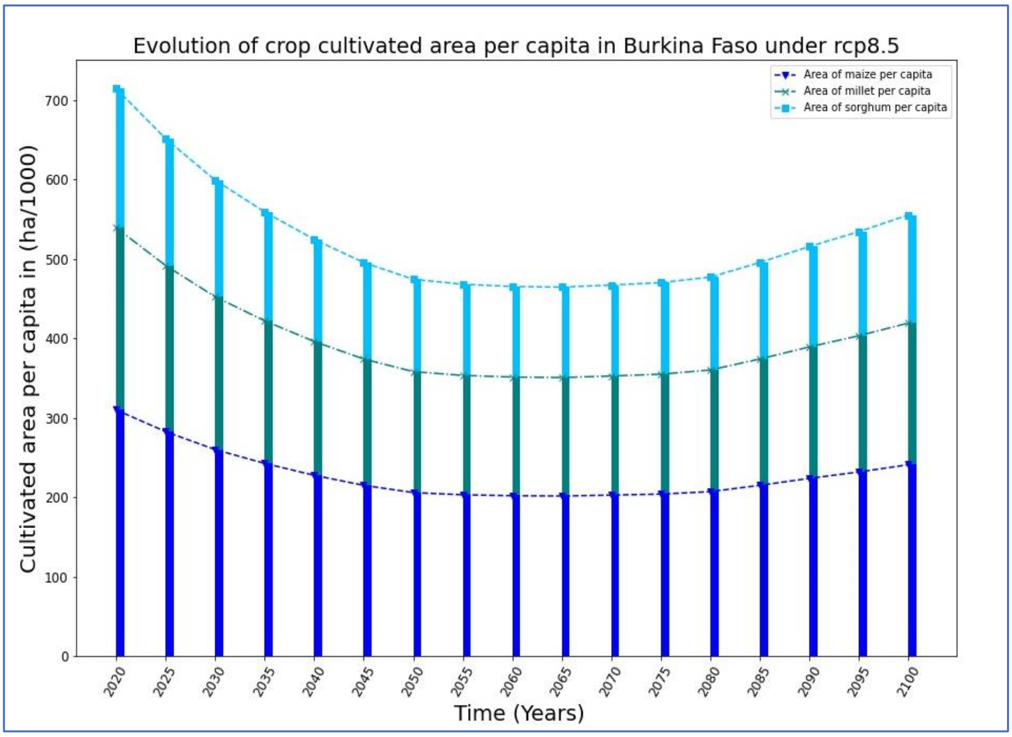



*Figure 12: cultivated areas per capita in Burkina Faso under RCP8.5 scenario.*

Comment: Though some increases are expected in cropland changes per capita from 2050 up to 2100, one could be alerted by the likely diminution in these areas from current date up to 2050 in both countries.

*Table 5: summary of the projected crop areas per capita in Mali and Burkina Faso under RCP8.5*

| Mali | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Year** | **Total area per capita** | **area per capita in maize** | | **Area per capita in millet** | | **Area per capita in sorghum** | |
| | **ha** | **$Ha10^{-3}$** | **%** | **$Ha10^{-3}$** | **%** | **$Ha10^{-3}$** | **%** |
| **2020** | 2802,90 | 326,93 | | 831,14 | | 576,52 | |
| **2025** | 2580,52 | 300,98 | -8% | 765,21 | -8% | 530,78 | -8% |
| **2030** | 2395,32 | 279,37 | -7% | 710,29 | -7% | 492,68 | -7% |
| **2035** | 2255,21 | 263,05 | -6% | 668,75 | -6% | 463,89 | -6% |
| **2040** | 2133,23 | 248,81 | -5% | 632,57 | -5% | 438,79 | -5% |
| **2045** | 2027,94 | 236,54 | -5% | 601,36 | -5% | 417,14 | -5% |
| **2050** | 1953,49 | 227,86 | -4% | 579,28 | -4% | 401,81 | -4% |
| **2055** | 1937,78 | 226,02 | -1% | 574,63 | -1% | 398,58 | -1% |
| **2060** | 1936,12 | 225,81 | 0% | 574,14 | 0% | 398,25 | 0% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **2065** | 1943,09 | 226,63 | 0% | 576,20 | 0% | 399,68 | 0% |
| **2070** | 1963,73 | 229,03 | 1% | 582,31 | 1% | 403,93 | 1% |
| **2075** | 1982,31 | 231,22 | 1% | 587,83 | 1% | 407,75 | 1% |
| **2080** | 2017,34 | 235,29 | 2% | 598,21 | 2% | 414,95 | 2% |
| **2085** | 2103,33 | 245,32 | 4% | 623,72 | 4% | 432,65 | 4% |
| **2090** | 2196,53 | 256,20 | 4% | 651,35 | 4% | 451,81 | 4% |
| **2095** | 2284,31 | 266,44 | 4% | 677,38 | 4% | 469,87 | 4% |
| **2100** | 2383,01 | 277,93 | 0% | 706,64 | 4% | 490,16 | 4% |
| **Average rate of changes from 2005-2100** | | | 0% | | -1% | | -1% |
| **Burkina Faso** | | | | | | | |
| **2020** | 2707,69 | 309,86 | | 539,30 | | 714,50 | |
| **2025** | 2468,62 | 282,52 | -9% | 491,69 | -9% | 651,39 | -9% |
| **2030** | 2270,83 | 259,87 | -8% | 452,31 | -8% | 599,23 | -8% |
| **2035** | 2118,91 | 242,49 | -7% | 422,04 | -7% | 559,14 | -7% |
| **2040** | 1987,81 | 227,49 | -6% | 395,95 | -6% | 524,54 | -6% |
| **2045** | 1877,39 | 214,86 | -6% | 373,93 | -6% | 495,41 | -6% |
| **2050** | 1797,47 | 205,71 | -4% | 358,03 | -4% | 474,32 | -4% |
| **2055** | 1773,48 | 202,97 | -1% | 353,26 | -1% | 467,98 | -1% |
| **2060** | 1763,06 | 201,78 | -1% | 351,18 | -1% | 465,24 | -1% |
| **2065** | 1760,05 | 201,41 | 0% | 350,57 | 0% | 464,44 | 0% |
| **2070** | 1769,80 | 202,54 | 1% | 352,51 | 1% | 467,01 | 1% |
| **2075** | 1781,36 | 203,86 | 1% | 354,81 | 1% | 470,05 | 1% |
| **2080** | 1807,73 | 206,89 | 1% | 360,08 | 1% | 477,02 | 1% |
| **2085** | 1877,66 | 214,88 | 4% | 373,99 | 4% | 495,48 | 4% |
| **2090** | 1953,91 | 223,60 | 4% | 389,19 | 4% | 515,59 | 4% |
| **2095** | 2024,62 | 231,70 | 4% | 403,26 | 4% | 534,26 | 4% |
| **2100** | 2104,75 | 240,86 | 4% | 419,23 | 4% | 555,39 | 4% |
| **Average rate of changes from 2005-2100** | | | **-1%** | | **-1%** | | **-1%** |

The average changes projected in each crop area per capita are expected to be about **0%** in maize, between 2020 and 2100 in Mali and **-1%** in each of the crops' area in both countries.

### 3.1.3. Projection of yield under climate scenarios

Cropland changes in its own will not be sufficient to narrow down its impacts on food security. Thereby, crop yield production is a great parameter which will reinforce and strengthen the results from cropland changes while stating their impacts on food security. Crop yield is the total quantity of grain that is harvested from a specific cultivated area (farm). It may be expressed in kg when the quantity is not so much significant, or in tones most of the time when the quantity is highly important. The FOASTAT database provides also some data about crop yield of the different crops that are grown in the two locations of our study area. We therefore computed the future possible changes in crop yield.

#### 3.1.3.1 Projecting yield under RCP4.5 scenarios

Like stated in the methodology section, the projection requires some additional information that have been obtained from previous studies that used simulation of crop yields under climate scenarios. This information are values to which the crop yields may be changing in the future. Thereby, in 2019 (Freduah et al., 2019) estimated a decrease in yield of -0.13% as rate, under RCP4.5 and RCP8.5 in Mali and Burkina Faso.

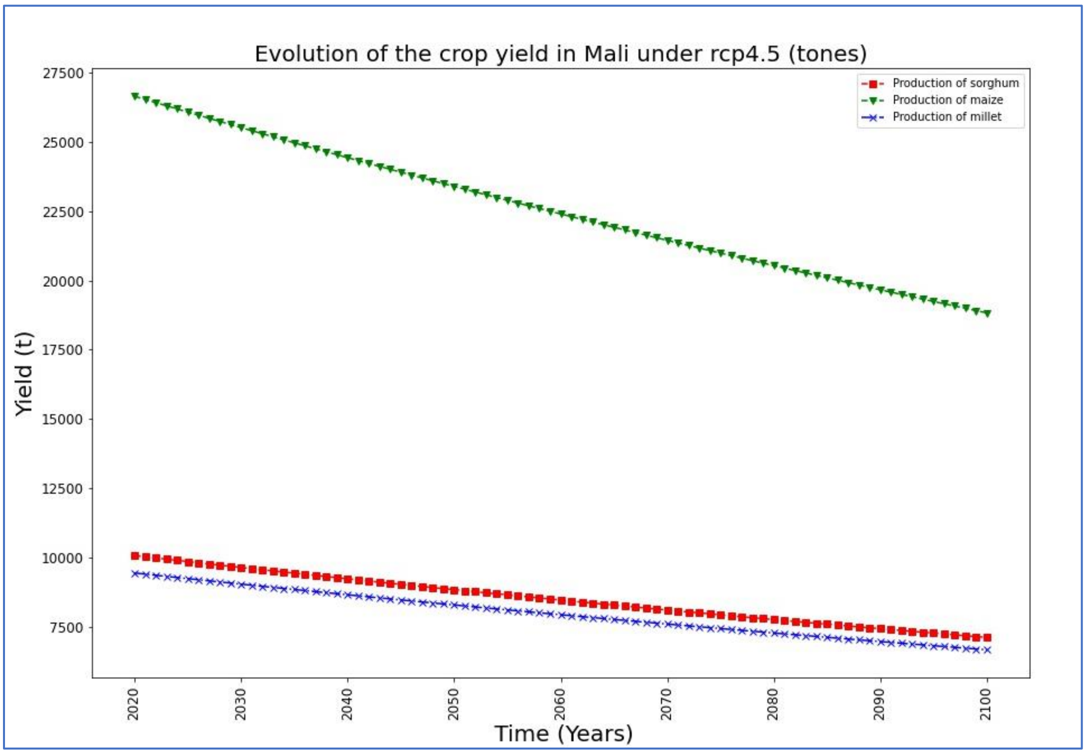



*Figure 13:Yield projection in Mali under RCP4.5*

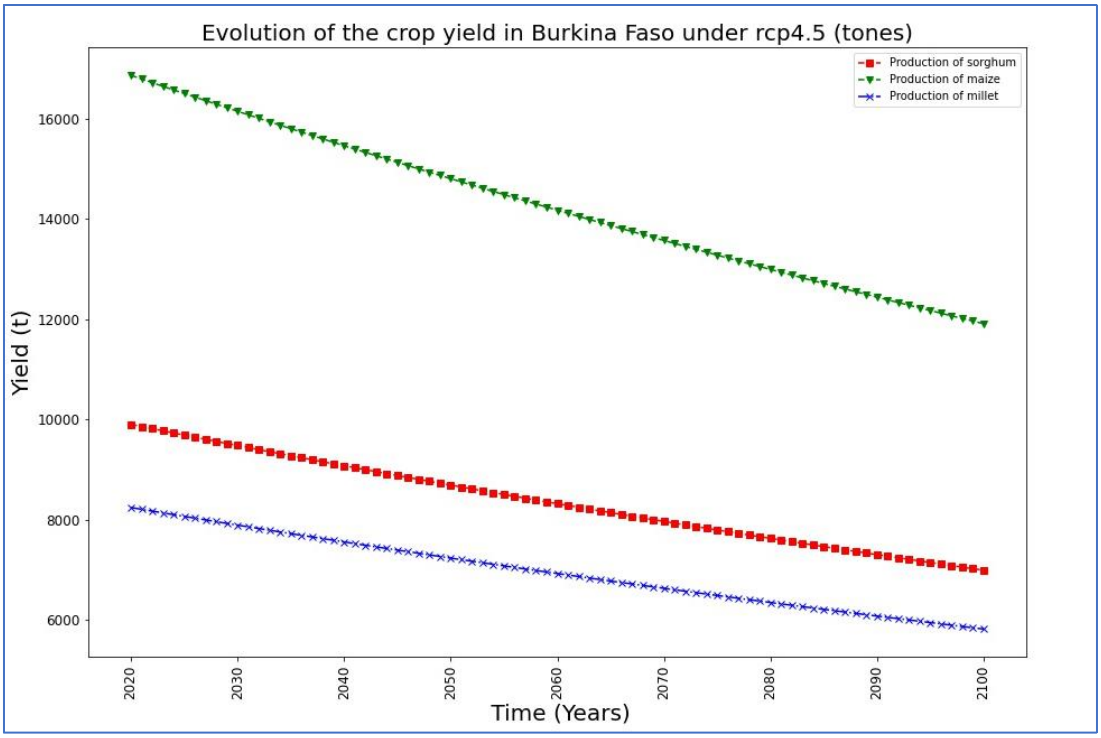



*Figure 14: Yield projection in Burkina Faso under RCP4.5*

In Mali, some decreases are pointing out how yields are likely to change from 2020 until 2100 in Mali under RCP4.5 climate scenario.

Changes are likely to be decreasing until 2100 under the effects of RCP4.5 in Burkina Faso. The used dataset is summarized in Table 6.

*Table 6:Projected yield of selected crop items in Mali and Burkina Faso under RCP4.5*

| Mali | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Year** | **Total yield** | **yield produced in maize** | | **yield produced in millet** | | **yield produced in sorghum** | |
| | | **tons** | **%** | **tons** | **%** | **tons** | **%** |
| **2020** | **46 158** | 26 649 | | 9 440 | | 10 069 | |
| **2025** | **45 168** | 26 078 | -2% | 9 237 | -2% | 9 853 | -2% |
| **2030** | **44 196** | 25 517 | -2% | 9 038 | -2% | 9 641 | -2% |
| **2035** | **43 246** | 24 968 | -2% | 8 844 | -2% | 9 434 | -2% |
| **2040** | **42 317** | 24 432 | -2% | 8 654 | -2% | 9 231 | -2% |
| **2045** | **41 408** | 23 907 | -2% | 8 468 | -2% | 9 033 | -2% |
| **2050** | **40 518** | 23 393 | -2% | 8 286 | -2% | 8 839 | -2% |
| **2055** | **39 648** | 22 891 | -2% | 8 108 | -2% | 8 649 | -2% |
| **2060** | **38 797** | 22 400 | -2% | 7 933 | -2% | 8 464 | -2% |
| **2065** | **37 964** | 21 919 | -2% | 7 763 | -2% | 8 282 | -2% |
| **2070** | **37 149** | 21 448 | -2% | 7 597 | -2% | 8 104 | -2% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **2075** | **36 350** | 20 987 | -2% | 7 434 | -2% | 7 929 | -2% |
| **2080** | **35 569** | 20 536 | -2% | 7 274 | -2% | 7 759 | -2% |
| **2085** | **34 806** | 20 095 | -2% | 7 118 | -2% | 7 593 | -2% |
| **2090** | **34 058** | 19 663 | -2% | 6 965 | -2% | 7 430 | -2% |
| **2095** | **33 326** | 19 241 | -2% | 6 815 | -2% | 7 270 | -2% |
| **2100** | **32 611** | 18 828 | -2% | 6 669 | -2% | 7 114 | -2% |
| **Average rate of changes from 2005-2100** | | | **-2%** | | **-2%** | | **-2%** |
| **Burkina Faso** | | | | | | | |
| **2020** | **35 007** | 16 858 | | 8 246 | | 9 903 | |
| **2025** | **34 255** | 16 496 | -2% | 8 069 | -2% | 9 690 | -2% |
| **2030** | **33 519** | 16 142 | -2% | 7 895 | -2% | 9 482 | -2% |
| **2035** | **32 798** | 15 795 | -2% | 7 725 | -2% | 9 278 | -2% |
| **2040** | **32 094** | 15 456 | -2% | 7 560 | -2% | 9 078 | -2% |
| **2045** | **31 405** | 15 124 | -2% | 7 398 | -2% | 8 883 | -2% |
| **2050** | **30 730** | 14 799 | -2% | 7 238 | -2% | 8 693 | -2% |
| **2055** | **30 070** | 14 481 | -2% | 7 083 | -2% | 8 506 | -2% |
| **2060** | **29 424** | 14 170 | -2% | 6 931 | -2% | 8 323 | -2% |
| **2065** | **28 791** | 13 866 | -2% | 6 781 | -2% | 8 144 | -2% |
| **2070** | **28 173** | 13 568 | -2% | 6 636 | -2% | 7 969 | -2% |
| **2075** | **27 567** | 13 276 | -2% | 6 493 | -2% | 7 798 | -2% |
| **2080** | **26 974** | 12 990 | -2% | 6 353 | -2% | 7 631 | -2% |
| **2085** | **26 395** | 12 711 | -2% | 6 217 | -2% | 7 467 | -2% |
| **2090** | **25 828** | 12 438 | -2% | 6 083 | -2% | 7 307 | -2% |
| **2095** | **25 274** | 12 171 | -2% | 5 953 | -2% | 7 150 | -2% |
| **2100** | **24 730** | 11 909 | -2% | 5 825 | -2% | 6 996 | -2% |
| **Average rate of changes from 2005-2100** | | | **-2%** | | **-2%** | | **-2%** |

The average changes projected of yield will likely decrease by **-2%** for each crop item between 2020 and 2100 in Mali. These may be due to the fact that the cultivated areas are not expected to change at that period. The same changing rate of **-2%** is expected for each crop item in Burkina Faso. These changes may not be explained by the changes in cultivated areas since those recoded some increases about **3%** within the same period of time.

#### 3.1.3.2 Projecting yield under RCP8.5 scenarios

As well as stated in the RCP4.5 section, the projection requires some additional information that have been obtained from previous studies that used simulation of crop yields under climate scenarios. It is about  changing rates found by (Freduah et al., 2019) in 2019 estimating a decrease in yield of 0,15% under RCP8.5 in Burkina Faso, and 0.1% and RCP8.5 in Mali.

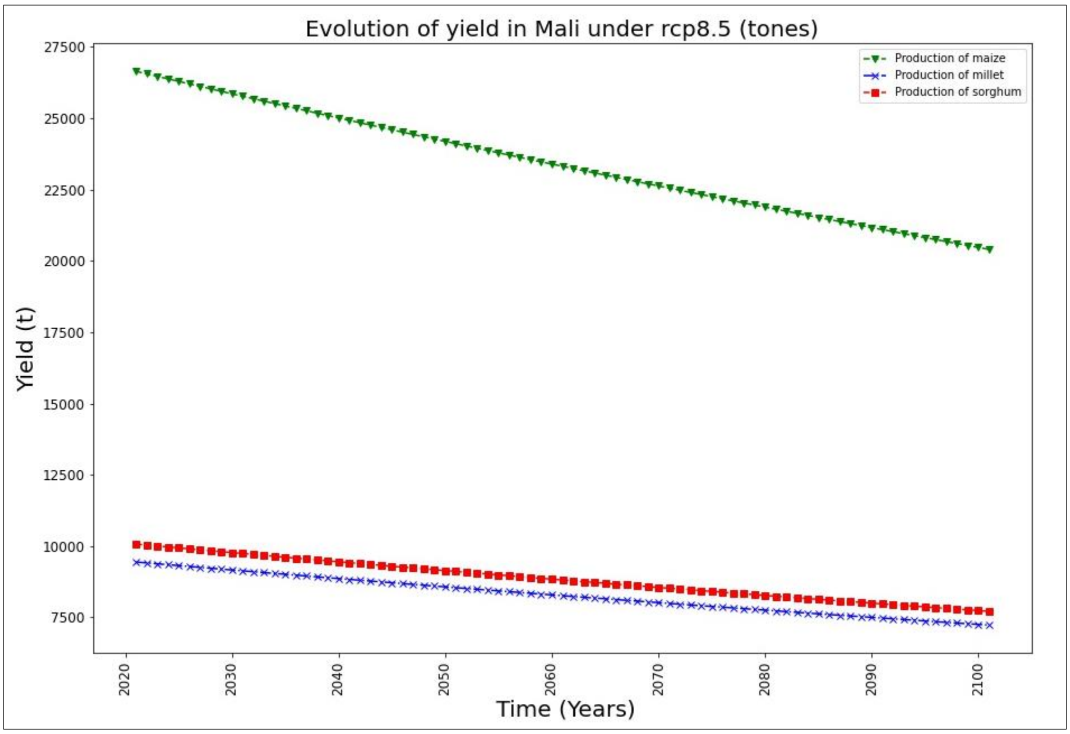



*Figure 15: Yield projected in Mali under RCP8.5*

The Figure above is showing how crop yields are likely to undergo in Mali in the future under RCP8.5 scenario between 2020 and 2100. These are mainly decreasing as pointed out by the slope. The used dataset is summary in Table 7.

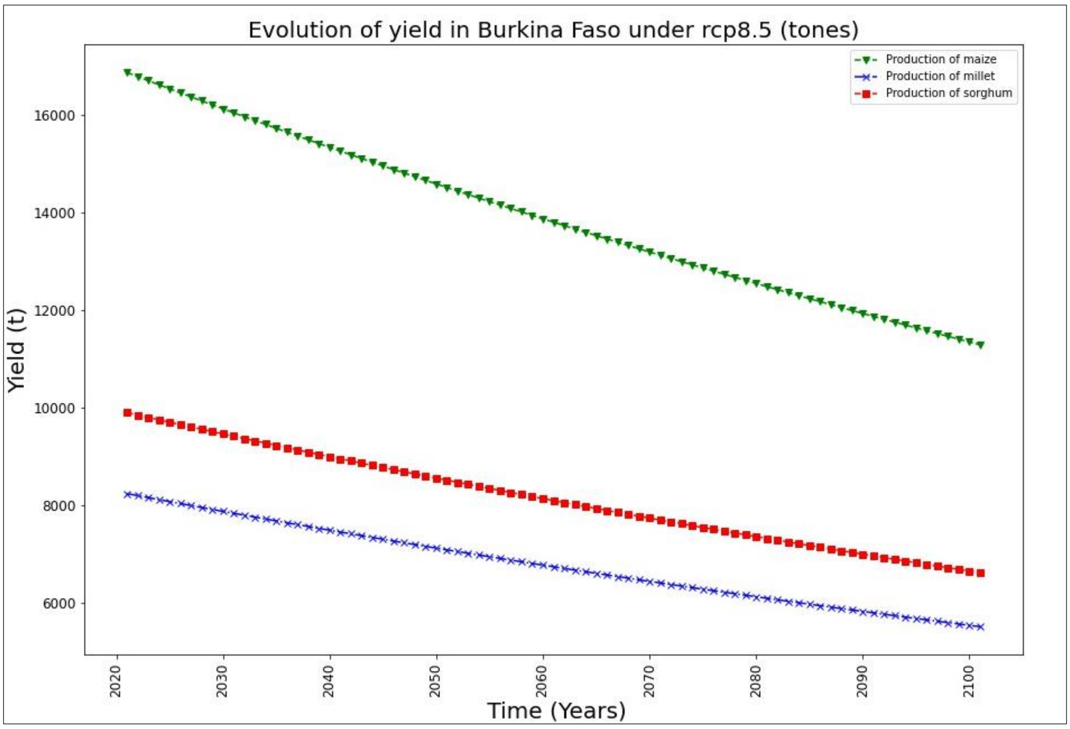



*Figure 16: Yield projected under in Burkina Faso under RCP8.5*

As one could guess, this is a decreasing pattern in crop yields in Burkina Faso under RCP8.5

scenario. They are likely to be decreasing in future. The used dataset is summarized in table 5.

*Table 7: Projected yield of selected crop items in Mali and Burkina Faso under RCP8.5*

| Mali | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Year** | **Total yield** | **yield produced in maize** | | **yield produced in millet** | | **yield produced in sorghum** | |
| | | **tons** | **%** | **tons** | **%** | **tons** | **%** |
| **2020** | **46 158** | 26 649 | | 9 440 | | 10 069 | |
| **2025** | **45 395** | 26 207 | -2% | 9 285 | -2% | 9 903 | -2% |
| **2030** | **44 642** | 25 774 | -2% | 9 130 | -2% | 9 738 | -2% |
| **2035** | **43 905** | 25 347 | -2% | 8 980 | -2% | 9 578 | -2% |
| **2040** | **43 176** | 24 928 | -2% | 8 830 | -2% | 9 418 | -2% |
| **2045** | **42 463** | 24 515 | -2% | 8 685 | -2% | 9 263 | -2% |
| **2050** | **41 758** | 24 109 | -2% | 8 540 | -2% | 9 109 | -2% |
| **2055** | **41 069** | 23 710 | -2% | 8 400 | -2% | 8 959 | -2% |
| **2060** | **40 387** | 23 317 | -2% | 8 260 | -2% | 8 810 | -2% |
| **2065** | **39 720** | 22 931 | -2% | 8 124 | -2% | 8 665 | -2% |
| **2070** | **39 062** | 22 552 | -2% | 7 989 | -2% | 8 521 | -2% |
| **2075** | **38 417** | 22 179 | -2% | 7 857 | -2% | 8 381 | -2% |
| **2080** | **37 780** | 21 812 | -2% | 7 727 | -2% | 8 241 | -2% |
| **2085** | **37 156** | 21 451 | -2% | 7 599 | -2% | 8 106 | -2% |
| **2090** | **36 540** | 21 095 | -2% | 7 474 | -2% | 7 971 | -2% |
| **2095** | **35 935** | 20 746 | -2% | 7 349 | -2% | 7 840 | -2% |
| **2100** | **35 342** | 20 403 | -2% | 7 229 | -2% | 7 710 | -2% |
| **Average rate of changes from 2005-2100** | | | **-2%** | | **-2%** | | **-2%** |
| **Burkina Faso** | | | | | | | |
| **2020** | **35 007** | 16 858 | | 8 246 | | 9 903 | |
| **2025** | **34 140** | 16 441 | -2% | 8 042 | -2% | 9 657 | -2% |
| **2030** | **33 295** | 16 034 | -2% | 7 843 | -2% | 9 418 | -2% |
| **2035** | **32 471** | 15 637 | -2% | 7 649 | -2% | 9 185 | -2% |
| **2040** | **31 668** | 15 250 | -2% | 7 460 | -2% | 8 958 | -2% |
| **2045** | **30 884** | 14 873 | -2% | 7 275 | -2% | 8 736 | -2% |
| **2050** | **30 120** | 14 505 | -2% | 7 095 | -2% | 8 520 | -2% |
| **2055** | **29 375** | 14 146 | -2% | 6 920 | -2% | 8 309 | -2% |
| **2060** | **28 648** | 13 796 | -2% | 6 749 | -2% | 8 103 | -2% |
| **2065** | **27 938** | 13 454 | -2% | 6 582 | -2% | 7 902 | -2% |
| **2070** | **27 246** | 13 121 | -2% | 6 419 | -2% | 7 706 | -2% |
| **2075** | **26 571** | 12 796 | -2% | 6 260 | -2% | 7 515 | -2% |
| **2080** | **25 913** | 12 479 | -2% | 6 105 | -2% | 7 329 | -2% |
| **2085** | **25 273** | 12 171 | -2% | 5 954 | -2% | 7 148 | -2% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **2090** | **24 647** | 11 869 | -2% | 5 807 | -2% | 6 971 | -2% |
| **2095** | **24 037** | 11 576 | -2% | 5 663 | -2% | 6 798 | -2% |
| **2100** | **23 442** | 11 289 | -2% | 5 523 | -2% | 6 630 | -2% |
| **Average rate of changes from 2005-2100** | | | **-2%** | | **-2%** | | **-2%** |

The average changes projected of yield will decreasing by **-2%** in each of the crop yields in Burkina Faso and Mali between 2020 and 2100 under RCP8.5 scenario. These changes may not be explained by the changes in cultivated aeras because, those recorded some increases of **3%** for each crop item.

#### 3.1.3.3. Crop yield per capita under the RCP4.5 and RCP8.5

The confidence of food security in a place depends sometimes on the number of tones that is produced to feed an inhabitant of this area. Thereby, getting insights of the harvested grain per capita will require both the information or data about production and the population data. The ratio of the formal by the second will give the quantity of grain produced for an inhabitant. In this section the population data correspond to the ones from socioeconomic scenarios such as the SRES A2 and B1 that correspond respectively to the climate scenarios RCP8.5 and RCP4.5 cf. Table 8.

*Table 8 : Correspondence between RCPs and SRES*

| RCPs | SRES |
|---|---|
| RCP8.5 | A2 |
| RCP4.5 | B1 |

#### a) Projected Population under RCP4.5 and RCP8.5

Among Global Models' outputs, the socio-economic data such as population, and food demand were collected. In this section, the population data will be used to find out the specific size of cropland area that is been harvested to feed an inhabitant and the quantity of yield that produced to meet his need in terms of grain. The colorific energy contained in the produced grain that could satisfy a person's energy demand, will be defined using the food demand dataset. The food demand dataset is compared with the projected calorific energy produced from the grain to point out the status of food security in Burkina Faso and Mali. Below are the plots:

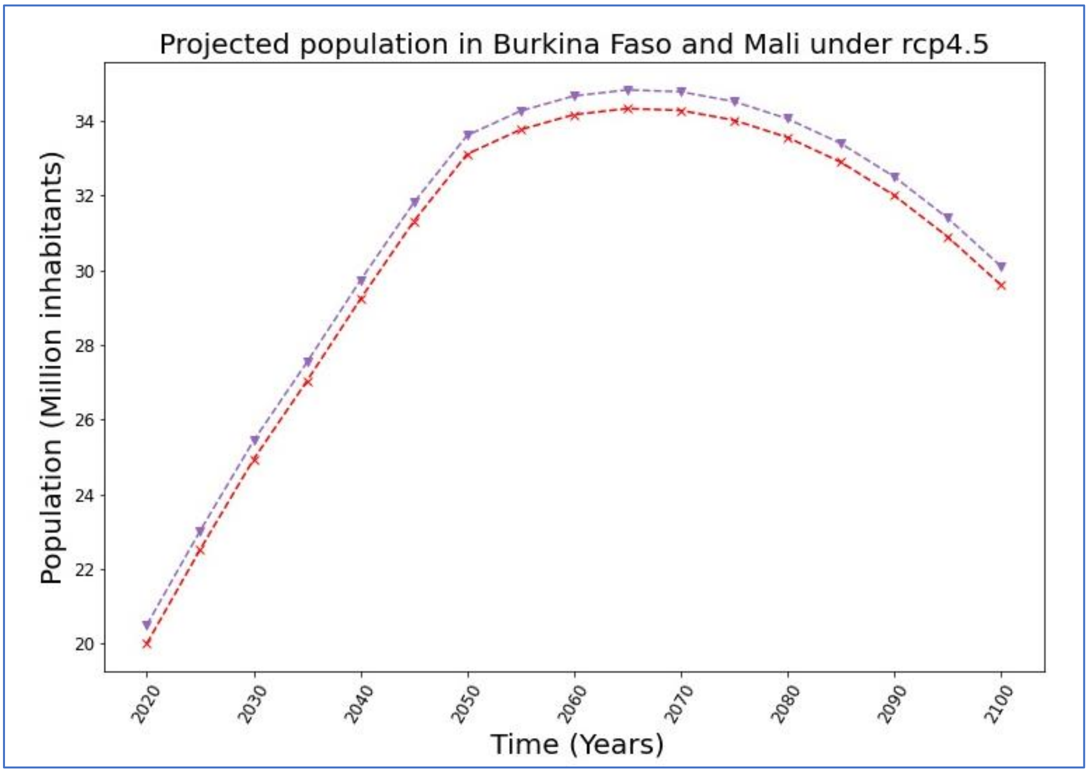



*Figure 17:projected Population in Mali and Burkina Faso under RCP4.5*

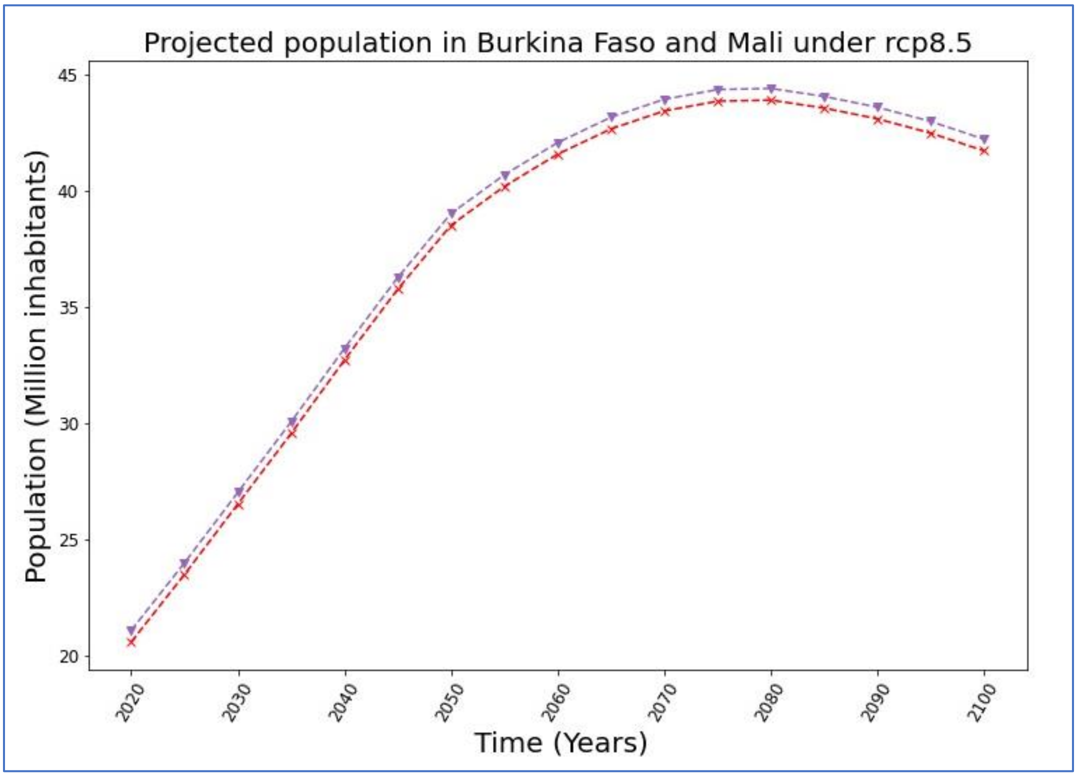



*Figure 18:Projected population in Mali and Burkina Faso under RCP8.5*

Comment : In both Burkina Faso and Mali, the current population is above 20 millions inhabitant. This is expected to grow till 2060 then it will reach its pick and remains constant till 2085. From this date, a decreasing slope is pointing out the possible reduction of the population under RCP4.5 scenarios (Figure 17). In addition, Figure 18 is showing an increasing population which will reach its pick around 2070 and remains constant till 2090 before it start decreasing.

**b) Crop yield per capita under RCP4.5 scenario**

As described up, the climate scenario RCP4.5 correspond to the socioeconomic scenario B1. Dividing the produced grain obtained under RCP4.5 by the population dataset will give the corresponding grain per capita. The following plots describe how an inhabitant is likely to be feeded in the future.

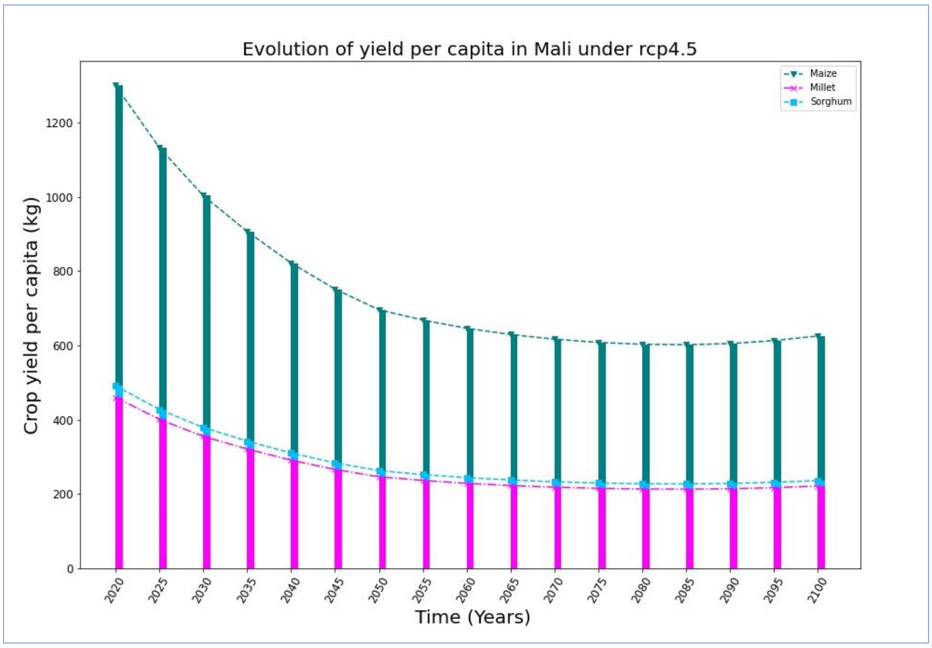



*Figure 19: production per capita in Mali under RCP4.5*

Just by observing the figure above, it is clear that the production per individual will gradually be experiencing some decreases between 2020 and 2100. These gradual decreases may continue until 2060, from which point stability is likely to be established until 2100. Table 9 summarizes the dataset used to plot.

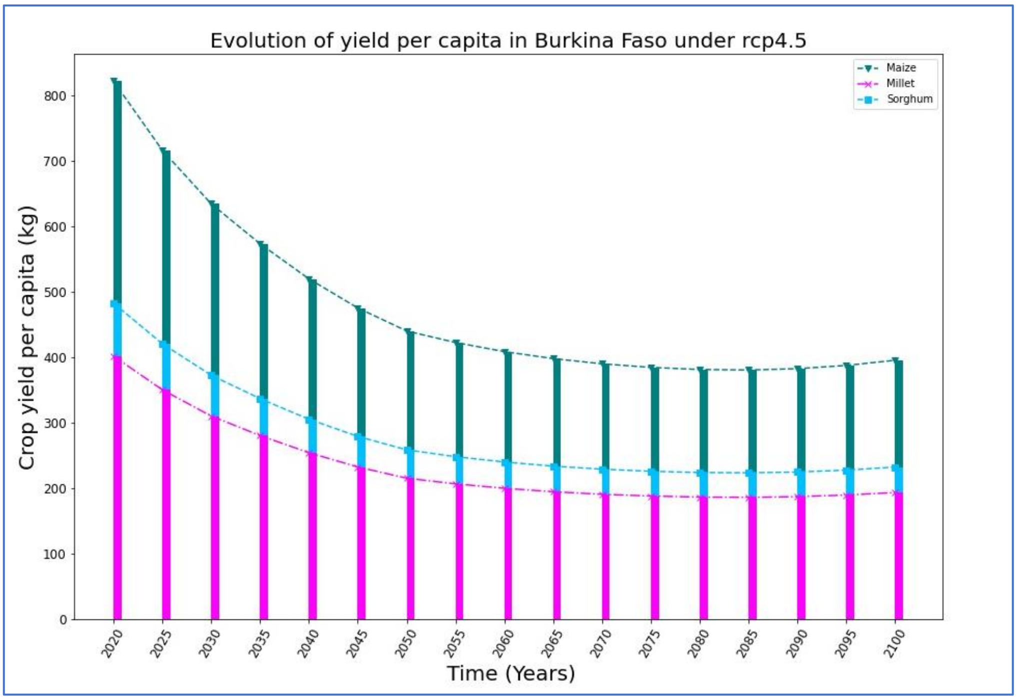



*Figure 20: Crop yield per capita in Burkina Faso under RCP4.5*

Just like in Mali, the production per capita in Burkina Faso, also is likely to some reduction in crop yields between the years 2020 and 2050 from where, production will stabilize until the 2080s. An increase in yield per capita of some crop items can be expected from then until the 2100s under RCP4.5 scenario. the relevant dataset is summarized in Table 9.

*Table 9: Production per capita (in tons) under RCP4.5 in Mali and Burkina Faso*

| Mali | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Year** | **Total** | **yield per capita in maize** | | **yield per capita in millet** | | **yield per capita in sorghum** | |
| | **kg** | **kg** | **%** | **kg** | **%** | **kg** | **%** |
| **2020** | **2 341,98** | 1 299,48 | | 460,32 | | 582,18 | |
| **2025** | **2 024,62** | 1 132,49 | -13% | 401,14 | -13% | 490,99 | -16% |
| **2030** | **1 786,31** | 1 003,12 | -11% | 355,30 | -11% | 427,89 | -13% |
| **2035** | **1 606,85** | 906,69 | -10% | 321,16 | -10% | 379,01 | -11% |
| **2040** | **1 455,65** | 821,93 | -9% | 291,14 | -9% | 342,59 | -10% |
| **2045** | **1 328,40** | 751,63 | -9% | 266,23 | -9% | 310,55 | -9% |
| **2050** | **1 226,62** | 696,07 | -7% | 246,56 | -7% | 283,99 | -9% |
| **2055** | **1 167,79** | 668,13 | -4% | 236,65 | -4% | 263,01 | -7% |
| **2060** | **1 127,53** | 646,22 | -3% | 228,86 | -3% | 252,44 | -4% |
| **2065** | **1 096,48** | 629,39 | -3% | 222,91 | -3% | 244,18 | -3% |
| **2070** | **1 073,00** | 616,73 | -2% | 218,45 | -2% | 237,81 | -3% |
| **2075** | **1 056,49** | 608,07 | -1% | 215,39 | -1% | 233,03 | -2% |
| **2080** | **1 046,37** | 603,04 | -1% | 213,60 | -1% | 229,73 | -1% |
| **2085** | **1 042,79** | 601,78 | 0% | 213,16 | 0% | 227,84 | -1% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **2090** | **1 046,66** | 604,98 | 1% | 214,30 | 1% | 227,39 | 0% |
| **2095** | **1 058,54** | 612,87 | 1% | 217,07 | 1% | 228,60 | 1% |
| **2100** | **1 078,48** | 625,40 | 2% | 221,52 | 2% | 231,56 | 1% |
| **Average rate of changes from 2005-2100** | | | **-4%** | | **-4%** | | **-5%** |
| **Burkina Faso** | | | | | | | |
| **2020** | **1 707,04** | 822,04 | | 402,10 | | 482,90 | |
| **2025** | **1 487,60** | 716,37 | -13% | 350,41 | -13% | 420,81 | -13% |
| **2030** | **1 317,69** | 634,57 | -11% | 310,37 | -11% | 372,76 | -11% |
| **2035** | **1 191,03** | 573,58 | -10% | 280,53 | -10% | 336,92 | -10% |
| **2040** | **1 079,70** | 519,97 | -9% | 254,33 | -9% | 305,40 | -9% |
| **2045** | **987,36** | 475,49 | -9% | 232,59 | -9% | 279,28 | -9% |
| **2050** | **914,39** | 440,35 | -7% | 215,37 | -7% | 258,67 | -7% |
| **2055** | **877,67** | 422,66 | -4% | 206,73 | -4% | 248,27 | -4% |
| **2060** | **848,86** | 408,79 | -3% | 199,95 | -3% | 240,11 | -3% |
| **2065** | **826,72** | 398,15 | -3% | 194,71 | -3% | 233,85 | -3% |
| **2070** | **810,11** | 390,15 | -2% | 190,82 | -2% | 229,15 | -2% |
| **2075** | **798,72** | 384,66 | -1% | 188,13 | -1% | 225,94 | -1% |
| **2080** | **792,09** | 381,45 | -1% | 186,56 | -1% | 224,08 | -1% |
| **2085** | **790,45** | 380,65 | 0% | 186,18 | 0% | 223,61 | 0% |
| **2090** | **794,66** | 382,69 | 1% | 187,16 | 1% | 224,82 | 1% |
| **2095** | **805,03** | 387,67 | 1% | 189,62 | 1% | 227,74 | 1% |
| **2100** | **821,44** | 395,57 | 2% | 193,49 | 2% | 232,38 | 2% |
| **Average rate of changes from 2005-2100** | | | **-4%** | | **-4%** | | **-4%** |

The yield per capita could know considerable changes in the future. In Mali, the mean value of the change is different from a crop to the other. Changes projected show a global decrease in yield produced per capita. Specifically, a decrease of **-4%** is expected in each crop item in both countries except sorghum which ‘s yield may be reduced by **-5%** in Mali under RCP4.5 scenario. These changes could be explained by the fact that each crop area is expected to remain the same or to decrease. Sorghum and millet surface areas recorded a possible decrease of **-3%** in Mali.

**b) Crop yield per capita under RCP8.5 scenario**

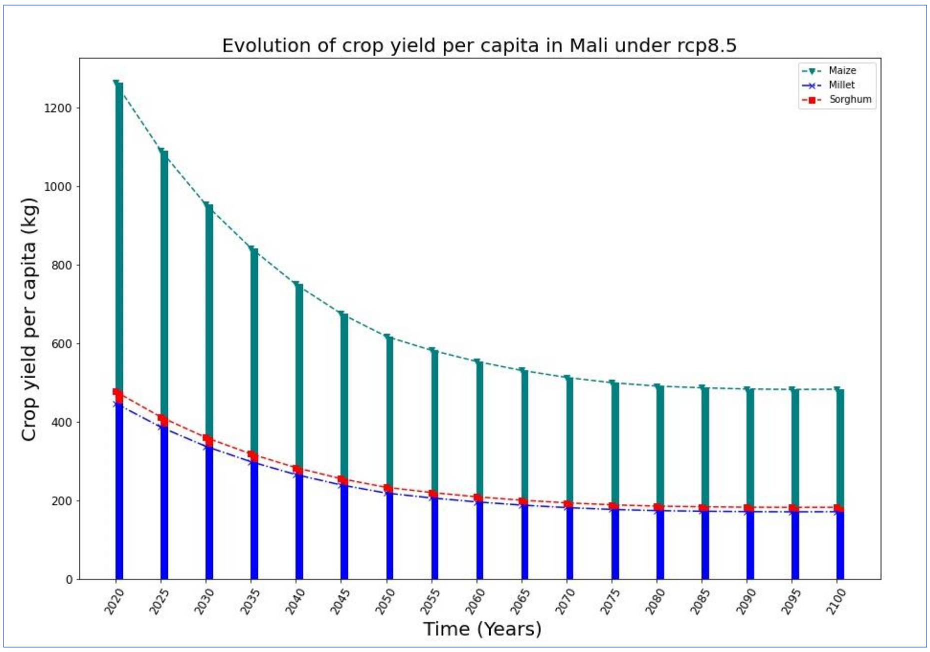



*Figure 21: Production per capita in Mali under RCP8.5*

Under RCP8.5 scenario, yield per capita in Mali is subject to reduction from 2020 until 2060. This production is assumed to fairly stabilize from the years 2060 until 2100. The summary of the dataset is stated in Table 10.

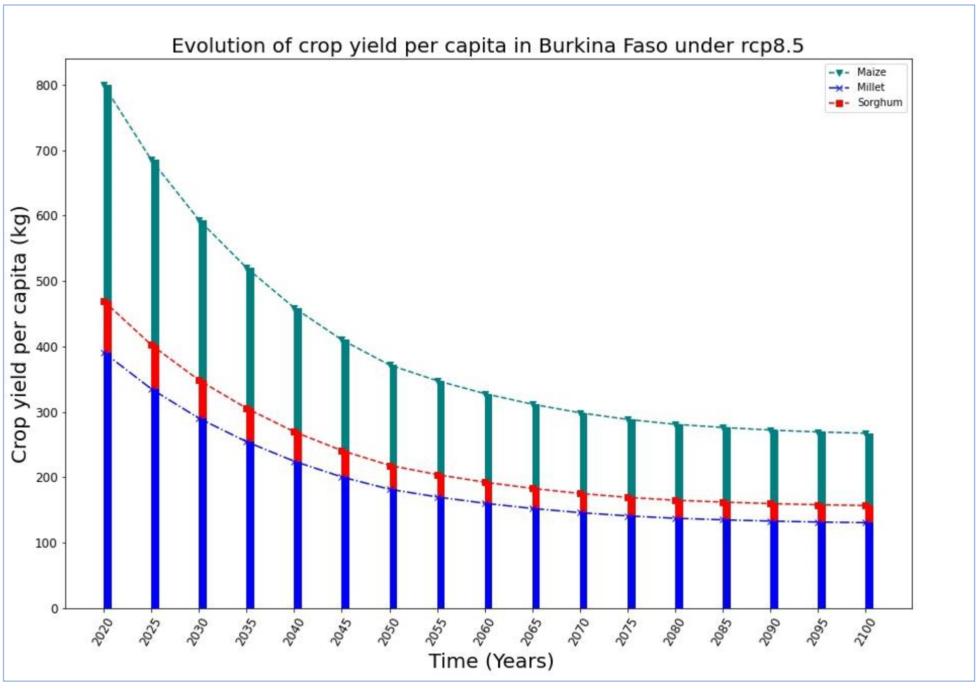



*Figure 22: Projection of crop yields per capita in Burkina Faso under RCP8.5*

Just like in Mali, the per capita crop yield in Burkina Faso will likely experience reductions under the effect of RCP8.5 scenario between the years 2020 and 2100. The dataset used is summarized in Table 10.

*Table 10 : Production per capita (in tons) under RCP8.5 in Mali and Burkina Faso*

| Mali | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Year** | **Total yield** | **yield per capita in maize** | | **yield per capita in millet** | | **yield per capita in sorghum** | |
| | **kg** | **kg** | **%** | **kg** | **%** | **kg** | **%** |
| **2020** | 2188,59 | 1263,57 | | 447,60 | | 477,42 | |
| **2025** | 1891,87 | 1092,20 | -14% | 386,96 | -14% | 412,72 | -14% |
| **2030** | 1652,10 | 953,84 | -13% | 337,88 | -13% | 360,38 | -13% |
| **2035** | 1460,63 | 843,24 | -12% | 298,75 | -12% | 318,64 | -12% |
| **2040** | 1299,94 | 750,53 | -11% | 265,85 | -11% | 283,56 | -11% |
| **2045** | 1171,04 | 676,07 | -10% | 239,51 | -10% | 255,45 | -10% |
| **2050** | 1070,28 | 617,93 | -9% | 218,89 | -9% | 233,47 | -9% |
| **2055** | 1009,52 | 582,82 | -6% | 206,48 | -6% | 220,22 | -6% |
| **2060** | 960,07 | 554,29 | -5% | 196,36 | -5% | 209,43 | -5% |
| **2065** | 920,40 | 531,36 | -4% | 188,25 | -4% | 200,79 | -4% |
| **2070** | 889,22 | 513,38 | -3% | 181,86 | -3% | 193,98 | -3% |
| **2075** | 866,26 | 500,11 | -3% | 177,17 | -3% | 188,98 | -3% |
| **2080** | 850,98 | 491,31 | -2% | 174,05 | -2% | 185,62 | -2% |
| **2085** | 843,46 | 486,95 | -1% | 172,50 | -1% | 184,01 | -1% |
| **2090** | 838,25 | 483,93 | -1% | 171,46 | -1% | 182,86 | -1% |
| **2095** | 836,14 | 482,72 | 0% | 171,00 | 0% | 182,42 | 0% |
| **2100** | 837,19 | 483,31 | 0% | 171,24 | 0% | 182,64 | 0% |
| **Average rate of changes from 2005-2100** | | | **-6%** | | **-6%** | | **-6%** |
| **Burkina Faso** | | | | | | | |
| **2020** | 1659,86 | 799,32 | | 390,99 | | 469,55 | |
| **2025** | 1422,81 | 685,19 | -14% | 335,16 | -14% | 402,46 | -14% |
| **2030** | 1232,17 | 593,38 | -13% | 290,25 | -13% | 348,54 | -13% |
| **2035** | 1080,25 | 520,21 | -12% | 254,47 | -12% | 305,57 | -12% |
| **2040** | 953,46 | 459,14 | -12% | 224,60 | -12% | 269,71 | -12% |
| **2045** | 851,72 | 410,17 | -11% | 200,63 | -11% | 240,92 | -11% |
| **2050** | 771,99 | 371,77 | -9% | 181,85 | -9% | 218,37 | -9% |
| **2055** | 722,07 | 347,73 | -6% | 170,10 | -6% | 204,25 | -6% |
| **2060** | 681,02 | 327,96 | -6% | 160,44 | -6% | 192,62 | -6% |
| **2065** | 647,39 | 311,76 | -5% | 152,52 | -5% | 183,11 | -5% |
| **2070** | 620,24 | 298,69 | -4% | 146,12 | -4% | 175,42 | -4% |
| **2075** | 599,14 | 288,53 | -3% | 141,16 | -3% | 169,45 | -3% |
| **2080** | 583,68 | 281,08 | -3% | 137,51 | -3% | 165,08 | -3% |
| **2085** | 573,71 | 276,29 | -2% | 135,16 | -2% | 162,26 | -2% |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **2090** | 565,41 | 272,28 | -1% | 133,22 | -1% | 159,92 | -1% |
| **2095** | 559,29 | 269,35 | -1% | 131,77 | -1% | 158,18 | -1% |
| **2100** | 555,30 | 267,42 | -1% | 130,83 | -1% | 157,05 | -1% |
| **Average rate of changes from 2005-2100** | | | **-6%** | | **-6%** | | **-6%** |

The Table 10 shows that crop yield per capita could undergo some changes in the future. The mean value of these changes is uniform for all the crop items under one or the other climate scenario and for both of two locations. This change could be explained by some shrinking of about **-1%** in cultivated areas of the respective crops under the two scenarios within the same period of time.

**3.1.4. Projection of daily intake in terms of calori under climate scenarios**

The human organism needs energy to be able to function well. This energy allows him to breathe, to think, to move is in the calories. These calories are found in foods and drinks we consume. On one hand, knowing the possible food demand of a growing population such as the case of Burkina Faso or Mali, could help define the status of its hunger and thereby, have an overview of its food security status. Thereby, the socio-economic output gotten from global Models estimates possible food demand in both of the countries Burkina Faso and Mali. Below are the plots.

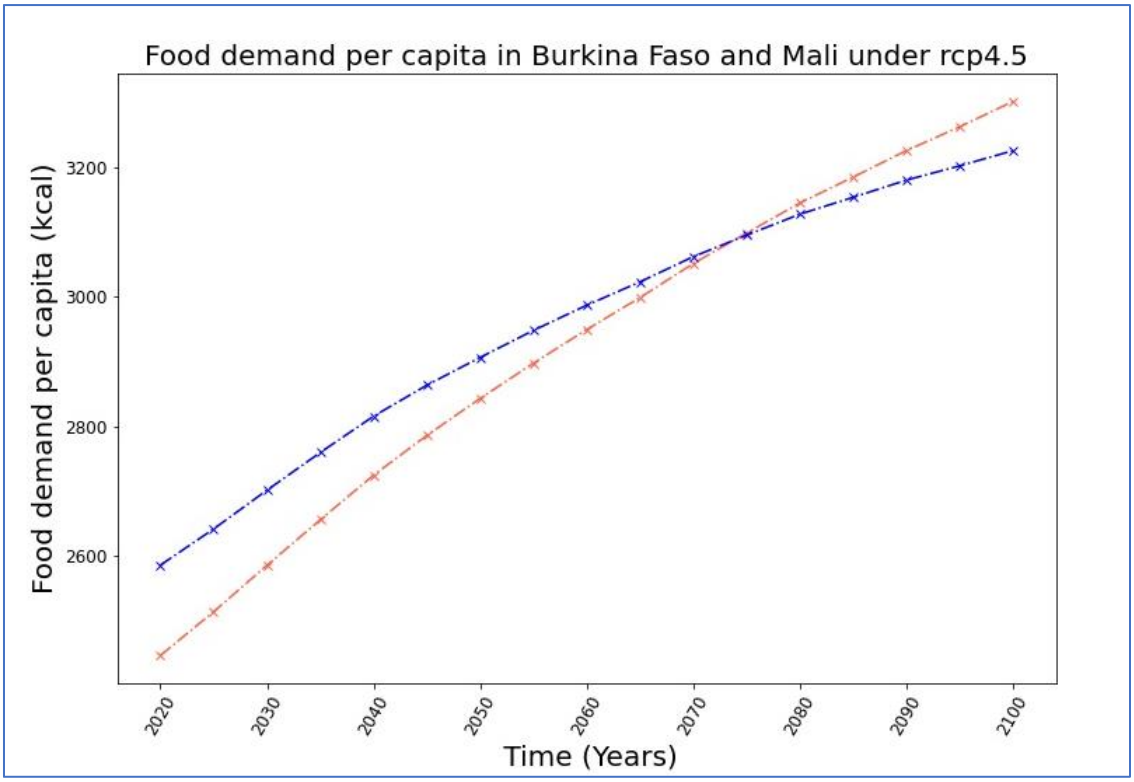



*Figure 23:Projecte food demand in Burkina Faso and Mali under RCP4.5*

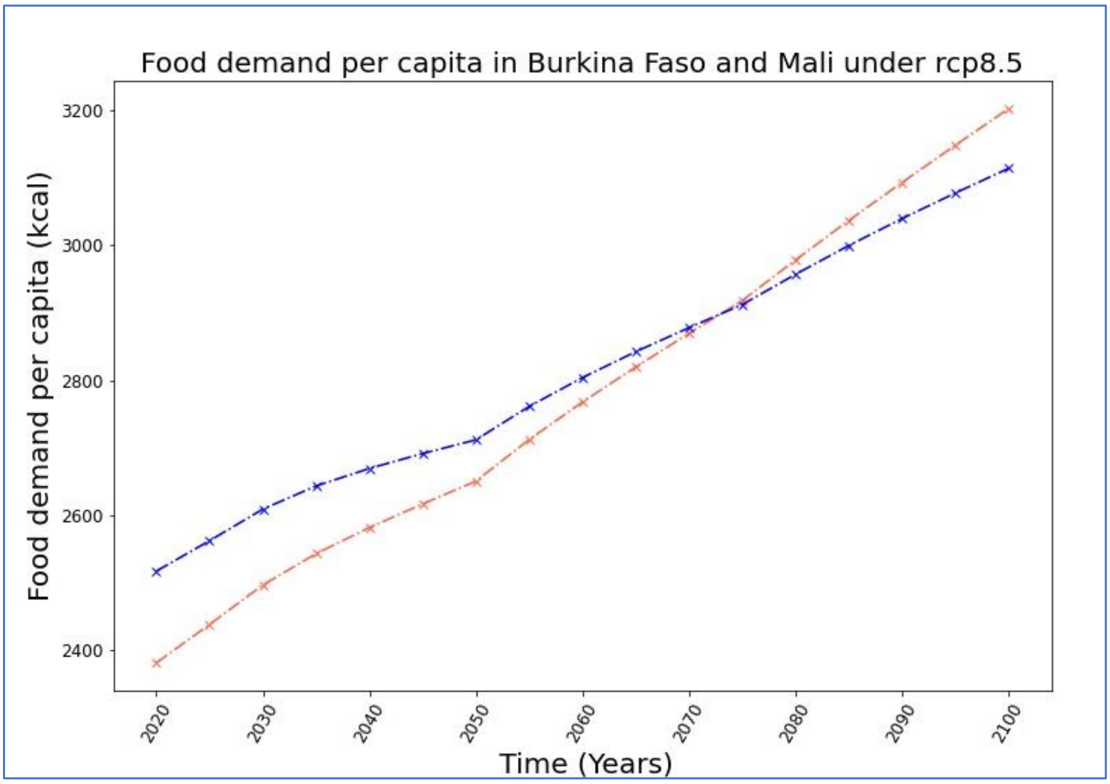



*Figure 24: Projected food demand in Burkina Faso and Mali under RCP8.5*

Comment : A growing population of a country will obviously lead to some increases in its food demand. Thereby, either under RCP4.5 or RCP8.5, food demand is just growing up from the current date till 2100.

On the other hand, getting insights of the calorific energy coming from crop yield production could highlight the level of satisfaction of the needs of a population, and could help a decision maker to take appropriate measures to meet these needs. Moreover, knowing the quantity of calories that the seeds of a crop can contain could serve as an indicator of the satisfaction of the population's needs for food.

#### 3.1.4.1. Daily intake projection under RCP4.5

The likely daily intake estimation is projected by multiplying the yield per capita of each crop by the quantity of calorie in this crop. The sum of calories of all the three crops will then be divided by 360 compared to the food demand in calori simulated by Bodirsky and collaborators (Bodirsky, Rolinski 1, et al., 2015).

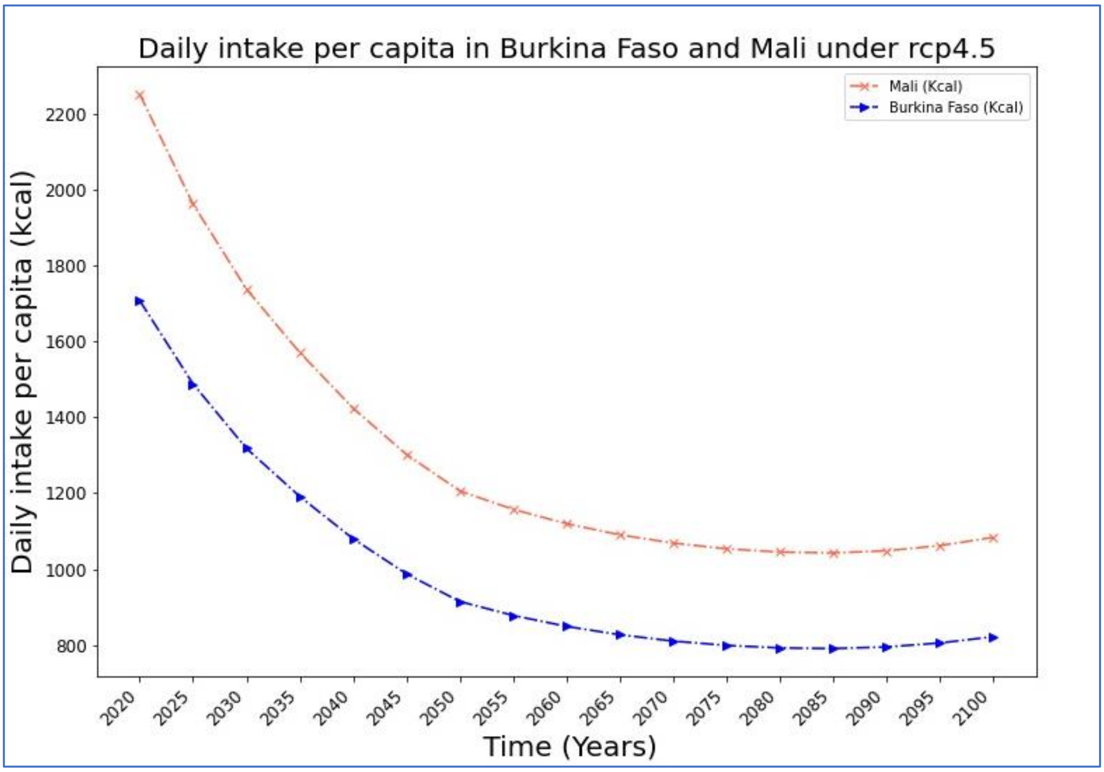



*Figure 25: Daily intake per individual in Burkina Faso and Mali under RCP4.5*

In the light of yield per individual under RCP4.5 in Mali, figure 15 shows an overall decrease in the daily intake in kcal per day in Mali under the effect of scenario RCP4.5. In addition, this decrease has been savior from 2020 to 2050. From this point, though it's shown some stabilities in the evolution of the daily intake, it could be an indicator of food insecurity since the daily intake is going to be under the normal.

Since the daily intake is a function of the yield produced per capita, it is then changing according to the yield production per capita under RCP4.5. The changes occur from 2020 to 2050 from which point it will get stability until 2080. In addition, some increase could occur from this date to the 2100s. the used dataset's summary is stated in Table 11.

*Table 11: Projection of daily intake in calori in Mali and Burkina Faso under RCP4.5*

| Mali | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Year** | **Total calori** | | **maize daily intake (kcal)** | | **millet daily intake (kcal)** | | **sorghum daily intake (kcal)** | |
| | **kcal** | **%** | **kcal** | **%** | **kcal** | **%** | **kcal** | **%** |
| **2020** | 2250,80 | | 1223,68 | | 436,03 | | 462,35 | |
| **2025** | 1961,52 | -13% | 1066,43 | -13% | 379,97 | -13% | 402,93 | -13% |
| **2030** | 1737,43 | -11% | 944,61 | -11% | 336,55 | -11% | 356,90 | -11% |
| **2035** | 1570,43 | -10% | 853,80 | -10% | 304,21 | -10% | 322,60 | -10% |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **2040** | 1423,61 | -9% | 773,99 | -9% | 275,77 | -9% | 292,43 | -9% |
| **2045** | 1301,85 | -9% | 707,78 | -9% | 252,18 | -9% | 267,43 | -9% |
| **2050** | 1205,64 | -7% | 655,47 | -7% | 233,54 | -7% | 247,67 | -7% |
| **2055** | 1157,22 | -4% | 629,16 | -4% | 224,16 | -4% | 237,72 | -4% |
| **2060** | 1119,27 | -3% | 608,53 | -3% | 216,78 | -3% | 229,94 | -3% |
| **2065** | 1090,11 | -3% | 592,68 | -3% | 211,15 | -3% | 223,94 | -3% |
| **2070** | 1068,21 | -2% | 580,76 | -2% | 206,92 | -2% | 219,44 | -2% |
| **2075** | 1053,20 | -1% | 572,60 | -1% | 204,02 | -1% | 216,33 | -1% |
| **2080** | 1044,48 | -1% | 567,86 | -1% | 202,33 | -1% | 214,55 | -1% |
| **2085** | 1042,33 | 0% | 566,68 | 0% | 201,91 | 0% | 214,12 | 0% |
| **2090** | 1047,88 | 1% | 569,69 | 1% | 202,99 | 1% | 215,27 | 1% |
| **2095** | 1061,50 | 1% | 577,12 | 1% | 205,62 | 1% | 218,06 | 1% |
| **2100** | 1083,22 | 2% | 588,92 | 0% | 209,83 | 2% | 222,52 | 2% |
| **Average rate of changes from 2005-2100** | | **-4%** | | **-4%** | | **-4%** | | -4% |
| **Burkina Faso** | | | | | | | | |
| **2020** | 1 707,04 | | 3215 | | 2572 | | 4501 | |
| **2025** | 1 487,60 | -13% | 3215 | 0% | 2572 | 0% | 3858 | -14% |
| **2030** | 1 317,69 | -11% | 2572 | -20% | 2572 | 0% | 3858 | 0% |
| **2035** | 1 191,03 | -10% | 2572 | 0% | 1929 | -25% | 3215 | -17% |
| **2040** | 1 079,70 | -9% | 2572 | 0% | 1929 | 0% | 3215 | 0% |
| **2045** | 987,36 | -9% | 1929 | -25% | 1929 | 0% | 3215 | 0% |
| **2050** | 914,39 | -7% | 1929 | 0% | 1929 | 0% | 2572 | -20% |
| **2055** | 877,67 | -4% | 1929 | 0% | 1929 | 0% | 2572 | 0% |
| **2060** | 848,86 | -3% | 1929 | 0% | 1929 | 0% | 2572 | 0% |
| **2065** | 826,72 | -3% | 1929 | 0% | 1929 | 0% | 2572 | 0% |
| **2070** | 810,11 | -2% | 1929 | 0% | 1929 | 0% | 2572 | 0% |
| **2075** | 798,72 | -1% | 1929 | 0% | 1929 | 0% | 2572 | 0% |
| **2080** | 792,09 | -1% | 1929 | 0% | 1929 | 0% | 2572 | 0% |
| **2085** | 790,45 | 0% | 1929 | 0% | 1929 | 0% | 3215 | 25% |
| **2090** | 794,66 | 1% | 2572 | 33% | 1929 | 0% | 3215 | 0% |
| **2095** | 805,03 | 1% | 2572 | 0% | 1929 | 0% | 3215 | 0% |
| **2100** | 821,44 | 2% | 2572 | 0% | 1929 | 0% | 3215 | 0% |
| **Average rate of changes from 2005-2100** | | **-4%** | | **-1%** | | **-2%** | | **-2%** |

The table 11 shows that the daily intake per capita could undergo some changes in the years to come. The mean value of the changes is not the for all crops. Changes projected shows a global decrease of **-4%** in daily intake per capita in both countries. Specifically, a decrease of **-4%** is expected in daily intake from each crop item in Mali, some decreases of, **-1%** in daily intake from maize, and **-2%** from millet and sorghum in Burkina Faso over the years under RCP4.5 scenario.

### 3.1.4.2. Daily intake projection under RCP8.5

The daily need of calori estimation under the RCP8.5 which is represented as the most pollutant scenario is done as it was done under the RCP4.5.

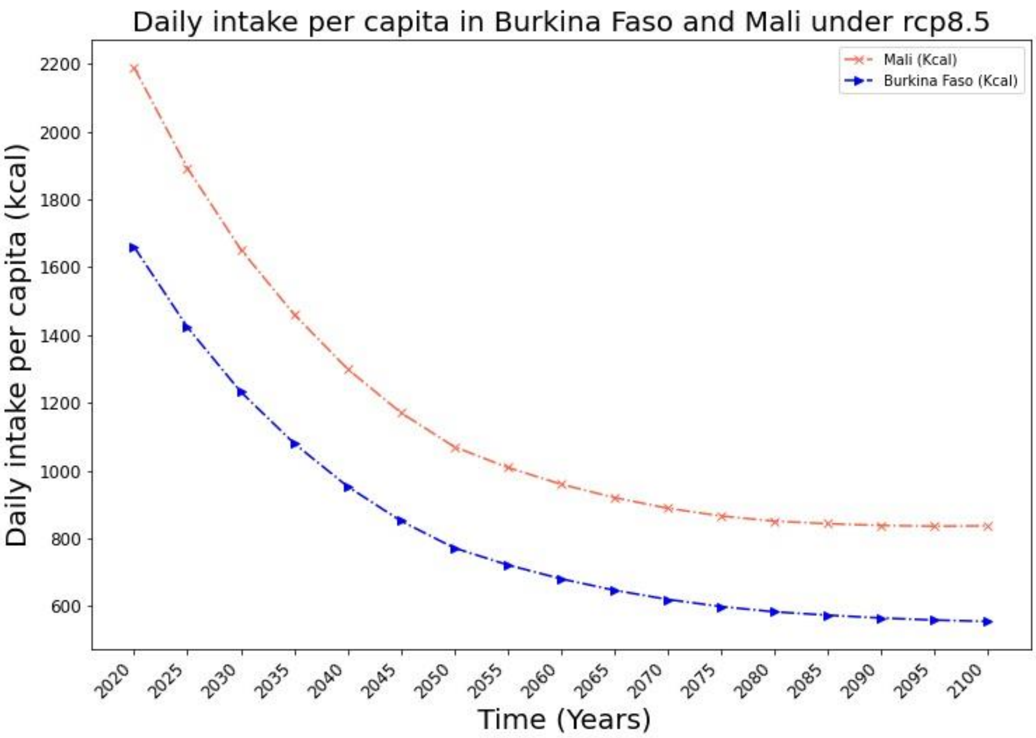



*Figure 26: Daily intake per individual in Burkina Faso and Mali under RCP8.5*

Being a function of yield production, the calorific need in Mali under the effect of the RCP8.5 scenario shows an overall decrease between 2020 and 2100. However, the trend shows a fall between 2020 and 2050 from which point it almost stabilizes until 2100. Moreover, this decrease could be an omen of food insecurity in both countries. Table 12 summarizes the used dataset.

*Table 12: Projection of daily intake in calori in Mali and Burkina Faso under RCP8.5*

| Year | Total calori | | maize daily intake (kcal) | | millet daily intake (kcal) | | sorghum daily intake (kcal) | |
|---|---|---|---|---|---|---|---|---|
| | kcal | % | kcal | % | kcal | % | kcal | % |
| **2020** | 2188,59 | | 1189,86 | | 423,98 | | 449,57 | |
| **2025** | 1891,87 | -14% | 1028,49 | -14% | 366,54 | -14% | 388,64 | -14% |
| **2030** | 1652,10 | -13% | 898,19 | -13% | 320,05 | -13% | 339,36 | -13% |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **2035** | 1460,63 | -12% | 794,06 | -12% | 282,98 | -12% | 300,05 | -12% |
| **2040** | 1299,94 | -11% | 706,75 | -11% | 251,82 | -11% | 267,01 | -11% |
| **2045** | 1171,04 | -10% | 636,63 | -10% | 226,87 | -10% | 240,55 | -10% |
| **2050** | 1070,28 | -9% | 581,88 | -9% | 207,33 | -9% | 219,85 | -9% |
| **2055** | 1009,52 | -6% | 548,82 | -6% | 195,58 | -6% | 207,38 | -6% |
| **2060** | 960,07 | -5% | 521,95 | -5% | 185,99 | -5% | 197,21 | -5% |
| **2065** | 920,40 | -4% | 500,37 | -4% | 178,32 | -4% | 189,08 | -4% |
| **2070** | 889,22 | -3% | 483,44 | -3% | 172,27 | -3% | 182,66 | -3% |
| **2075** | 866,26 | -3% | 470,94 | -3% | 167,82 | -3% | 177,96 | -3% |
| **2080** | 850,98 | -2% | 462,65 | -2% | 164,86 | -2% | 174,80 | -2% |
| **2085** | 843,46 | -1% | 458,54 | -1% | 163,40 | -1% | 173,28 | -1% |
| **2090** | 838,25 | -1% | 455,70 | -1% | 162,41 | -1% | 172,19 | -1% |
| **2095** | 836,14 | 0% | 454,56 | 0% | 161,97 | 0% | 171,78 | 0% |
| **2100** | 837,19 | 0% | 455,12 | 0% | 162,20 | 0% | 171,98 | 0% |
| **Average rate of changes from 2005-2100** | | **-6%** | | **-4%** | | **-6%** | | **-6%** |
| **Burkina Faso** | | | | | | | | |
| **2020** | 1659,86 | | 742,39 | | 365,28 | | 436,10 | |
| **2025** | 1422,81 | -14% | 636,38 | -14% | 313,12 | -14% | 373,79 | -14% |
| **2030** | 1232,17 | -13% | 551,11 | -13% | 271,17 | -13% | 323,71 | -13% |
| **2035** | 1080,25 | -12% | 483,16 | -12% | 237,74 | -12% | 283,80 | -12% |
| **2040** | 953,46 | -12% | 426,44 | -12% | 209,84 | -12% | 250,49 | -12% |
| **2045** | 851,72 | -11% | 380,95 | -11% | 187,44 | -11% | 223,76 | -11% |
| **2050** | 771,99 | -9% | 345,29 | -9% | 169,89 | -9% | 202,82 | -9% |
| **2055** | 722,07 | -6% | 322,96 | -6% | 158,92 | -6% | 189,70 | -6% |
| **2060** | 681,02 | -6% | 304,59 | -6% | 149,89 | -6% | 178,90 | -6% |
| **2065** | 647,39 | -5% | 289,55 | -5% | 142,49 | -5% | 170,06 | -5% |
| **2070** | 620,24 | -4% | 277,42 | -4% | 136,52 | -4% | 162,93 | -4% |
| **2075** | 599,14 | -3% | 267,98 | -3% | 131,87 | -3% | 157,38 | -3% |
| **2080** | 583,68 | -3% | 261,06 | -3% | 128,47 | -3% | 153,32 | -3% |
| **2085** | 573,71 | -2% | 256,61 | -2% | 126,27 | -2% | 150,70 | -2% |
| **2090** | 565,41 | -1% | 252,89 | -1% | 124,46 | -1% | 148,53 | -1% |
| **2095** | 559,29 | -1% | 250,16 | -1% | 123,10 | -1% | 146,91 | -1% |
| **2100** | 555,30 | -1% | 248,37 | -1% | 122,23 | -1% | 145,87 | -1% |
| **Average rate of changes from 2005-2100** | | **-6%** | | **-6%** | | **-6%** | | **-6%** |

The table 12 shows possible changes in daily intake per capita in the years to come. The projected changes show a global decrease in daily intake per capita of **-6%** in both countries. In details, an increase of **-4%** could occur in daily intake from maize in Mali between 2020 and 2100. likewise, the daily intake per capita from each of the three crops could decrease by about

**-6%** in Burkina Faso under RCP8.5 scenario.

### 3.1.5. Spatial visualization of the results

In most of the studies the results are shown as figure and table just like we did in the past sections. An added value of this study will be to see our results in an interactive way. Thus, a spatial database is to be created which will be used as source of data for the visualization tools. Concretely, building a spatial database implies defining steps like requirement statement, analysis and so on. But here we already have our input data for the database which are the outputs obtained in the previous sections. Thereby, these files will be used to create the required tables in our database. Moreover, these files are in Comma Separated Value (CSV) format. They will be converted in to sql files to meet the requirements of the database management system (DBMS). The obtained sql files are then executed on the database to get the corresponding tables. One more thing to precise is that PostgreSQL has a plugin named PostGIS which is coupled with the spatial reference system to take care of the geometric aspects of the DBMS. The following steps are done after installing the PostgreSQL DBMS, the data visualization tool Power BI and the conversion of the csv files into sql files. The operating system used in Windows.

#### 3.1.5.1. Creating the spatial database

Creating a database in PostgreSQL is done via the createdb command using the terminal. The following figure shows an example.

```
C:\Users\Wascal-gp>createdb -U postgres myspatial_db
Mot de passe :

C:\Users\Wascal-gp>
```

*Figure 27: Creating spatial database*

Once the database is created, it needs to be spatialized to take geometries into account. This is done by running the files postgis.sql and spatial_ref_sys.sql located in the directory [prefix]/PostgreSQL/share/contrib/postgis-3.0/ as follows:

```
stgreSQL\12\share\contrib\postgis-3.0\postgis.sql" postgres
Mot de passe pour l'utilisateur postgres :
BEGIN
SET
DO
DO
CREATE FUNCTION
CREATE FUNCTION
CREATE FUNCTION
CREATE TYPE
CREATE FUNCTION
CREATE FUNCTION
CREATE FUNCTION
CREATE FUNCTION
CREATE FUNCTION
```

If the command is successful, the message BEGIN, SET, DO will be prompt out and will end with a commit.

The next step is to create the tables with our converted sql files by executing them on the database as we did with the postgis.sql file. Below is an example of creating the cultivated areas table.

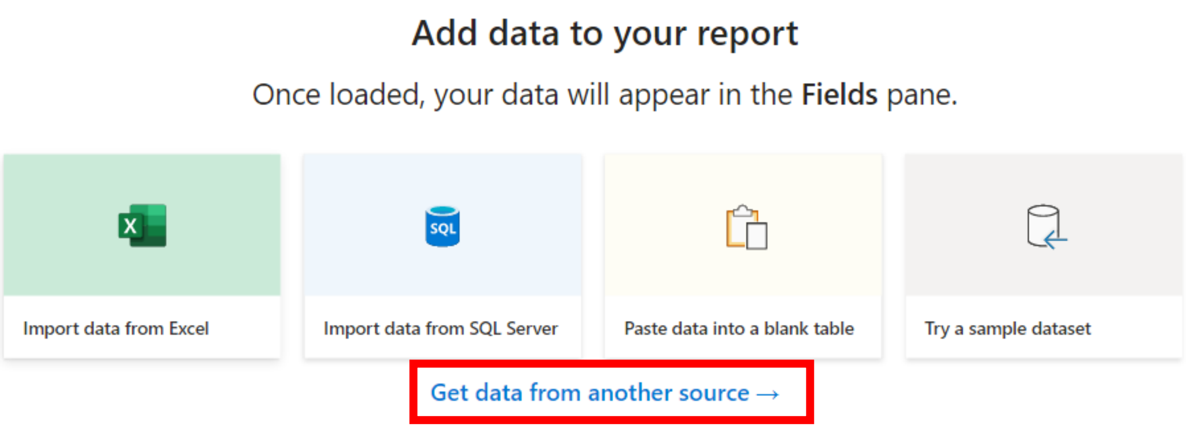
```
C:\Users\Wascal-gp>psql -d myspatial_db -f "C:\Users\Wascal-gp\
Documents\proposal writing\csv_climate_data_thseis\db_sql_files
\bf_rcp45_cultivated_areas.sql" postgres
Mot de passe pour l'utilisateur postgres :
CREATE TABLE
INSERT 0 96
```

*Figure 28: Creating table in the database*

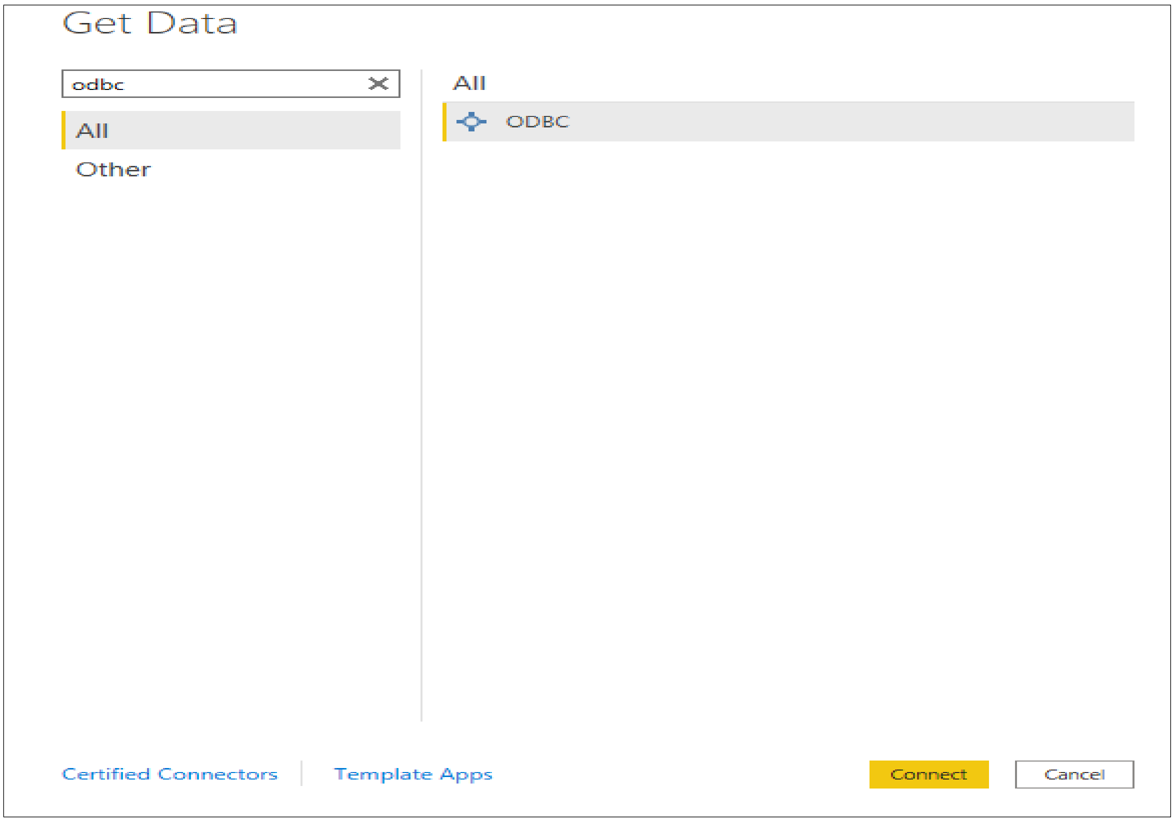
Once all the tables are created, we can move to the visualization tool here (Power BI) to query the database and build charts and dashboards that are going to be shared with users.

#### 3.1.5.2. Building charts and dashboards

As stated in the methodology section, Power BI is tool we are going to use to visualize our data. Thereby, it needs to be connected with the database in order to use that one as a source of data. Power BI uses numerous sources of data. It may not show directly PostgreSQL among the list of sources that is not a problem. You just click on |file → Get data → "Getdata from another source" or click directly on "Getdata from another source" on the picture bellow.




Then use the following windows and the instructions to connect.




In the following windows, set the data source name to None.

Then use the driver parameters and the user's information to connect.

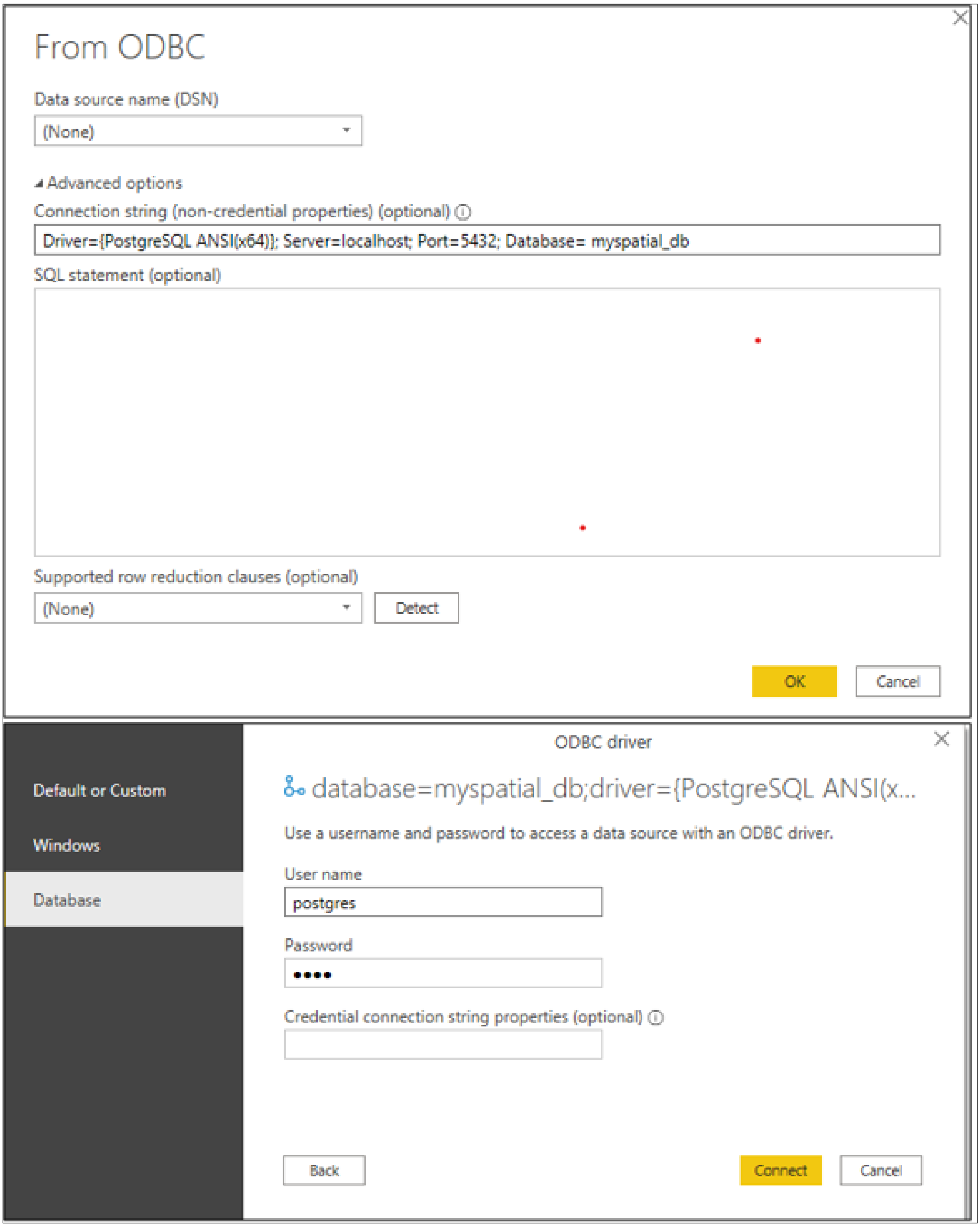



*Figure 29: Connecting PowerBI to PostgreSQL.*

From this point, the data can be imported and queried and then used for the reports. After connexion, one can now import all the necessary tables into the working space, they could be transformed to be lightened. The following chart is an example of what we build from the cultivated areas dataset in both of the countries. It can be shared and viewed on different platforms (PC, Android etc..).

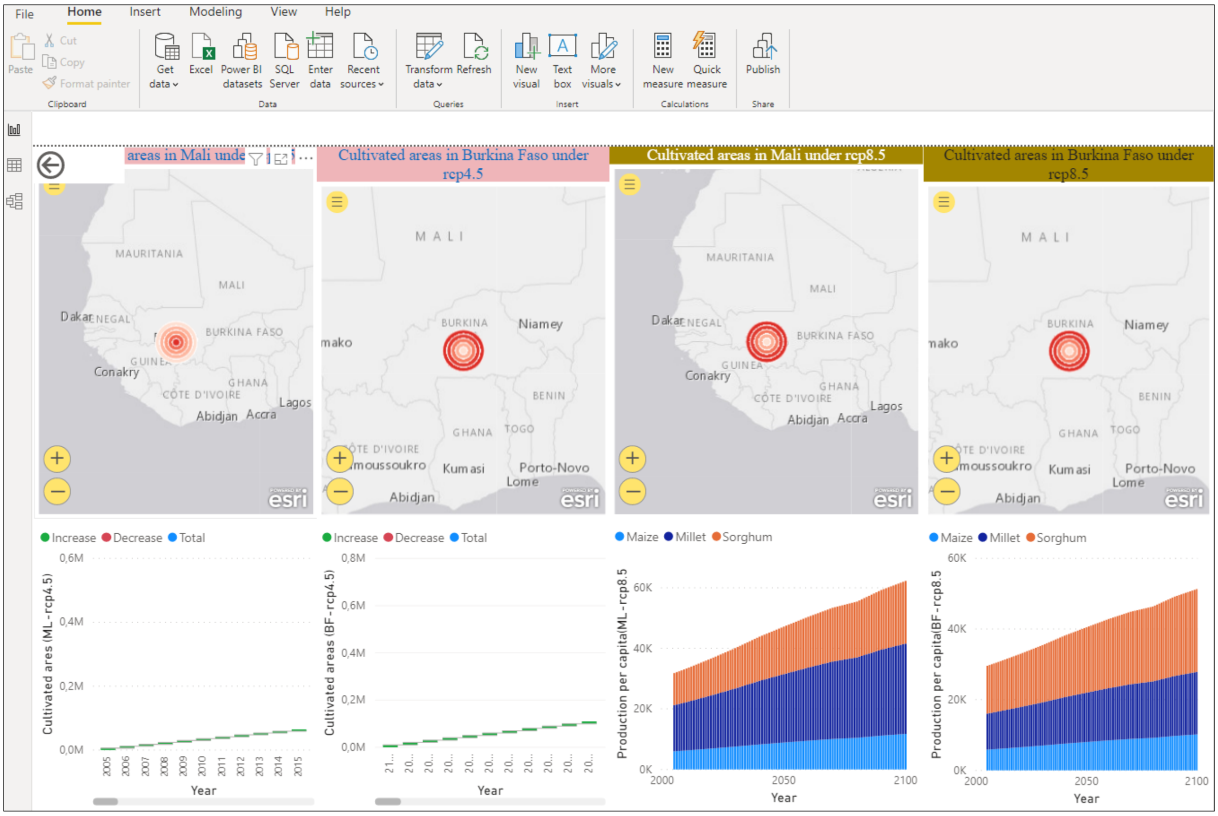



*Figure 30: web charts*

Figure 25 is an overview of the web pages derived from the dashboards created with the different tables of our database. That could be accessed from anywhere by anyone it's shared with.

## THESIS PERSPECTIVES

On the one hand, this work is a nationwide effort that could be improved in the future by reducing the scale or size of the study area as a first step. Second, the future possibilities for improvement may also concern certain additional aspects of food security such as the market capacity of the population. In addition, other climatic parameters such as relation soil humidity could be subject to new investigations. On the other hand, we initially wanted to cover the whole West Africa with this work, but due to time constraint and financial issues, it has been narrowed to just two of the West African Countries. Thereby, extending this study to the others countries may also be a new starting point for future researches. In addition, building a spatial database implies getting georeferenced data and that was a challenge for us in this study because we were having the reverse of what we needed as data though we managed to build the database with limited options. Therefore, a new aspect that could raise new questions to this research is the georeferenced data issues among others.

# CONCLUSION

The current investigation highlighted the possible changes in agricultural land areas in Mali and Burkina Faso under two climate scenarios namely the RCP4.5 and the RCP8.5, and their possible impact on agricultural production. In details, the future cultivated area and yield, per capita under each climate scenario were estimated. On one hand, the results show some reduction about **3%** in millet and sorghum cropland area per capita under RCP4.5. This change will imply a loss of **4%** in millet crop yield and some loss of **5%** in sorghum yield per capita under the same climate scenario in Mali, while the loss of **4%** in maize yield per capita cannot be explained by this change yet its area remains the same within the same period of time. On the other hand, the cultivated area per capita are expected to averagely remain the same for each crop under RCP4.5 in Burkina Faso. Therefore, the loss of **4%** in each crop yield could not be explained by these assertions. In addition, some projections were done also under RCP8.5. This variation about **1%** in millet and sorghum crop area in Mali could result on changes in these crops' yield produced by **6%**. Moreover, cropland surface areas will likely be changing by **-1%** in each crop area in Burkina Faso and could lead to changes about **6%** in crop yield production.  Moreover, the daily intake was computed. Its changes are about **4%** for each crop item in Mali. Daily intake could be changing by **1%** for maize and **2%** for millet and sorghum in Burkina Faso under RCP4.5. In addition, the daily intake from maize may change by **4%**, and by **6%** for millet and sorghum in Mali under RCP8.5 scenario. They will be changing in a uniform manner by **6%** under RCP8.5 for each crop in Burkina Faso. In addition, these results are in the range of rates of change of agricultural yields from similar studies such as Chisanga's paper where they conclude that the **%** change in grain yield would range from **-3.81%** to **-8.88%,** and **-2.33%** to **10.63%** under RCP4.5 and RCP8.5 scenarios (Chisanga et al., 2020). Furthermore, this work ended by building a spatial database that can be accessed using either laptops or smartphones(androids). This could be a decision support system for policy makers.

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## APPENDICES

<table>
<tr><th colspan="2">Data</th><th>Source</th><th>Time period</th><th>Description</th></tr>
<tr><td colspan="2">Areas Harvested in Mali and Burkina Faso</td><td>FAOSTAT</td><td>1999 - 2019</td><td></td></tr>
<tr><td colspan="2">Model output MinicamRCP4.5</td><td rowspan="4">Hyde data</td><td rowspan="4">2005 – 2100</td><td rowspan="2">Global model projection</td></tr>
<tr><td colspan="2">Model output MessageRCP8.5</td></tr>
<tr><td rowspan="2">Model output FoodAndPopulation</td><td>Pop_b1</td><td>Global model projection SRES B1</td></tr>
<tr><td>Pop_a2</td><td>Global model projection SRES A2</td></tr>
<tr><td colspan="2">Estimated changing rate of yields</td><td>Article of Freduah2019</td><td>30 years</td><td>Freduah2019 Estimated yield changing rate as - 0.13/30 under RCP4.5 and - 0.15/30 under RCP8.5 in Burkina Faso; - 0.13/30 under RCP4.5 and 0.1/30 under RCP8.5 in Mali</td></tr>
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