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The Macroeconomics of Climate Change and Adaptation Options in Agriculture: Evidence from Kenya and Mali

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Abstract

Africa has achieved impressive economic growth in recent decades, but now climate change puts livelihoods at risk and threatens to reverse that development. Kenya and Mali are experiencing changes in climatic conditions that include decreases in precipitation, increases in temperature, an extension of the hot season, and heat waves during the cold season. Given the important role that rain-fed agriculture plays in the economies of both, the countries are highly vulnerable to the adverse impacts of these climate changes. The risk of food insecurity, in particular, is likely to further increase as a result. This is also evident in independent assessments of their vulnerability to climate change. At the same time, the agriculture sector holds enormous potential to mitigate the risk of food insecurity. In particular, the adoption of climate-smart agriculture (CSA) approaches appears to be a promising adaptation pathway. Elements of CSA already are included in climate change adaptation planning in both countries. However, low adaptation readiness means that there is limited ability to leverage investments and convert them into adaptive actions in the agriculture sector.

In this paper, we use a macroeconomic model—a Computable General Equilibrium model—combined with a microsimulation model to describe the economic effects of climate change in Kenya and Mali and to assess the impacts of implementing climate change adaptation strategies in agriculture. Compared to agricultural yield trends between 2000 and 2019, we estimate that projected changes in yields due to climate change will decrease total GDP by 8.3 percent in Kenya and 8.9 percent in Mali. The negative effects of these changes in agricultural productivity are also observed in employment and poverty. Adaptation in the agricultural sector using CSA approaches can mitigate the economic effects of climate change. Increasing the area under soil and water conservation techniques or planting improved seed are particularly promising strategies. The multiplier effects created by the adoption of these two strategies can be expected to lead to an increase in GDP, employment, consumption, and income. These economic effects are similar for both the conservation and the improved seed adaptation strategies in Kenya but stronger for the improved seed strategy in Mali. However, both would need to be implemented on a large scale and, thus, require significant funding.

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1. INTRODUCTION

Climate change, both in terms of warming trends and the increased frequency of extreme weather events, presents a major threat globally. Sub-Saharan Africa is one of the most vulnerable regions to climate change. As weather conditions become less favorable, the volatility of crop and livestock yields is set to increase. Under a 3°C warming scenario, for example, Africa is expected to lose up to 30 percent of current growing areas for maize and banana and 60 percent for beans by 2050 (Nelson et al. 2010). Climate change poses systemic risks to the region's economies, infrastructure investments, food and water supply systems, public health, agriculture, and livelihoods and threatens to undo its hard-fought development and reverse decades of economic progress (GCA 2021). For the two countries examined in this paper, Kenya's vulnerability score in the ND-GAIN Index, which measures a country's exposure and sensitivity to climate change, is 38.7 (rank 149 out of 182), while Mali, with a rank of 170, is one of the most vulnerable countries in the world (ND-GAIN 2023). Due to climate-related events as well as conflicts, Kenya, together with Ethiopia and Somalia, in late 2022 was facing an unprecedented food crisis with 23 million people affected by hunger (Humanitarian Information Unit 2022).

Accounting for almost 16 percent of Africa's GDP and 20 percent of its total merchandise exports and employing up to 80 percent of the population, agriculture plays a key role in African economies (Diao et al. 2010; Diallo and Wouterse 2023). Small-scale farmers produce about 85 percent of Africa's agricultural output. In most African countries south of the Sahara, traditional production techniques dominate. Livestock and cropping systems are 95 percent rainfed. The use of improved seed and fertilizer is expanding but remains limited. Up to 85 percent of farm work is done manually, without machinery or even animal power (MaMo Panel 2018). Agricultural growth in Africa is generally achieved by area expansion,

which is not sustainable, and by mobilizing more farm labor. Yields have remained low, and the continent remains a net food importer at an annual cost of USD 43 billion in 2020, making Africa also highly vulnerable to fluctuations in world food prices (Kray et al. 2022). However, according to ND-GAIN, the main contributors to the high vulnerability scores in Mali and Kenya are projected changes in cereals yields and limited agriculture capacity which reflects a country's ability to acquire and deploy agriculture technology.

The agricultural sector holds enormous potential for mitigating the risk of food insecurity under climate change. Calzadilla et al. (2013) have shown that investments in agricultural research and development could increase yields in rainfed and irrigated agriculture by up to 25 percent in sub-Saharan African countries even under climate change. Growth in agriculture GDP has a multiplier effect within the economy, most notably through reducing the prevalence of malnutrition and improving human health. To make the agricultural sector of countries in sub-Saharan Africa more resilient to climate change, adaptation needs to be accelerated. Countries have advanced their planning for adaptation, and these plans often contain elements of climate-smart agriculture (CSA) strategies. However, large gaps remain in the financing of these plans for developing countries. This poses a high hurdle in developing effective adaptation projects to reduce the negative impacts of climate change-related events, such as droughts, floods, and sea-level rise (UNEP 2022).

Making adaptation investment decisions can be complex, requiring careful consideration of multiple factors and perspectives, and balancing different priorities over different timescales. At the macroeconomic level, adaptation decision-making involves balancing trade-offs across sectors and promoting synergies, avoiding inefficient investments of (scarce) resources, and creating coherence and consistency in implementing actions on the ground. To enable decision-makers to move

in their planning from predict-then-act approaches to assess-risk-of-policy approaches, there is a need to assess the effectiveness of adaptation policies at the sector level, including the performance of adaptation interventions under different climate scenarios (Bhave et al. 2016). This paper aims to contribute to the economics of adaptation evidence base. We use a macroeconomic model to quantify the economic losses associated with climate change in Mali and Kenya and assess the potential of adaptation solutions to mitigate that risk. We uncover significant losses to GDP under climate change, which highlights the need to accelerate adaptation action. CSA strategies, particularly soil and water conservation measures and improved seed use, are shown to be promising candidates for climate risk mitigation. However, it has to be noted that the increase in the area of cropland under these CSA measures would need

to be substantial. Both also hold wider economic benefits in terms of employment creation and GDP growth, although these are more modest in Mali than in Kenya. These results can be used to direct climate financing and accelerate Nationally Determined Contribution (NDC) and National Adaptation Plan (NAP) implementation as countries work to effectively reduce the adverse impacts of climate change on their economies and society.

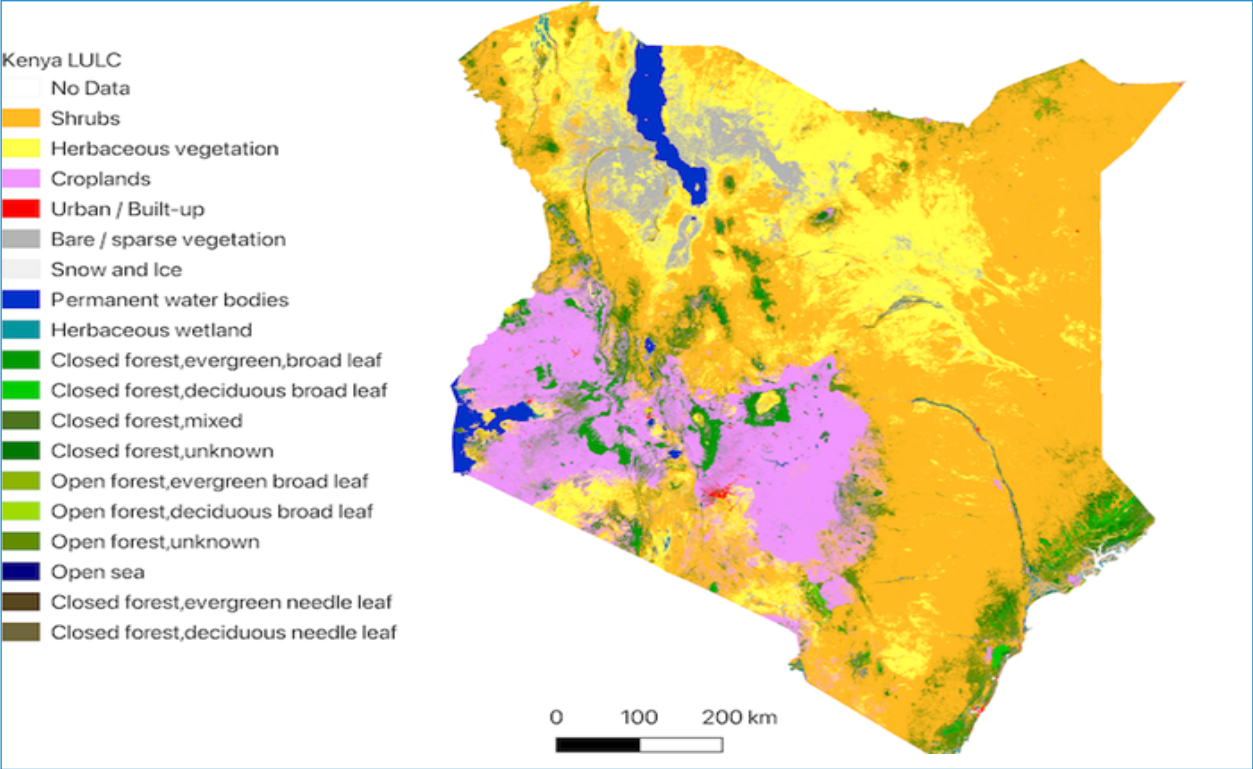
The paper is organized into four sections. Section 2 describes the risk climate change poses to agriculture in both countries. Section 3 presents the models, data, and results regarding the economic impacts of climate change. Section 4 presents two adaptive production strategies in agriculture and assesses their economy-wide impacts, and section 5 is the conclusion.

2. AGRICULTURE CLIMATE RISK IN KENYA AND MALI

2.1 Kenya

Kenya is located in the Horn of Africa. The country’s seasonal climate is controlled by the large-scale pressure systems of the Western Indian Ocean. The country has two main rainy seasons: March to May (long rains) and June to August (short rains). About half the country is covered by shrubland (Figure 2.1). Cropland accounts for a little over 13 percent of land cover.

Figure 2.1. Kenya land use and land cover map, 2019

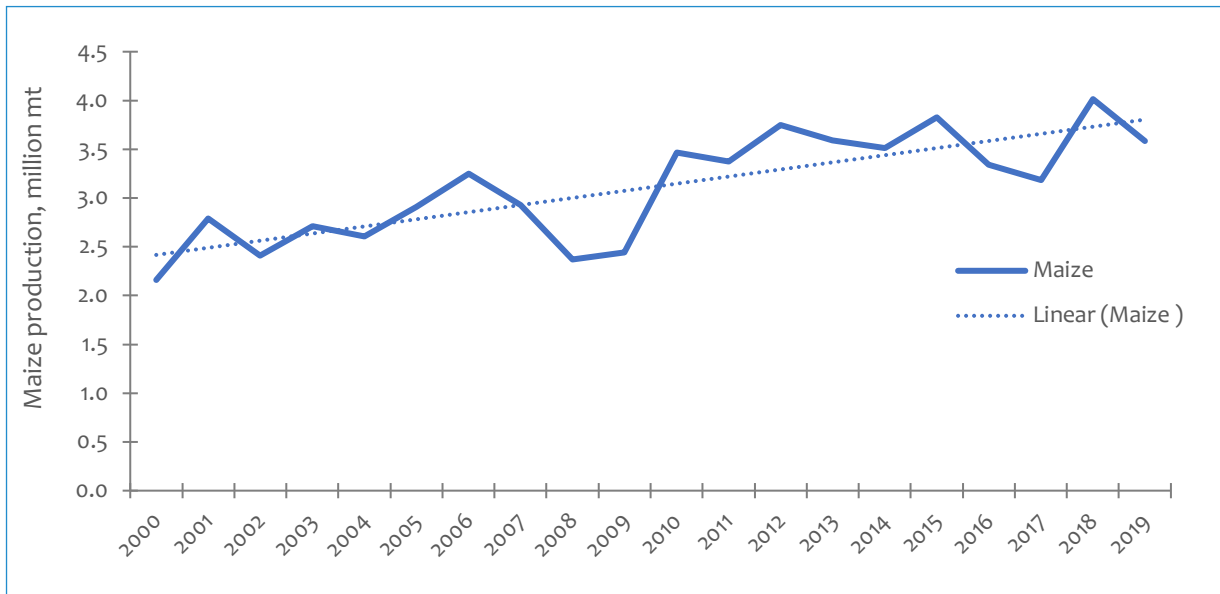


Data source: PROBA-V 2019. Data processing and mapping by authors.

The agricultural sector continues to play a critical role in Kenya's economy, contributing around 21 percent of GDP value-added and employing about 54 percent of the population.

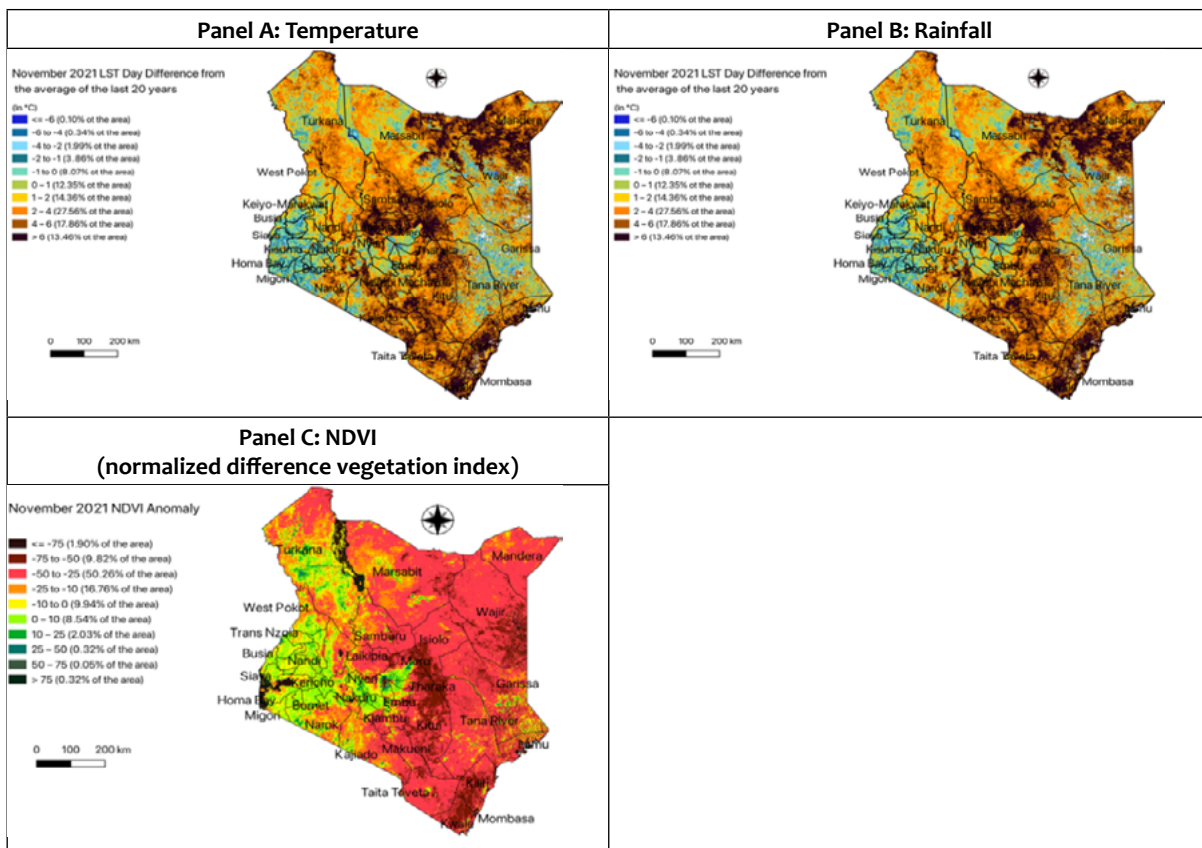
Maize is Kenya's main staple crop. The national maize production varies from year to year, but there is a weak increasing trend (Figure 2.2).

Figure 2.2. Annual national maize production in Kenya, 2000 to 2019



Source: FAOSTAT.

Figure 2.3. Kenya daytime land surface temperature, rainfall, and NDVI anomaly maps for November 2021



Source: Authors' computations.

Note: The data shown in the figures above were generated using the Quantum Geographical Information System (QGIS), ver. 3.30 software. The country shapefile was obtained from the Database of Global Administrative Areas (GADM - <https://gadm.org/>). The parameter anomalies were computed by subtracting the value of interest for the specific month from the 20-year historical average.

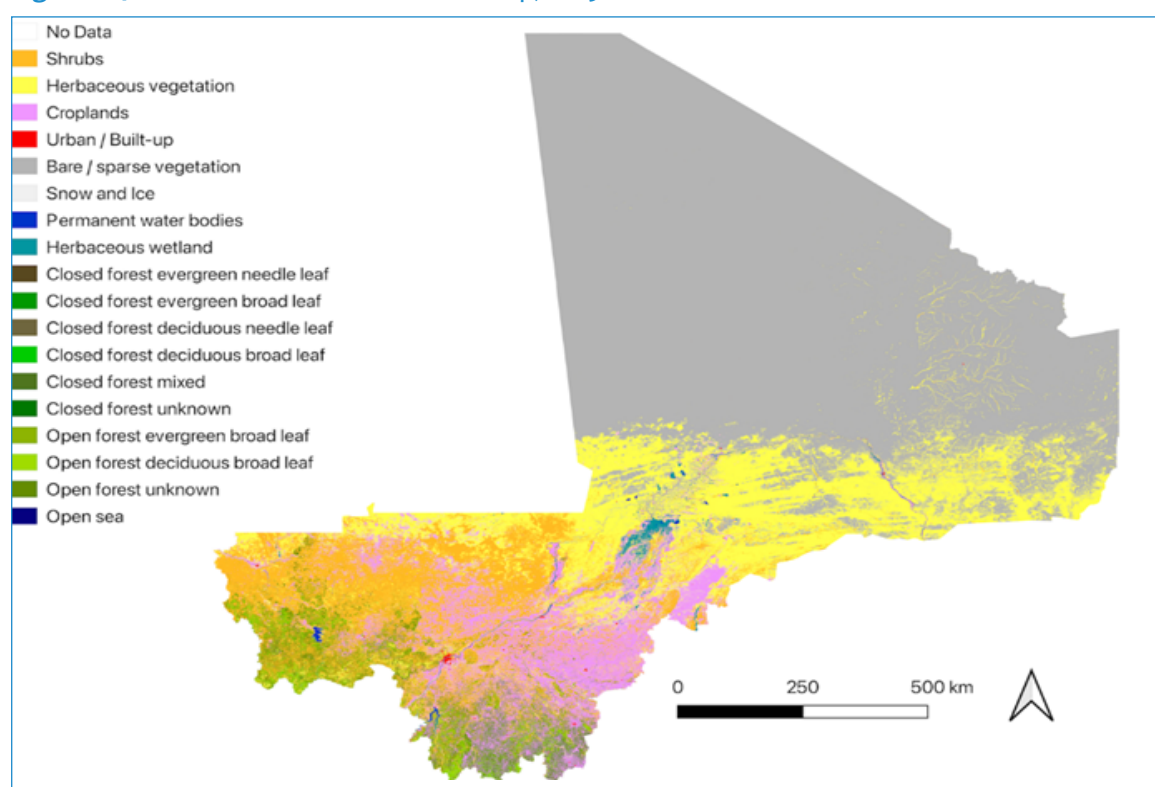
An anomaly analysis for November 2021 using remotely sensed data for daytime land surface temperatures, rainfall, and normalized difference vegetation index (NDVI) reveals the extent to which climate is changing in Kenya.¹ Panel A of Figure 2.3 shows that in November 2021 about 20 percent of the country experienced a temperature anomaly of between 4 and 6°C. About 14 percent of the country experienced warming of more than 6°C. Panel B shows that more than half of the country experienced rainfall decreases of between 20 to 50 mm compared to the average. Panel C shows that in November, half of the country’s total area had only between 25 and 50 percent of its usual level of NDVI.

2.2 Mali

Mali experiences three main seasons: a dry season from March to June, a rainy season from June to September, and an off-season or cold season from October to February. Figure 2.4 shows that more than half of the country is bare land with the Sahara Desert in the north. Cropland makes up 7 percent of the land area, while shrubland makes up a little over 13 percent.

The agricultural sector continues to play a critical role in Mali’s economy contributing 37 percent to GDP value-added in 2019 and employing 63 percent of the population. Millet and sorghum are the most prominent staples, although both maize and rice are becoming increasingly important. Figure 2.5 demonstrates that Mali has experienced a significant increase in maize and rice production since 2010.

Figure 2.4. Mali land use and land cover map, 2019



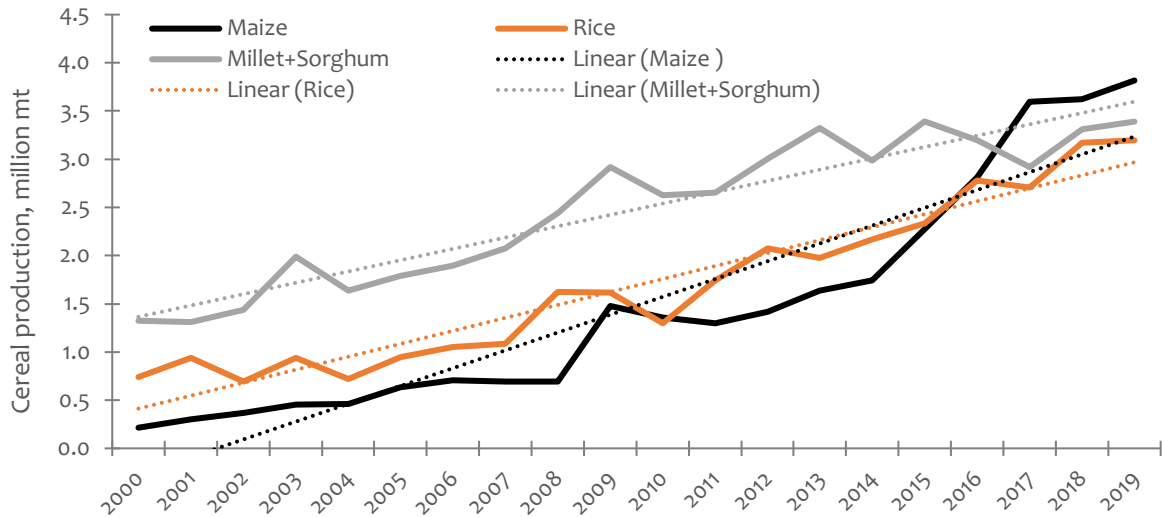
Data source: PROBA-V 2019. Data processing and mapping by authors.

¹ The data is scaled over 20 years from 2001 to 2021. The analysis consists of three steps:

- The data were averaged by month, resulting in a dataset of 240 raster files (20 years x 12 months).
- An average raster file by month was computed for the period, resulting in 12 average raster files (one for each month).
- Each month’s raster file for 2021 was compared (difference) with the average raster file of the same month to compute the deviation of the biophysical parameter by month in 2021 compared to the previous 19 years.

Remote sensing products have several advantages over field data—coverage of large areas; images captured several times a year to enable monitoring of seasonal changes; and high spatial resolution to permit observation of more detail.

Figure 2.5. Annual national cereal production in Mali, 2000 to 2019

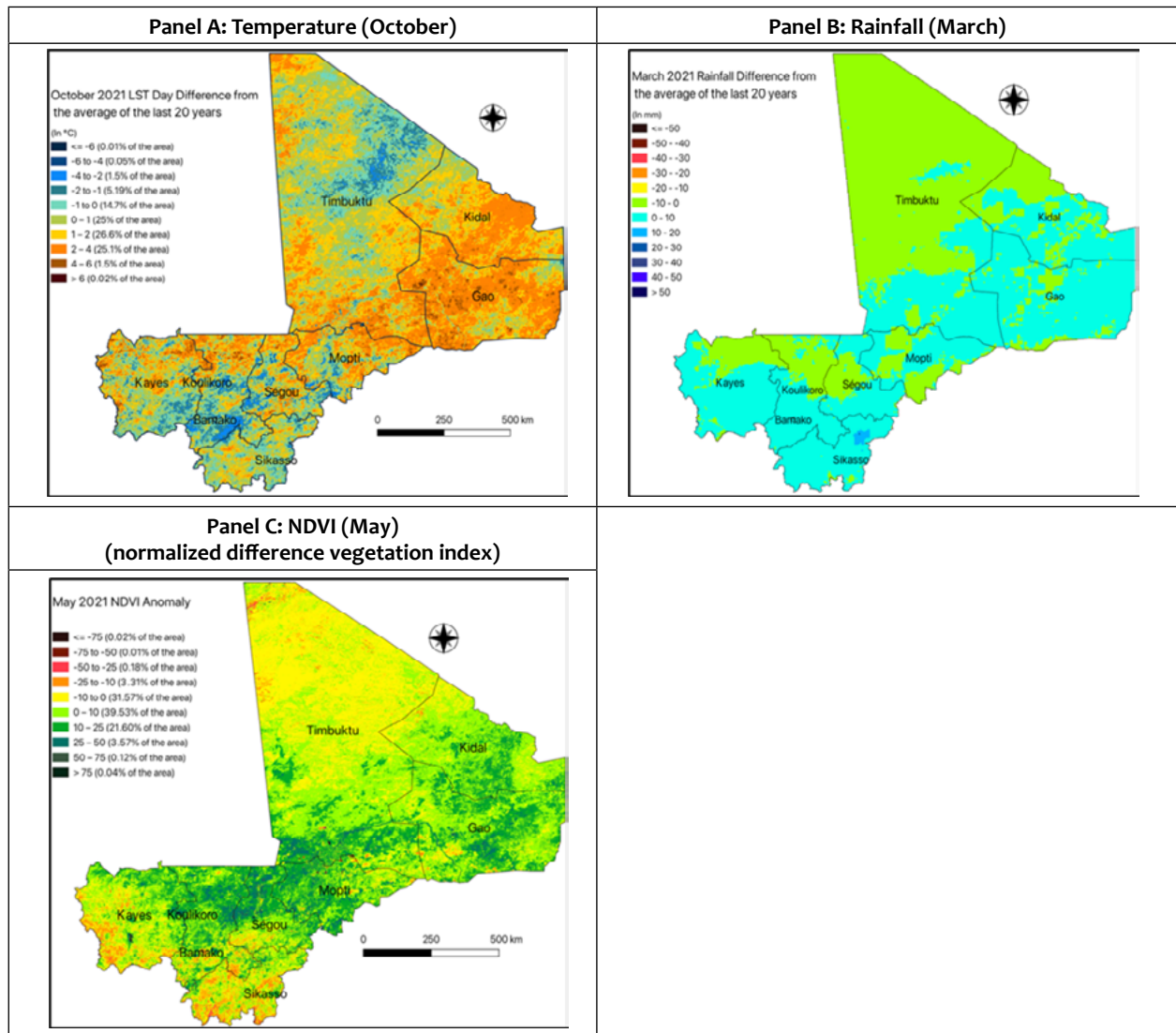


Source: FAOSTAT

Our anomaly analysis reveals that for Mali in October 2021, a warming pattern of 2 to 4°C was observed on about a quarter of the land area, being an extension of the hot season. This is shown in Panel A of Figure 2.6. Panel B shows that in March 2021, half of the land area of the country experienced an increase in rainfall of up to 10 mm, above the long-term average rainfall. Panel C shows that almost half of the country

experienced an increase of at least 10 percent in NDVI relative to its usual level. Relative to average climate conditions of the previous 20 years, Mali is experiencing increased levels of rainfall and vegetation greenness outside of the rainy season, particularly in the months from March to May. In addition, temperatures in October, early in the cold season, appear to be higher than average.

Figure 2.6. Mali daytime land surface temperature, rainfall, and NDVI anomaly maps for 2021



Source: Authors' computations.

Note: The data shown in the figures above were generated using the Quantum Geographical Information System (QGIS, ver. 3.30) software. The country shapefile was obtained from the Database of Global Administrative Areas (GADM - <https://gadm.org/>). The parameter anomalies were computed by subtracting the value of interest for the specific month of interest from the 20-year historical average.

3. ECONOMIC IMPACTS OF CLIMATE CHANGE

To understand the economic impacts of the climatic changes in Kenya and Mali, we used a macroeconomic model combined with a microsimulation model. The macroeconomic model captures issues related to growth, employment, and income generation. The model assesses the direct and indirect effects of a policy and policy reforms until an equilibrium is reached within an economy. The microsimulation model uses macroeconomic model results to assess the impacts of the policies or programs on income distribution, poverty, food security, and nutrition. The macroeconomic and microsimulation models communicate in a top-down fashion through a set of interdependent variables available in both models. The CGE model uses the 2019 Social Accounting Matrix for Kenya and the 2018 Social Accounting Matrix for Mali.² The microsimulation model uses household-level data from the 2015/16 Kenya Integrated Household Budget Survey (KiHBs) and the 2017-2018 Mali Living Standards Measurement Survey (LSMS).³

² A Social Accounting Matrix is a comprehensive, flexible, and disaggregated framework that elaborates and articulates the generation of income by activities of production within the economy and the distribution and redistribution of income between groups. More details on the SAMs used can be found in Annex 1.

³ The two surveys are quite similar in that they capture household living conditions (education, health, food security, etc.). The Living Standards Measurement Survey is a World Bank initiative in Mali aimed at improving the quality of microdata to better inform development policies, and the Integrated Household Budget Survey is produced by the Kenya National Statistical Office.

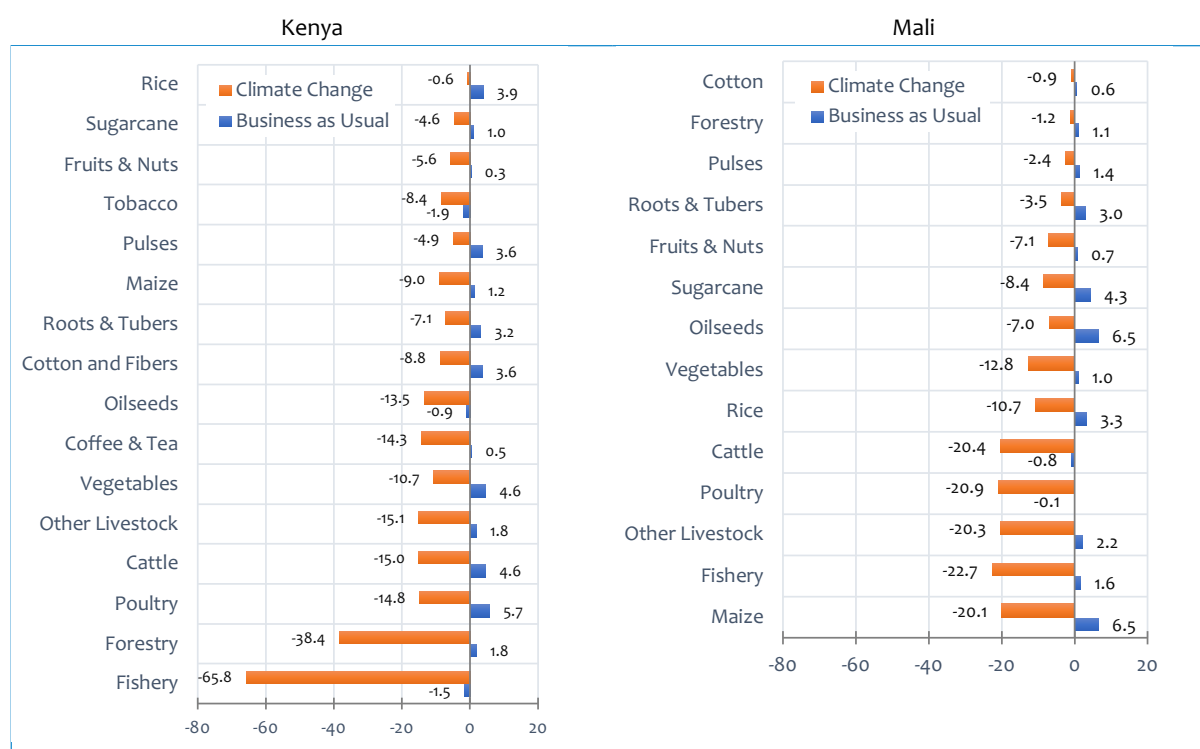
We calibrate the models using two scenarios:

- The business-as-usual scenario projects the continuation of historical trends in the agricultural sector and the economy in general. The scenario is built on agricultural sector-specific productivity trends of the past 20 years, i.e., 2000 to 2019. Low bounds are average values of negative changes in agricultural productivity, while high bounds are average values of positive changes.
- The climate change scenario is built on the existing empirical evidence on the impacts of climate change on agricultural productivity for various global warming (0.5° to 5.5°C) and precipitation levels. The extreme values (low and high bounds) predicted by these studies are used for the analysis.⁴

More details on the modeling tools and the construction of the modeling scenarios by crop in each of the study countries are provided in Annex 1.

Figure 3.1 presents the changes in agricultural productivity by sub-sector in the two countries under business-as-usual and as induced by various levels of global warming and precipitation. The left panel for Kenya shows that under the business-as-usual scenario on average slight increases in productivity are seen for most agricultural sub-sectors. However, under climate change, declines are seen in all agricultural sub-sectors. The largest average decline is seen in fisheries, followed by forestry. The three livestock sub-sectors decline on average by about 15 percent, while maize productivity declines by 9 percent. Rice is the sub-sector least affected by climate change in Kenya.⁵ The right panel in Figure 3.1 for Mali shows that the maize, fisheries and the three livestock sub-sectors are most affected by climate change, with productivity declines under climate change of around 20 percent on average. Cotton and forestry are the agricultural sub-sectors in Mali least affected by climate change.

Figure 3.1. Kenya and Mali—mean percentage change in agricultural productivity by agricultural sub-sector under the climate change scenarios, compared to business-as-usual scenarios



Source: Simulation results; Authors' computations.

Note: Values reported are the average changes of the low and high bounds for each scenario.

⁴ Due to limitations in studies focused on Mali or West Africa, in particular, we are not able to assess the impact of different levels of temperature or rainfall change within the low and high bounds.

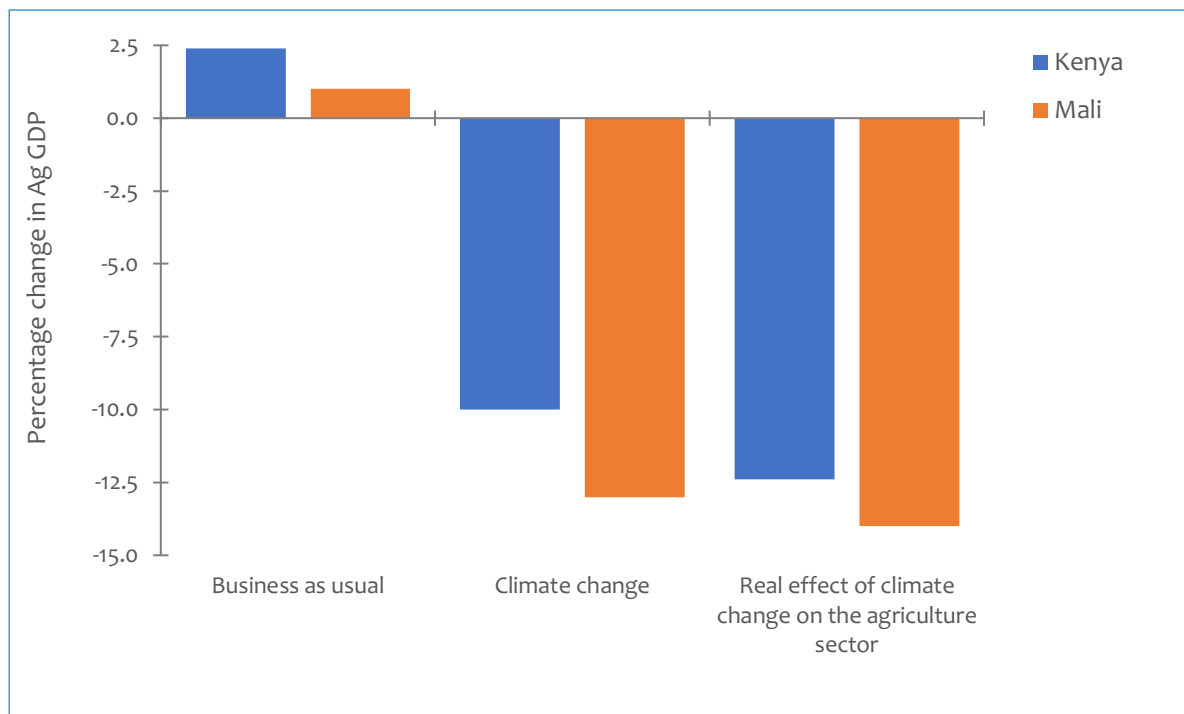
Full details on the estimates of crop-specific impacts of climate change for Kenya and Mali are presented in the tables in Annex 2

⁵ The impact of climate change has been calculated as the value differences between business as usual with values for climate change scenario.

Given these predicted changes in productivity, Figure 3.2 shows that in Kenya, under business-as-usual, average productivity for the agricultural sector as a whole is set to increase by 2.4 percent compared to 2019 levels. Production would be severely affected by climate change shocks in the country, falling

by almost 10 percent by 2050 compared to 2019 levels. For Mali, under business-as-usual, agricultural productivity increases slightly at an annual rate of about 1.0 percent compared to the 2019 level, but can be expected to decrease by almost 14 percent with climate change.

Figure 3.2. Percentage change in agricultural GDP under business-as-usual and climate change scenarios

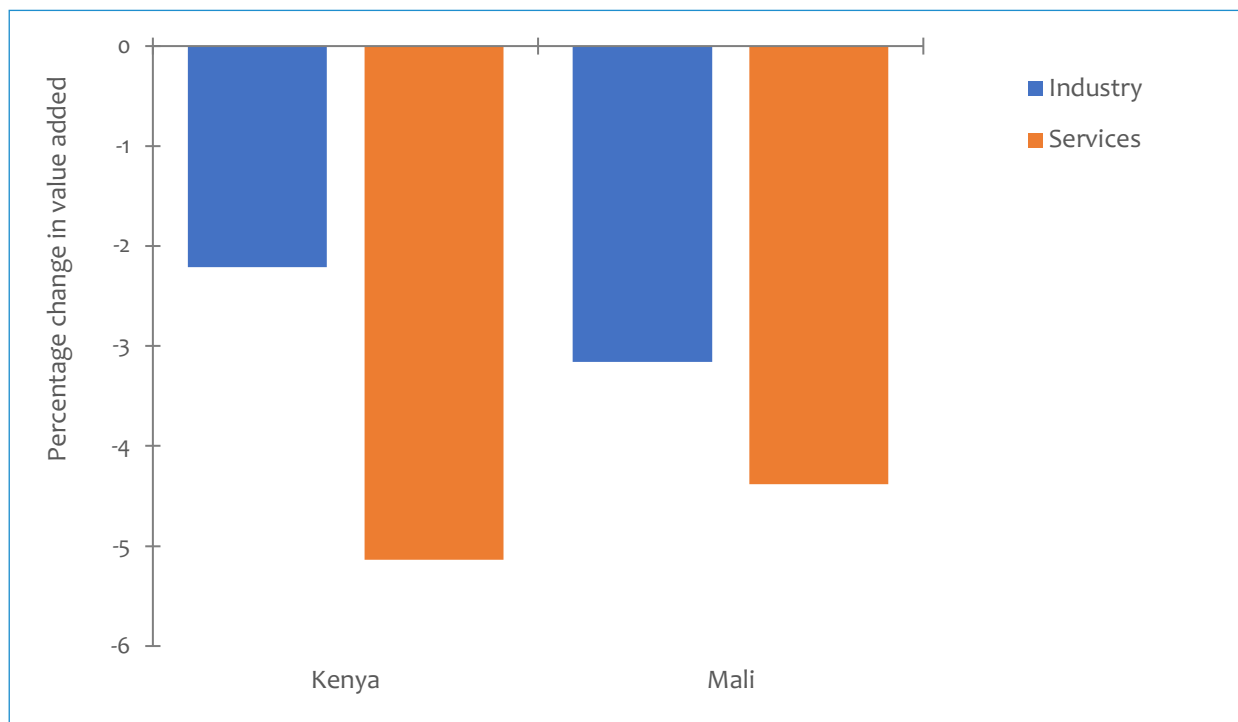


Source: Simulation results; Authors' computations

Agricultural raw materials are key inputs for the non-agricultural sectors. This means that the negative effects of climate change on agricultural value-added will affect productivity and value-added in the industrial and service sectors as well (Figure 3.3). In Kenya, backward linkages measured by input intensity—the ratio of input costs to value-added—of the industry and services sectors relative to the agriculture sector were 17 and 5 percent, respectively, in 2018. Forward linkages measured by the shares of total demand for agricultural products by the industry and service sectors were 18 and 3.5

percent, respectively, in 2018. Due to higher levels of backward and forward linkages for industry compared to the services sector, our analysis reveals that value-added declines more for the industrial sector. Comparison of the Climate Change scenario with the Business-as-Usual (BaU) scenario indicates that in Kenya, industrial sub-sectors that stand to lose in terms of value-added as a result of climate change are wood and paper products because of the high dependency on forestry products (32 percent of total input cost).

Figure 3.3. Percentage change in industry and services value-added in Kenya and Mali under climate change



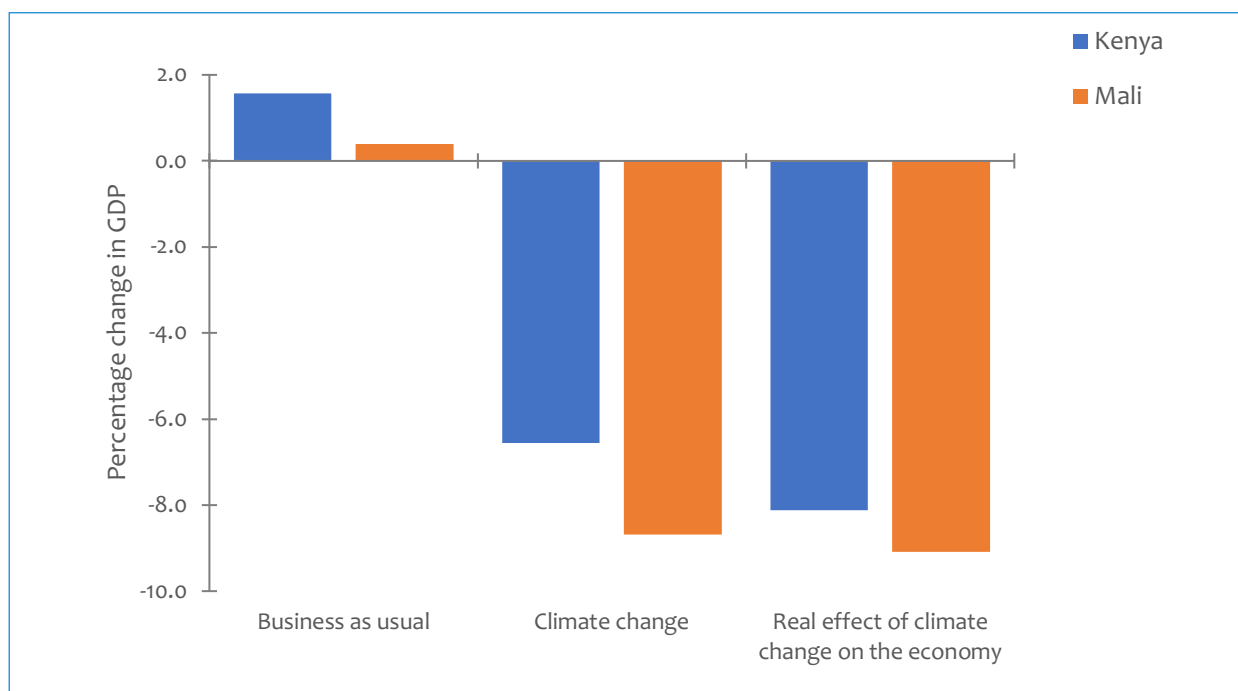
Source: authors' computations.

In Mali, the industrial sector shows stronger linkages with the agricultural sector. The input intensity representing the backward linkages to the agricultural sector of the industrial and services sectors were almost 12 percent and a little over 4 percent, respectively, in 2018. Forward linkages were almost 24 and a little over one percent, respectively, in the industry and services sector in 2018. Because of the high exposure of the industrial sector to external trade compared to the services sector, in Mali industry value-added declines less than services value-added under climate change. Public administration, health and social work, and education are negatively affected by climate change shocks on agricultural yields because of their linkages with the agricultural and food industries. Public administration, education, and health services play a crucial role in Mali's economy and are less exposed to external trade. Given high input intensity—the ratio of input costs to value-added—in Mali's agricultural sector, a decrease in agricultural value-added induced by climate change leads to a lower value-added in tertiary and quaternary services. It should be noted, however,

that several non-agricultural industries in Mali, such as metals and mining, stand to benefit from climate change shocks on agricultural yields through the real exchange rate depreciation effect, i.e., the relative increase in domestic prices compared to external prices improving the terms of trade for Mali. Thus, these industries, with export propensity rates of 76.6 and 65.4 percent respectively, increase their value-added under the CC scenario compared to the BaU scenario.

Given the effects of climate change on value-added in agriculture as well as industry and services, compared to business-as-usual, total GDP is slated to fall by 6.5 and 8.7 percent in Kenya and Mali, respectively (Figure 3.4). With a contribution of 68 percent in Kenya and 75 percent in Mali, the agricultural sector is the main contributor to the decline in GDP. The industry and services sectors also contribute significantly to the decline in GDP in Kenya, at 11 percent and 21 percent, respectively (authors' estimation). In Mali, the services sector also contributes significantly to the decline in GDP, while the contribution of the industrial sector is minimal.

Figure 3.4. Percentage change in total GDP under business-as-usual and climate change scenarios



Source: authors' computations.

The effects of climate change on employment would be sizeable for all three categories of workers: low, medium, and high-skilled (Figure 3.5). The employment rate for low-skilled workers would fall by more than 5 and almost 7 percent, respectively, in Kenya and Mali. In terms of earnings, high-skilled workers would be most affected by climate change, experiencing a drop of 2.5 percent and almost 2

percent in Kenya and Mali, respectively. Similarly, the returns to agricultural land and other capital decrease significantly under climate change compared to business-as-usual. In Kenya, the earnings of land would fall by more than 13 percent and the return to other capital by almost 7 percent, while in Mali, the returns to land are reduced by almost 10 percent and the returns to other capital by more than 7 percent.

Figure 3.5. Adjustments in employment and factor earnings under climate change

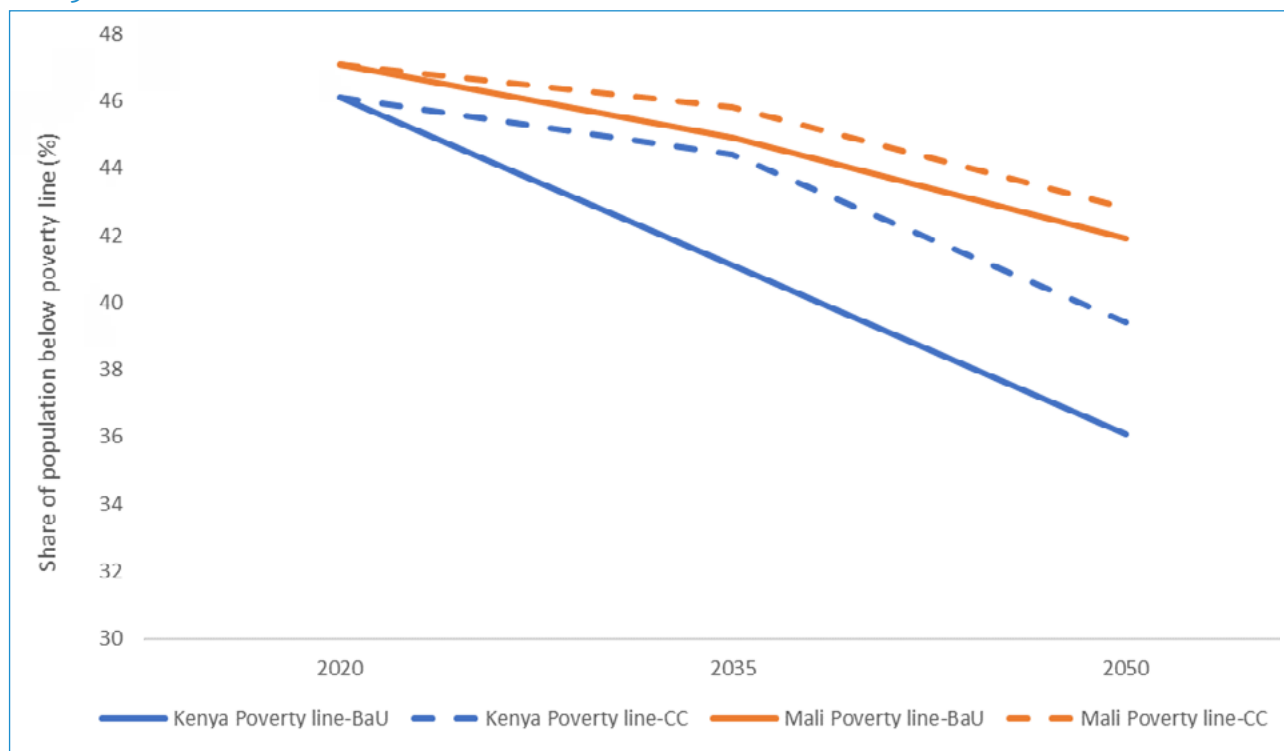


Source: Authors' computations.

With climate change, there will be an increase in poverty compared to business-as-usual. Figure 3.6 shows that in Kenya the number of poor people, i.e., individuals with total consumption expenditures below the USD 1.90 per person per day poverty line increases by 3.3 percent by 2035 with climate change compared to business-as-usual. In Mali, the number

of poor people would increase by about 1 percent in the climate change scenario relative to the business-as-usual scenario. Although not shown here, income inequality as measured by the Gini index increases slightly under climate change compared to business-as-usual in Mali, but decreases under climate changes in Kenya.

Figure 3.6. Evolution of poverty rates under business-as-usual (BaU) and climate change (CC) scenarios, 2020 to 2050



Source: Authors' computations.

Note: The poverty line used is the USD 1.90 per person per day poverty line (2011 PPA, World Bank)—in Kenya, this line is KShs 197 for urban areas and KShs 107 for rural areas; in Mali, it is CFA 738.

4. THE ECONOMIC EFFECTS OF ADAPTATION STRATEGIES

Realizing the long-term adverse effects of climate change, 52 African countries had submitted by 2021 their Nationally Determined Contributions (NDC) to the United Nations Framework Convention on Climate Change. Almost all had included National Adaptation Plans (NAP) in their NDCs, while six countries developed separate NAPs. The NDC and NAP define strategic planning and prioritize mitigation and adaptation actions in each country for the short, medium, and long term.

Kenya's National Adaptation Plan (NAP) presents the country's socio-economic conditions and examines future climate scenarios that it will need to consider in decision-making, planning, and budgetary processes. The document also provides a vulnerability analysis for the risks identified in the National Climate Change Action Plan, such as drought, floods, and sea level rise. According to its NAP,

Kenya plans to increase climate resilience to achieve strong economic growth, resilient ecosystems, and sustainable livelihoods. For the agricultural sector, Kenya plans to build resilience in crops, livestock, and fisheries value chains by promoting climate-smart crop production and livestock rearing. CSA interventions in Kenya were said to have supported over 67,000 farmers, 90,000 pastoralists, and 250 persons engaged in fishing to transition to specialized and market-oriented outputs in 13 priority value chains.

Under its NAP, Mali has identified as important strategies for adaptation in the agriculture sector adoption of improved varieties for key crops, such as millet, sorghum, corn, and rice, implementation of soil and water conservation measures, and creating and making better use of meteorological information systems (early warning systems). However, the use

of CSA technologies is still very low in Mali. Within its NAP, Mali presented a proposal to promote irrigated rice production through intermittent irrigation at a cost of USD 590 million and a technological action plan for adaptation that is estimated to cost USD 1.0 billion to implement.

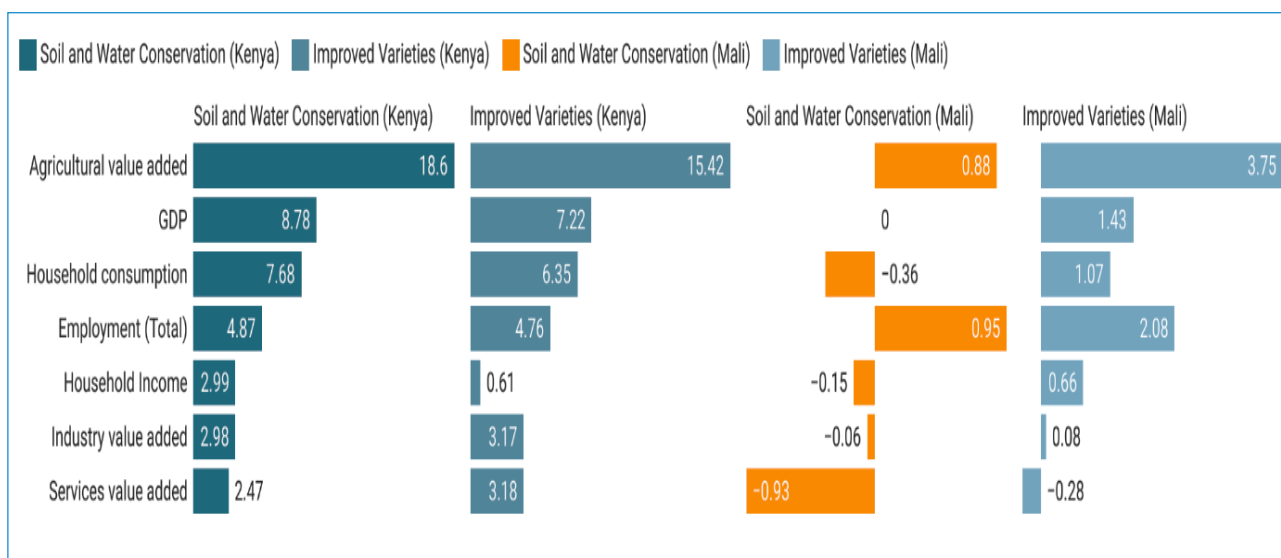
CSA is a unified governance framework designed to enhance productivity and simultaneously build resilience to climate change and reduce greenhouse gas emissions (FAO 2017; Rosenstock et al. 2019). Key elements of CSA systems include the management of farms to balance near-term food security and livelihood needs with climate change adaptation priorities. Examples of climate-smart farming strategies include:

- Changing the timing of specific farming activities or amounts of inputs applied.
- Using insurance and other financial risk management solutions.
- Using improved, climate-sensitive agricultural inputs, e.g., climate-smart seeds.

- Adopting alternative production practices, such as cover crops or improved crop residue management.
- Increasing the use of soil testing, water management, controlled drainage, and tree management to support climate-smart farm production.
- Transitioning to new farming systems and agroecological practices.
- Diversifying the primary crops and livestock produced

CSA also includes the provision of services to farmers, so that they are better able to manage and anticipate climate risks and impacts and to take mitigation actions, and changes in the wider food system, including demand-side measures and value chain interventions that enhance the benefits of the CSA technologies.

Figure 4.1. Economy-wide effects of soil and water conservation and improved crop variety adoption as climate change adaptation measures in Kenya and Mali, percentage change



Source: Simulation results. Authors' computations.

In light of these approaches to mitigating the impact of climate change through agriculture, we used our model to simulate the mitigating effects (shock) of two CSA strategies: soil and water conservation measures and the use of improved crop varieties (Figure 4.1). Our modeling results show that in Kenya, to mitigate the effects of climate change on the economy to maintain 2019 levels, the share of cropland under improved varieties would have to increase by 36 percent, while the share of land with soil and water conservation measures would have to

increase by 42 percent.⁶ In Mali, the share of the area cultivated with improved varieties would need to increase by 59 percent to maintain 2018 levels, while the share of the area cultivated under soil and water conservation would need to rise by 73 percent. While interesting, an analysis of the economy-wide impacts of the interaction between the two adaptation solutions is beyond the scope of this study. These are sizeable increases that would have important implications for public expenditure but adoption of these measures is critical. If no adaptation were to

⁶ This means restoring economic losses and recovering Kenya's 2019 level of economic growth.

take place, the effect of the climate change shocks on the economy would not be mitigated and hence the economy would contract by 6.5 and 8.7 percent in Kenya and Mali, respectively.

Figure 4.1 also shows that the contribution of agriculture to GDP growth as a result of the two adaptation strategies increases in both countries. Growth is larger in Kenya than in Mali. GDP, employment, consumption, and income in Kenya all

5. CONCLUSION

Both Kenya and Mali are vulnerable to climate change and have placed adaptation firmly on their agenda. Both countries have prepared NDCs and NAPs. The assessment of the extent and spatial distribution of biophysical anomalies related to climate change over the last 20 years indicates that Kenya's climate is changing. Land surface temperatures and rainfall maps show irregular patterns, particularly for rainfall in October, November, and December. The climate in Mali is changing but in a different way to that of Kenya. In Mali, there is an extension of the hot season with heat waves during the cold season which runs from October to February. Similarly, what used to be the dry season running from March to May now shows more green vegetation than before and more than half of the country now receives rainfall of up to 20 millimeters during the dry period. For Kenya, these changes imply a shift in the cropping calendar and an increased risk of crop failure. For Mali, there is a potential shift to an extended agricultural season which could be an advantage in terms of food security. However, it is important to identify the areas where the conditions are favorable for the production of a specific crop.

A review of the scientific literature reveals that maize yields and livestock productivity in Mali would be most affected by a change in climate, while in Kenya, yields of other cereals, primarily sorghum, and forestry productivity are expected to be most affected. Our economic modeling results reveal that with these projected changes in agricultural productivity and without adaptation, total GDP is slated to fall by 6.5 percent in Kenya and by 8.7 percent in Mali. The agricultural sector is the main contributor to the decline in GDP in both regions with a contribution of 68 and 75 percent in Kenya and Mali, respectively. Climate change would also affect employment and factor earnings. The employment rate for low-skilled workers would fall by more than 5 and by almost 7 percent, respectively, in Kenya and Mali. Using the 1.90 USD per day poverty line, with

improve as a result of the implementation of both CSA strategies. While Mali is expected to be heavily affected by climate change, only the adoption of improved varieties is projected to yield positive returns, beyond climate shock mitigation, on GDP, consumption, income, and employment. The impacts on consumption, income, and employment in Mali of the widespread adoption of soil and water conservation measures are much less.

climate change and without adaptation, the number of poor people will increase by 3.3 and 1.0 percent in Kenya and Mali, respectively. This represents 1,412,259 additional people falling into poverty in Kenya and 166,000 people in Mali.

The assessment of the economic impacts of climate change underlines the urgent need to implement adaptation strategies. For most countries, the sections of their NAP that contain plans for adaptation in the agricultural sector invariably mention CSA strategies. We have assessed for Kenya and Mali the economic impact of two of these CSA strategies—soil and water conservation measures and the use of improved seed. We find that the promotion and large-scale implementation of both strategies will help mitigate the climate impact on agricultural productivity in both countries. In addition, there are important returns in terms of GDP growth and employment related to investments in these two strategies, though more so in Kenya than in Mali. Although not shown here, it is likely that a combination of the two strategies i.e., having farmers use appropriate seeds while simultaneously managing their soils and water appropriately, would be even more impactful. Future research will build the evidence base of the impact of such combined interventions.

These findings provide evidence that implementation of adaptation strategies in the agricultural sector would allow for the mitigation of the effect of climate shocks on the economy and have beneficial effects on household welfare although this is highly country-specific. These findings should support decision-makers and provide part of the evidence base for adaptation investment programming in the agriculture sector. To complete the picture and further refine the analysis, we would still need to estimate the costs for both adaptation measures in each country.

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7. ANNEXES

Annex 1. The modeling tools and description of the scenarios modeled

The CGE model uses a Social Accounting Matrix (SAM). The latter is a comprehensive, flexible, and disaggregated framework that elaborates and articulates the generation of income by activities of production and the distribution and redistribution of income between groups. The study uses the 2019 SAM for Kenya and the 2018 SAM for Mali. The Kenya SAM has 42 industries, including 18 agricultural activities, five inputs, including agricultural land, three labor categories, and ten representative household groups (Thurlow 2021). Mali's 2018 SAM considers 42 industries, including 18 agricultural activities, five factors of production, including agricultural land, three labor categories, and ten representative household groups (Randriamamonjy 2021).

The microsimulation component of the analysis is conducted using the latest available household survey data—for Kenya, the 2015/16 Kenya Integrated Household Budget Survey (KiHBs); and for Mali, the 2017/2018 Mali Living Standards Measurement Survey (LSMS). Survey data is used to calibrate the microsimulation models and to perform the microeconomic analysis.

Annex Table 1. Description of business-as-usual and climate change scenarios—crop and sector-specific changes in productivity

| Agricultural activities | Kenya | | | | Mali | | | |
|-------------------------|--|------------|-------------------------|------------|--|------------|-------------------------|------------|
| | Business-as-usual (2000-2019)-Baseline | | Climate change Scenario | | Business-as-usual (2000-2019)-Baseline | | Climate change Scenario | |
| | Low bound | High bound | Low bound | High bound | Low bound | High bound | Low bound | High bound |
| Maize | -10.5 | 13.0 | -25.0 | 6.3 | -13.4 | 26.4 | -57.0 | 13.5 |
| Rice | -9.1 | 16.8 | -16.0 | 15.0 | -8.8 | 13.2 | -25.0 | 4.4 |
| Other Cereals | -14.1 | 29.9 | -35.0 | 25.0 | -10.6 | 11.0 | -17.1 | 6.2 |
| Pulses | -11.0 | 15.6 | -4.9 | -4.9 | -6.6 | 11.1 | -4.9 | 0.0 |
| Oilseeds | -17.2 | 15.5 | -13.5 | -13.5 | -14.3 | 27.3 | -13.5 | 0.0 |
| Roots & Tubers | -13.6 | 17.0 | -7.1 | -7.1 | -5.6 | 13.4 | -7.1 | 0.0 |
| Vegetables | -10.1 | 16.7 | -10.7 | -10.7 | -3.6 | 3.5 | -14.2 | -11.3 |
| Sugarcane | -7.2 | 9.2 | -10.8 | 1.6 | -4.2 | 9.9 | -9.5 | -7.3 |
| Tobacco | -11.3 | 7.5 | -16.6 | -0.6 | <i>na</i> | <i>na</i> | <i>na</i> | <i>na</i> |
| Cotton and Fibers | -16.9 | 22.4 | -16.6 | -0.6 | -8.3 | 9.4 | -7.7 | 6.2 |
| Fruits & Nuts | -9.6 | 10.1 | -10.7 | -10.7 | -21.1 | 22.6 | -7.1 | -7.0 |
| Coffee & Tea | -9.5 | 15.4 | -40.0 | 12.3 | <i>na</i> | <i>na</i> | <i>na</i> | <i>na</i> |
| Other Crops | -6.9 | 7.7 | -16.6 | -0.6 | -3.6 | 7.1 | <i>na</i> | <i>na</i> |
| Cattle | -10.4 | 23.1 | -20.0 | -10.0 | -5.2 | 3.7 | -36.0 | -5.0 |
| Poultry | -14.0 | 19.9 | -20.0 | -10.0 | -4.1 | 7.0 | -36.0 | -5.0 |
| Other Livestock | -9.0 | 7.7 | -20.0 | -10.0 | -13.6 | 10.7 | -36.0 | -5.0 |
| Forestry | -0.5 | 2.4 | -70.0 | -5.0 | 0.0 | 1.1 | -18.0 | 14.0 |
| Fishery | -12.1 | 7.1 | -76.0 | -56.0 | -19.4 | 15.7 | -42.0 | -3.0 |

Source: FAO (2022) for the business-as-usual scenario. Climate change scenario is from a review of the literature.

Note: 'na'=not applicable.

Annex 2. Estimated crop-specific climate change impacts for Kenya and Mali from the research literature

Annex Table 2. Maize yields in Kenya—evidence of climate change impacts

| Region/ Country | Temperature change | Precipitation change | Yield variation range, % | Publication | Authors, year |
|--------------------|-----------------------|-------------------------|-----------------------------|---|--|
| East Africa | 0.5 to 2°C | -10 to +5% | +5.0 to -5.0 | Science | Lobell, D.B., M.B. Burke, C.Tebaldi, M.D. Mastrandrea, W.P. Falcon, and R.L. Naylor (2008) |
| East Africa | 1.1 to 1.9°C | +26 to +184mm | +6.3 to -1.7 | “Climate Change and Food Systems” book chapter (FAO) | Thomas, T.S., and M.W. Rosegrant (2015) |
| East Africa | 1.0 to 1.8°C | -- | -5.0 to -20.0 | Global Environmental Change | Thornton, P.K., P.G. Jones, G. Alagarswamy, and J. Andresen (2009) |
| Ethiopia | 1.0 to 3.5°C | +100 to +300mm | -5.0 to -25.0 | IFPRI Research Monograph | Waithaka, M.; G.C. Nelson; T.S. Thomas, and M. Kyotalimye (2013) |
| Ethiopia | 1.4 to 5.5°C | +10 to +15% | -7.0 to -12.0 | Food and Energy Security | Adhikari, U., A.P. Nejadhashemi, and S.A. Woznicki (2015) |
| Kenya | 2 to 3°C | +15 to +20% | -6.0 to -11.0 | Food and Energy Security | Adhikari, U., A.P. Nejadhashemi, and S.A. Woznicki (2015) |
| Rwanda | 3 to 4°C | +10 to +15% | -6.0 to -10.0 | Food and Energy Security | Adhikari, U., A.P. Nejadhashemi, and S.A. Woznicki (2015) |
| Tanzania | 1.0 to 3.5°C | +100 to +300mm | -5.0 to -25.0 | IFPRI Research Monograph | Waithaka, M., G.C. Nelson, T.S. Thomas, and M. Kyotalimye (2013) |
| Tanzania | 2 to 3°C | +5 to +15% | -6.0 to -12.0 | Food and Energy Security | Adhikari, U., A.P. Nejadhashemi, and S.A. Woznicki (2015) |
| Tanzania | +2°C | +20% | -3.6 to -13.0 | Agricultural and Forest Meteorology | Rowhani, P., D.B. Lobell, M. Linderman, and N. Ramankutty (2011) |
| Uganda | 2 to 3°C | +5 to +15% | -7.0 to -11.0 | Food and Energy Security | Adhikari, U., A.P. Nejadhashemi, and S.A. Woznicki (2015) |
| Zambia | 1.4 to 5.5°C | 0 to +5% | -7.0 to -13.0 | Food and Energy Security | Adhikari, U., A.P. Nejadhashemi, and S.A. Woznicki (2015) |

Source: Authors' compilation

Annex Table 3. Coffee and tea yields in East Africa—evidence of climate change impacts

| Region/ Country | Temperature change | Precipitation change | Yield variation range, % | Publication | Authors, year |
|--------------------|-----------------------|-------------------------|-----------------------------|-------------------------------------|---|
| East Africa | 1.4 to 5.5°C | -2 to +20% | 0 to -40.0 | Food and Energy Security | Adhikari, U., A.P. Nejadhashemi, and S.A. Woznicki (2015) |
| Tanzania | 2 to 4°C | 0 to +48mm | -30 to -20 | CIAT Report | Läderach, P., A. Eitzinger, O. Ovalle, and S.E. Carmona Rahn (2012) |
| Tanzania | +1.0°C | -- | -12.3 to +12.3 | Agricultural and Forest Meteorology | Craparo, A.C.W., P.J.A. van Asten, P. Läderach, L.T.P. Jassogne, and S. Grab (2015) |

Source: Authors' compilation

Annex Table 4. Rice yields in East Africa—evidence of climate change impacts

| Region/ Country | Temperature change | Precipitation change | Yield variation range, % | Publication | Authors, year |
|-------------------------|--|-------------------------|-----------------------------|--|--|
| East Africa | 1 to 3°C | -- | +16.0 to -4.0 | “Climate Change 2007:” book chapter (NASA) | Easterling, W.E., P.K. Aggarwal, P. Batima, K.M. Brander, L. Erda, S.M. Howden, A. Kirilenko, J. Morton, J.-F. Soussana, J. Schmidhuber and F.N. Tubiello (2007) |
| East Africa | 1.1 to 1.9°C | +26 to +184mm | +6.3 to -1.7 | “Climate Change and Food Systems” book chapter (FAO) | Thomas, T.S., and M.W. Rosegrant (2015) |
| East Africa | 1°C | -40% to +20% | -3.0 to -1.0 | Environmental Research Letters | Lobell, D.B., and C.B. Field (2007) |
| East Africa | 1.3 to 1.5°C | 0 to 4.7% | +3.0 | IFPRI Research Monograph | Waithaka, M., G.C. Nelson, T.S. Thomas, and M. Kyotalimye (2013) |
| East Africa | 0.5 to 8°C | 2 to 10% | -15.0 | IFPRI Report | Nelson, G.C., M.W. Rosegrant, J. Koo, R. Robertson, T. Sulser, T. Zhu, C. Ringler, S. Msangi, A. Palazzo, M. Batka, M. Magalhaes, R. ValmonteSantos, M. Ewing, and D. Lee (2009) |
| East Africa | 0.5 to 2.0°C | -10 to +5% | -5.0 to 15.0 | Science | Lobell, D.B., M.B. Burke, C.Tebaldi, M.D. Mastrandrea, W.P. Falcon, and R.L. Naylor (2008) |
| East Africa (rainfed) | 1.1 to 1.9°C | +26 to +184mm | +2.2 to +6.7 | “Climate Change and Food Systems” book chapter (FAO) | Thomas, T.S., and M.W. Rosegrant (2015) |
| East Africa (irrigated) | 1.1 to 1.9°C | +26 to +184mm | -19.7 to -10.4 | “Climate Change and Food Systems” book chapter (FAO) | Thomas, T.S., and M.W. Rosegrant (2015) |
| East Africa (rainfed) | Base: 14°C; Optimum: 31°C (RCP 8.5 scenario) | -- | -21.0 | Global Change Biology | Van Oort, P.A.J., and S.J. Zwart (2017) |

Source: Authors’ compilation

Annex Table 5. Agricultural yields in East Africa—evidence of climate change impacts

| Agricultural activity | Region/ Country | Temperature change | Precipitation change | Yield variation range, % | Publication | Authors, year |
|-----------------------|--------------------|--------------------|----------------------|--------------------------|----------------------------------|--|
| Fruits and Vegetables | Sub-Saharan Africa | 1.4 to 4.5°C | 0.7 to 4.7% | -10.7 | IFAD Rural Development Report | Brooks K., S. Dunston, K. Wiebe, C. Arndt, F. Hartley, and R. Robertson (2007) |
| Livestock | Sub-Saharan Africa | 1.0 to 4.0°C | -- | -20.0 | Environmental Science and Policy | Jones, P.G., and P.K. Thornton (2009) |
| Oilseeds | Sub-Saharan Africa | 1.4 to 4.5°C | 0.7 to 4.7% | -13.5 | IFAD Rural Development Report | Brooks K., S. Dunston, K. Wiebe, C. Arndt, F. Hartley, and R. Robertson (2007) |
| Pulses | Sub-Saharan Africa | 1.4 to 4.5°C | 0.7 to 4.7% | -4.9 | IFAD Rural Development Report | Brooks K., S. Dunston, K. Wiebe, C. Arndt, F. Hartley, and R. Robertson (2007) |
| Roots & Tubers | Sub-Saharan Africa | 1.4 to 4.5°C | 0.7 to 4.7% | -7.1 | IFAD Rural Development Report | Brooks K., S. Dunston, K. Wiebe, C. Arndt, F. Hartley, and R. Robertson (2007) |
| Sugarcane | East Africa | 0.5 to 2.0°C | -10 to +5% | +1.6 | Science | Lobell, D.B., M.B. Burke, C.Tebaldi, M.D. Mastrandrea, W.P. Falcon, and R.L. Naylor (2008) |

Source: Authors’ compilation

Annex Table 6. Sorghum yields in East Africa—evidence of climate change impacts

| Region/ Country | Temperature change | Precipitation change | Yield variation range, % | Publication | Authors, year |
|--------------------|-----------------------|-------------------------|-----------------------------|---|--|
| DR Congo | 1.0 to 3.5°C | -400 to +400mm | -25.0 to +5.0 | IFPRI Research Monograph | Waithaka, M.; G.C. Nelson; T.S. Thomas, and M. Kyotalimye (2013) |
| East Africa | 1.1 to 1.9°C | +26 to +184mm | -15.5 to -0.5 | “Climate Change and Food Systems” book chapter (FAO) | Thomas, T.S., and M.W. Rosegrant (2015) |
| East Africa | 1.3 to 1.5°C | 0 to 4.7% | -25.0 to +5.0 | IFPRI Research Monograph | Waithaka, M., G.C. Nelson, T.S. Thomas, and M. Kyotalimye (2013) |
| Ethiopia | 1.4 to 5.5°C | +10 to +15% | -33 to -18 | Food and Energy Security | Adhikari, U., A.P. Nejadhashemi, and S.A. Woznicki (2015) |
| Kenya | 2.0 to 3.0°C | +15 to +20% | -29 to -16 | Food and Energy Security | Adhikari, U., A.P. Nejadhashemi, and S.A. Woznicki (2015) |
| Kenya | 1.0 to 3.5°C | +100 to +300mm | +5.0 to +25.0 | IFPRI Research Monograph | Waithaka, M.; G.C. Nelson; T.S. Thomas, and M. Kyotalimye (2013) |
| Malawi | 3.0 to 4.0°C | 0 to +5% | -34 to -17 | Food and Energy Security | Adhikari, U., A.P. Nejadhashemi, and S.A. Woznicki (2015) |
| Rwanda | 2.0 to 4.0°C | -5 to +10% | -25 to -15 | Food and Energy Security | Adhikari, U., A.P. Nejadhashemi, and S.A. Woznicki (2015) |
| Sudan | 1.5 to 2.5°C | -50 to +200mm | +5.0 to +25.0 | IFPRI Research Monograph | Waithaka, M.; G.C. Nelson; T.S. Thomas, and M. Kyotalimye (2013) |
| Tanzania | 2.0 to 3.0°C | +5 to +15% | -30 to -16 | Food and Energy Security | Adhikari, U., A.P. Nejadhashemi, and S.A. Woznicki (2015) |
| Tanzania | 1.0 to 2.0°C | +20% | -8.9 to -7.2 | Agricultural and Forest Meteorology | Rowhani, P., D.B. Lobell, M. Linderman, and N. Ramankutty (2011) |
| Tanzania | 0.5 to 3.5°C | +50 to +200mm | +5.0 to +25.0 | IFPRI Research Monograph | Waithaka, M.; G.C. Nelson; T.S. Thomas, and M. Kyotalimye (2013) |
| Uganda | 2.0 to 3.0°C | +5 to +15% | -30 to -17 | Food and Energy Security | Adhikari, U., A.P. Nejadhashemi, and S.A. Woznicki (2015) |
| Zambia | 1.4 to 5.5°C | 0 to +5% | -35 to -19 | Food and Energy Security | Adhikari, U., A.P. Nejadhashemi, and S.A. Woznicki (2015) |

Source: Authors' compilation

Annex Table 7. Forestry yields in East Africa—evidence of climate change impacts

| Region/ Country | Temperature change | Precipitation change | Yield variation range, % | Publication | Authors, year |
|--------------------|-----------------------|-------------------------|-----------------------------|------------------------------|---|
| East Africa | 1.1 to 1.9°C | +26 to +184mm | -5.0 | IFPRI Research Monograph | Waithaka, M.; G.C. Nelson; T.S. Thomas, and M. Kyotalimye (2013) |
| Kenya | +5.0°C | -- | -76 to -63 | Ocean and Coastal Management | Wilson, R.J., S.F. Sailley, Z.L. Jacobs, J. Kamau, S. Mgeleka, G.M. Okemwa, J.O. Omukoto, K.E. Osuka, M. Samoilys, W. Sauer, M.O. Silas, J.S. Sululu, and M.J. Roberts (2021) |
| Southern Africa | 1.0 to 2.1°C | -- | -41 to -51 | IPCC Report | IPCC (Intergovernmental Panel on Climate Change) (2007) |
| Tanzania | 4.3 ± 0.7°C | +766 to +1140mm | -70.0 | Diversity and Distribution | John, E., P. Bunting, A. Hardy, O. Roberts, R. Giliba, and D.S. Silayo (2020) |

Source: Authors' compilation

Annex Table 8. Livestock in Mali—evidence of climate change impacts

| Region/ Country | Temperature change | Precipitation change | Yield variation range, % | Publication | Authors, year |
|--------------------|------------------------------------|-------------------------|-----------------------------|-----------------|---|
| Mali | Greenhouse gas- ses integration | -- | -14 to -16 | Climatic Change | Butt, T.A., B.A. McCarl, J. Angerer, P.T. Dyke, and J.W. Stuth (2005) |
| Mali | 1.0 to 2.75°C | -- | -5 to -36 | Climate Policy | Butt, T.A., B.A. McCarl, and A.O. Kergna (2006) |

Source: Authors' compilation

Annex Table 9. Maize yields in Mali—evidence of climate change impacts

| Region/ Country | Temperature change | Precipitation change | Yield variation range, % | Publication | Authors, year |
|--------------------|--|-------------------------|-----------------------------|----------------------|--|
| Mali | Greenhouse gas- ses integration | -- | 13.5 to -11.2 | Climatic Change | Butt, T.A., B.A. McCarl, J. Angerer, P.T. Dyke, and J.W. Stuth (2005) |
| Mali | Minimum 35.3°C (CESM-driven climate); Maximum 36.8°C (MI- ROC-driven) | -- | -30.4 to -52.1 | Nature | Ahmed, K.F., G. Wang, M. Yu, J. Koo, and L. You (2015) |
| Mali | 2.9°C and 3.3°C (rcp 4.5 and 8.5 scenarios) | -- | -51.0 to -57.0 | Field Crops Research | Traore, B., K. Descheemaeker, M.T. van Wijk, M. Corbeels, I. Supit, and K.E. Giller. (2017)) |
| Mali | IPCC A1B emis- sions scenario (3°C) | -- | -17.2 to -21.7 | Nature | Ebi, K.L., J. Padgham, M. Doumbia, A. Kergna, J. Smith, T.A. Butt, and B.A. McCarl (2011) |
| Mali | 1.5° to 2°C (RCP 4.5, 8.0, and 8.5) | -5.4 to +24.8% | -17.2 to -21.7 | World Bank | World Bank (2019) |

Source: Authors' compilation

Annex Table 10. Rice yields in West Africa—evidence of climate change impacts

| Region/ Country | Temperature change | Precipitation change | Yield variation range, % | Publication | Authors, year |
|---|---|-------------------------|-----------------------------|---|--|
| West Africa | 0.5 to 4.0°C | 2 to 10% | -1.8 to +0.4 | IFPRI Report | Nelson, G.C., M.W. Rosegrant, J. Koo, R. Robertson, T. Sulser, T. Zhu, C. Ringler, S. Msangi, A. Palazzo, M. Batka, M. Magalhaes, R. ValmonteSantos, M. Ewing, and D. Lee (2009) |
| West Africa | 0.5 to 2.0°C | -10 to +5% | -6.0 to -1.0 | Science | Lobell, D.B., M.B. Burke, C.Tebaldi, M.D. Mastrandrea, W.P. Falcon, and R.L. Naylor (2008) |
| West Africa | 1.5 to 2.3°C | -23 to +30 mm | -4.4 to +0.5 | “Climate Change and Food Systems” book chapter (FAO) | Thomas, T.S., and M.W. Rosegrant (2015) |
| West Africa (irrigated) | 1.0 to 3.0°C | 0 to +4.7% | -20 to -12.4 | IFPRI Research Monograph | Jalloh, A., G.C. Nelson, T.S. Thomas, R. Zougmore, and H. Roy-Macauley (2013). |
| West Africa (rainfed) | 1.0 to 3.0°C | 0 to +4.7% | 0.5 to -4.4 | IFPRI Research Monograph | Jalloh, A., G.C. Nelson, T.S. Thomas, R. Zougmore, and H. Roy-Macauley (2013). |
| West Africa (irrigated) | Optimum: 31°C (RCP 8.5 scenario) Base: 14°C; | -- | -20.0 | Global Change Biology | Van Oort, P.A.J., and S.J. Zwart (2017) |
| West Africa (rainfed) | Optimum: 31°C (RCP 8.5 scena- rio) | -- | -25 to -19 | Global Change Biology | Van Oort, P.A.J., and S.J. Zwart (2017) |
| Côte d’Ivoire, Ghana, and Togo (rainfed) | 1.0 to 1.5°C | -400 to -100mm | -25 to -5 | IFPRI Research Monograph | Jalloh, A., G.C. Nelson, T.S. Thomas, R. Zougmore, and H. Roy-Macauley (2013). |
| Benin | 1.8° to 4.0°C (B2 scenario) | -- | -9.0 to -3.0 | Erdkunde | Paeth, H., A. Capo-Chichi, and W. Endlicher (2008) |
| Burkina Faso | RCP 8.5 scenario | -- | -4.0 to -3.4 | Working Paper | Deryng, D. (2015) |
| Senegal | RCP 8.5 scenario | -- | -4.9 to -4.1 | Working Paper | Deryng, D. (2015) |
| Nigeria | IPCC A1B sce- nario | -- | -25 to -8.0 | Climatic Change | Mereu, V., A. Gallo, G. Carboni, and D. Spano (2015) |

Source: Authors’ compilation

Annex Table 11. Millet and sorghum yields in Mali, the Sahel, and West Africa—evidence of climate change impacts

| Region/ Country | Temperature change | Precipitation change | Yield variation range, % | Publication | Authors, year |
|-----------------------|--|-------------------------|-----------------------------|----------------------|--|
| Mali (Millet) | Greenhouse gases integration | -- | -11.5 to -6.3 | Climatic Change | Butt, T.A., B.A. McCarl, J. Angerer, P.T. Dyke, and J.W. Stuth (2005) |
| Mali (Millet) | 2.9°C and 3.3°C (rcp 4.5 and 8.5 scenarios) | -- | -12.0 to -7.0 | Field Crops Research | Traore, B., K. Descheemaeker, M.T. van Wijk, M. Corbeels, I. Supit, and K.E. Giller. (2017)) |
| Mali (Millet) | 1.5° to 2°C (RCP 4.5, 8.0, and 8.5) | -5.4 to +24.8% | -9.2 to -8.5 | World Bank | World Bank (2019) |
| Mali (Sorghum) | Greenhouse gases integration | -- | -17.1 to -11.5 | Climatic Change | Butt, T.A., B.A. McCarl, J. Angerer, P.T. Dyke, and J.W. Stuth (2005) |
| Mali (Sorghum) | 1.5° to 2°C (RCP 4.5, 8.0, and 8.5) | -5.4 to +24.8% | -5.4 to -9.0 | World Bank | World Bank (2019) |
| Sahel (Sorghum) | 0.5 to 2.0°C | -10 to +5% | -15.3 to -6.2 | Science | Lobell, D.B., M.B. Burke, C.Tebaldi, M.D. Mastrandrea, W.P. Falcon, and R.L. Naylor (2008) |
| West Africa (Sorghum) | 0.5 to 2.0°C | -10 to +5% | -5.0 to +5.0 | Science | Lobell, D.B., M.B. Burke, C.Tebaldi, M.D. Mastrandrea, W.P. Falcon, and R.L. Naylor (2008) |

Source: Authors' compilation



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