Chapter 6

ETHIOPIA

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Ethiopia is a country that is particularly exposed to possible adverse impacts of climate change because a large proportion of the population is dependent on agriculture for employment and income and the country has a low gross domestic product (GDP) per capita, offering agricultural households little capacity to compensate for income losses from weather-related shocks.

Understanding the country's socioeconomic and biophysical vulnerability is important in order to devise appropriate adaptation measures that can save the environment and the livelihoods of the people. Knowledge of expected adverse effects of climate change has led to the establishment of the Ethiopian National Forum for Climate Change, established in July 2008, which is playing a significant role in bringing the potential impact of climate change to the attention of political leaders and the public. Several other initiatives are in place: the National Policy on Disaster Prevention and Preparedness, the Plan for Accelerated and Sustainable Development to End Poverty, the National Adaptation Programme of Action, and the Disaster Risk Management Policy. There is a plan to establish a National Commission for Climate Change that will be responsible for the integration of climate issues into development practices and for the coordination of policies.

In this chapter we present our assessments of the current socioeconomic and biophysical vulnerability of the Ethiopian agricultural sector, mainly focusing on key indicators of socioeconomic vulnerability and selected food enterprises. General circulation model (GCM) projections to 2050 are used to uncover what the future holds for the agricultural sector and what should be considered to enhance the sector's adaptive capacity. Crop simulation models are used to assess the changes in prices of major commodities expected with climate change. Finally, a future direction for sustainable planned adaptation is suggested for policymakers to guide their actions.

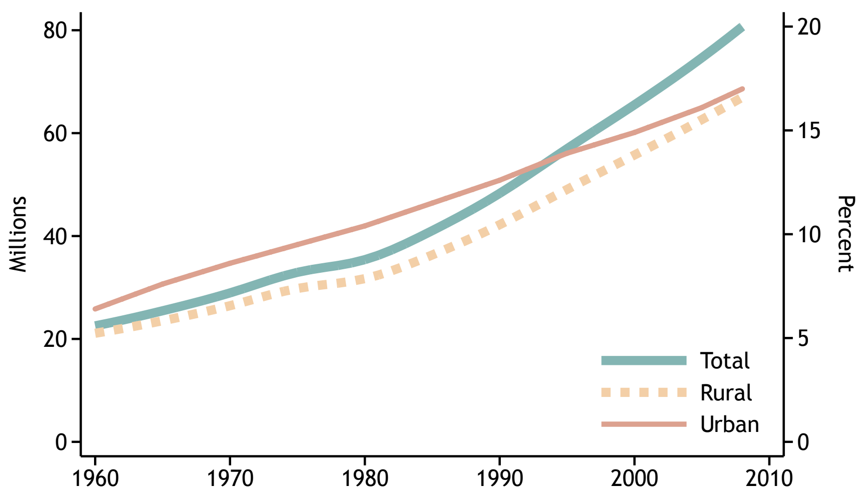
Review of the Current Situation and Trends

Economic and Demographic Indicators

Population

Figure 6.1 shows the total population and rural population (left axis) of Ethiopia as well as the share of the population that is urban (right axis). The figure shows that both the urban and the rural populations in Ethiopia have been continuously growing. From around 24 million in 1960, the total population reached 34 million in the mid-1970s. The population growth rate has fluctuated, from about 2.5 percent (1960–1969) to 2.0 percent (1970–1979), then increasing to 3.1 percent (1980–1999) and declining again to around 2.6 percent by 2008. In the late 1970s and early 1980s, population growth leveled off owing to high rates of mortality from diseases and famine (Table 6.1). In recent years, growth has picked up, and the population is almost 79 million. Factors in the recent rapid population growth are increasing fertility, reduction in adult mortality, and lack of fertility control. The urban population has grown steadily in recent years due to the expansion of the service sector and industrialization.

FIGURE 6.1 Population trends in Ethiopia: Total population, rural population, and percent urban, 1960–2008



Source: *World Development Indicators* (World Bank 2009).

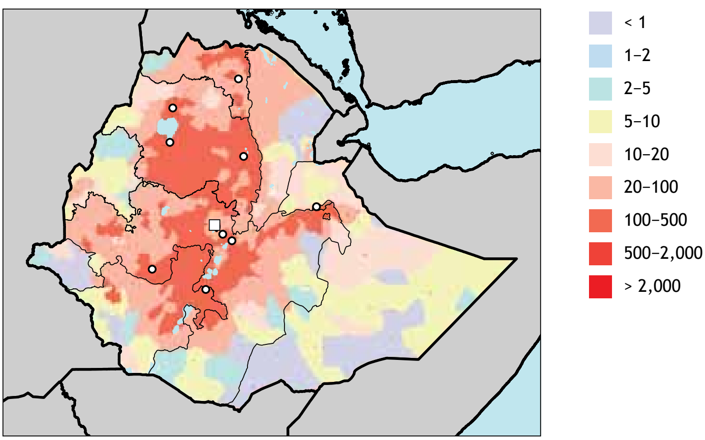
TABLE 6.1 Population growth rates in Ethiopia, 1960–2008 (percent)

Decade	Total growth rate	Rural growth rate	Urban growth rate
1960–1969	2.5	2.2	5.5
1970–1979	2.0	1.8	3.9
1980–1989	3.1	2.9	5.1
1990–1999	3.1	2.8	4.8
2000–2008	2.6	2.3	4.2

Source: Authors' calculations based on *World Development Indicators* (World Bank 2009).

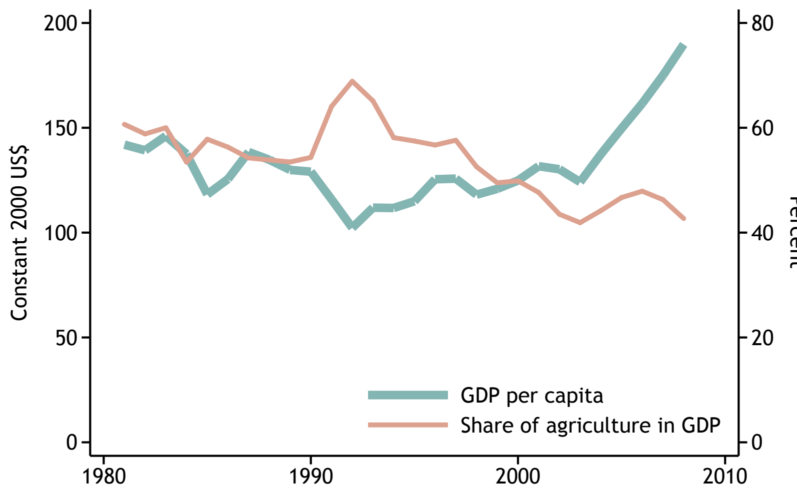
Figure 6.2 shows the geographic distribution of population in Ethiopia using estimates based on census data. The map for 2000 shows several densely populated areas in the highlands that have recently been settled, including the fertile areas in and around the Rift Valley lakes in the Southern Peoples Nations and Nationalities (SPNN) as well as the eastern highlands of Hararghe. The highest population density—500 people per square kilometer—prevails in the northeastern areas of SPNN and the southeastern parts of Oromia Region. Vast lowlands, including pastoral and agropastoral areas in the southwest, southeast, east, and north, were inhabited by few people in the year 2000 but are now highly populated. The encroachment on fragile lowland areas increases pressure on the natural resources of these areas.

FIGURE 6.2 Population distribution in Ethiopia, 2000 (persons per square kilometer)



Source: CIESIN et al. (2004).

FIGURE 6.3 Per capita GDP in Ethiopia (constant 2000 US$) and share of GDP from agriculture (percent), 1981-2008



Source: *World Development Indicators* (World Bank 2009).
Note: GDP = gross domestic product; US$ = US dollars.

Income

Figure 6.3 shows great fluctuation in the proportion of GDP in agriculture, with downward trends in recent years. Agriculture as a percentage of total GDP reached its maximum during 1992, following the economic reforms, declined to its historic low in 2003, again rose slightly, and then trended downward in recent years. GDP per capita has fluctuated as well, with its lowest level in the early 1990s and a dramatic increase beginning in 2004. "The agriculture sector's share of GDP declined by three percentage points between 2003/2004 and 2008/2009 and has now been surpassed by services. This impressive growth in services was driven by the rapid expansion in financial intermediation, public administration, and retail business activities" (ADB 2010, 3).

In spite of the decreasing contribution of agriculture to GDP, the figure is still more than 40 percent; the contribution of agriculture to the economy will thus continue to be significant as Ethiopia remains predominantly an agrarian society.

Vulnerability to Climate Change

Table 6.2 provides statistics on education and nutrition for Ethiopia. Statistics on education provide data on several indicators of a population's vulnerability

TABLE 6.2 Education and nutrition statistics for Ethiopia, 2000s

Indicator	Year	Percent
Primary school enrollment: Percent gross (three-year average)	2007	90.8
Secondary school enrollment: Percent gross (three-year average)	2007	30.5
Adult literacy rate	2004	35.9
Under-five malnutrition (weight for age)	2005	34.6

Source: *World Development Indicators* (World Bank 2009).

and resiliency to economic shocks: level of education, literacy, and concentration of labor in poorer or less dynamic sectors. Primary school enrollment is much higher than secondary school enrollment in Ethiopia; however, the adult literacy rate is relatively high.

The percentage of people with full-time paid employment in agriculture is very low; however, the percentage with vulnerable employment (including work on their own farms or as day labors) is still very high. Agriculture (including own-farm labor) employs over 85 percent of the population (Wolde-Giorgis 1997). The percentage of children under age five who are suffering from malnutrition is also high. Huge tasks lie ahead to reduce the level of vulnerability of Ethiopians or to engage them in less vulnerable sectors.

Life Expectancy and Under-Five Mortality

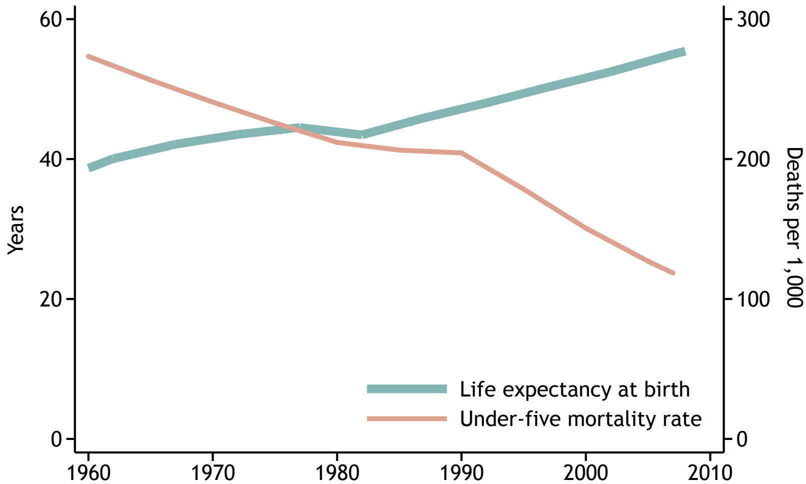
Figure 6.4 shows two noneconomic correlates of poverty: life expectancy and under-five mortality. Generally, life expectancy has been rising steadily in Ethiopia, from less than 40 years in 1960 to about 55 years in 2008. The rapid drop in under-five mortality in two time periods—the early 1960s to the late 1970s and the early 1990s to the present—is associated with a rising trend in life expectancy.

Child mortality decreased gradually from 1960 to 1980, from about 270 to 210 per 1,000 children; the level remained constant into the 1990s and declined to just over 100 children per 1,000 by 2008. The combined effect of declining child mortality and increasing life expectancy has resulted in an overall population increase, putting additional pressure on the land to meet the food requirements of the growing population.

Poverty

Figure 6.5 shows the percentage of the population living below the poverty line (on less than $2 per day). There is great regional variation: more than 90 percent of the people in Tigray, Afar, and Beneshangul earn less than $2 per

FIGURE 6.4 Well-being indicators in Ethiopia, 1960–2008



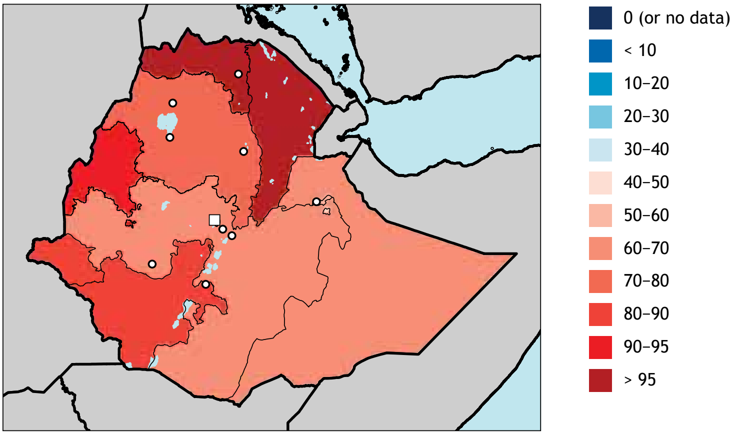
Source: *World Development Indicators* (World Bank 2009).

day, as do 60–70 percent of the people in Oromia and Somali, 70–80 percent in Amhara, and 80–90 percent in SNNP and Gambella states. More than 80 percent of Ethiopian people overall live below the poverty line and hence are vulnerable to small shocks and less able to recover from their impact.

Food Security and Malnourishment

A recent assessment indicates that today much of Ethiopia is facing serious food insecurity. In general, food consumption is lower among the poor, those with smaller agricultural plots, and those living in large families. Food security is attained when all people have physical and economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life at all times, without undue risk of losing such access (FAO 1996). Ethiopia has had a structural food deficit since 1980, and about 30 million people live in absolute poverty (Adenew 2003). Approximately 7.8 million Ethiopians received food assistance in 2009/2010 through the Productive Safety Nets Programme. Poor rural households and those without land are the most food insecure (Ethiopia, MOFED 2002b). Children are the most vulnerable and suffer during periods of food deficit following drought. Food shortage in Ethiopia is reportedly the worst among the African countries, as is child malnutrition manifested in the form of wasting and stunting (Ethiopia, MOFED 2002a). Even when some areas have surplus production,

FIGURE 6.5 Poverty in Ethiopia, circa 2005 (percentage of population below US$2 per day)



Source: Wood et al. (2010).
Note: Based on 2000 US$ (US dollars) and on purchasing power parity value.

the inadequate infrastructure and limited purchasing power of households constrain access to food, particularly in remote areas.

The standard requirement for subsistence calls for consumption of an average 2,100 kilocalories per day; the average daily per capita calorie requirement needed to maintain the health of the population in Ethiopia is approximately 2,200. Currently, 60 percent of the population consumes fewer calories than this daily physiological requirement. The average daily per capita calorie consumption in Ethiopia is about 1,980—a shortfall of about 220 calories per day, on average, compared with internationally recommended norms (Moreland and Smith 2012). Any lessening of food insecurity in a changing climate will heighten the vulnerability of the people.

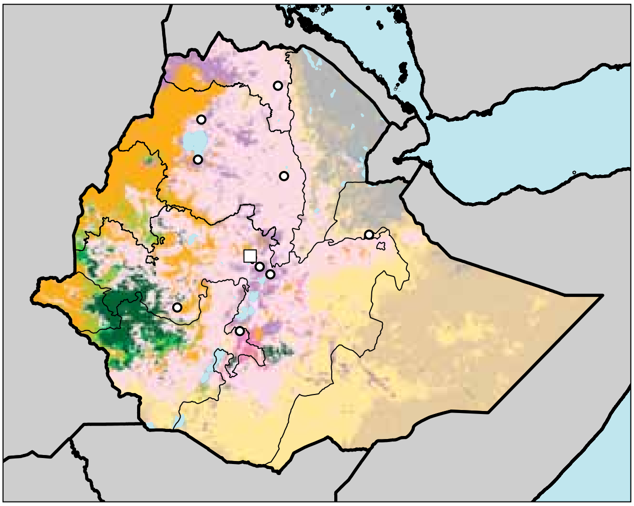
Review of Land Use, Potential, and Limitations

Land Use Overview

Ethiopian forest cover has decreased steadily over time, from 30 percent in the 1900s to about 10 percent. The annual loss of highland mountain forest cover has been estimated at about 141,000 hectares, resulting in soil erosion, environmental deterioration, and loss of biodiversity.

Figure 6.6 shows land cover and land use in the country in the year 2000. Shrub-covered closed and open areas dominated the northwestern and

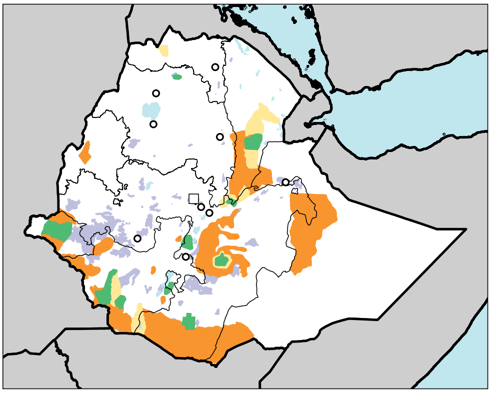
FIGURE 6.6 Land cover and land use in Ethiopia, 2000



- Tree cover, broadleaved, evergreen
- Tree cover, broadleaved, deciduous, closed
- Tree cover, broadleaved, open
- Tree cover, broadleaved, needle-leaved, evergreen
- Tree cover, broadleaved, needle-leaved, deciduous
- Tree cover, broadleaved, mixed leaf type
- Tree cover, broadleaved, regularly flooded, fresh water
- Tree cover, broadleaved, regularly flooded, saline water
- Mosaic of tree cover/other natural vegetation
- Tree cover, burnt
- Shrub cover, closed-open, evergreen
- Shrub cover, closed-open, deciduous
- Herbaceous cover, closed-open
- Sparse herbaceous or sparse shrub cover
- Regularly flooded shrub or herbaceous cover
- Cultivated and managed areas
- Mosaic of cropland/tree cover/other natural vegetation
- Mosaic of cropland/shrub/grass cover
- Bare areas
- Water bodies
- Snow and ice
- Artificial surfaces and associated areas
- No data

Source: GLC2000 (Bartholome and Belward 2005).

FIGURE 6.7 Protected areas in Ethiopia, 2009



Sources: Protected areas are from the World Database on Protected Areas (UNEP and IUCN 2009). Water bodies are from the World Wildlife Federation's Global Lakes and Wetlands Database (Lehner and Döll 2004)

parts of the western, southwestern, and east central parts of the country. Sparse herbaceous shrubs now dominate the eastern part, with the remaining dense forest limited to the southern and southwestern sections of the country. The northern, north central, and central areas and parts of the southern areas are now under crop production with little or no tree cover. The northern parts of the highlands are almost devoid of trees. Ethiopia faces a challenging future, because the various forms of land cover react differently to climate change and require unique adaptive strategies.

Figure 6.7 shows protected areas of Ethiopia. Crucial areas in the northern parts of the country are still unprotected, unlike those in the south, southwest, and east and in stretches of the Ethiopian Rift Valley. These fragile sites need to be protected.

Ethiopia has 9 national parks, 3 sanctuaries, 8 reserves, and 18 controlled hunting areas. Due to the declining area under forest, wildlife has been under pressure since the early 1970s. Of the 277 terrestrial mammals found in Ethiopia, 31 are endemic to the country, 20 of which are highland forms. There are 862 bird species recorded in Ethiopia, of which 261 (30.2 percent) are species of international concern; 16 bird species are endemic to Ethiopia, the highest number in Africa south of the Sahara. There are 214 palearctic migrant bird species in Ethiopia, of which a total of 47 are found to summer in Ethiopia (James 2012).

There are about 63 globally recognized endemic bird sites in Ethiopia, mostly in the central highlands, the southern highlands, and the Juba-Sheballe Valley. The Abijata-Shalla Lakes National Park (Southern Rift Valley) has also been proposed as a park due to the high diversity of water birds there. It is estimated that at least 6 reptiles and 34 amphibians are also endemic. Seven mammal and two bird species have been listed by the International Union for the Conservation of Nature as critically endangered. Threats to biodiversity include undervaluation of environmental resources, deforestation due to agricultural expansion and settlement, lack of adequate knowledge of biological resources, and overexploitation.

Wetlands are valuable for rural communities, because they contribute directly to food security in the dry seasons. However, wetlands are being degraded due to human-related activities such as draining for agriculture, cattle grazing, industrial pollution, and unsustainable use. Although there are several sectoral policies, a national wetlands policy is lacking.

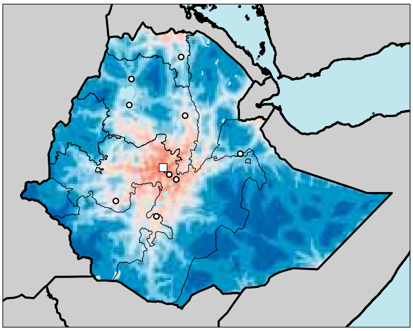
An estimated 16.4 percent of the total land area of Ethiopia is under some form of protection. Federal and regional governmental offices as well as environmental nongovernmental organizations are helping local communities reverse the current degradation trends in protected areas. Current interventions aim to promote and strengthen wildlife-based tourism, ecotourism, and nature tourism within the parks; to establish transboundary protected areas; and to develop plans and infrastructure for managing the existing protected areas.

Figure 6.8 shows travel times to cities and towns of various sizes. The upper left-hand map shows that most of the population is remote from large cities. The majority of rural people have to travel considerable distances to towns of more than 100,000 people, limiting their access to good markets. Many rural people, however, live near small towns (with populations in the range of 10,000–25,000). Some of the remote areas (WabeShebele and the Genale Plains) with fertile lands and access to irrigation lack the road infrastructure and markets that could expand their potential for agriculture. The time and transportation costs to move produce to large cities limits access to input and output markets, perpetuating the rural subsistence mode of low-input/low-output production practices. In order to reduce the vulnerability of the rural poor, expansion of road networks is crucial.

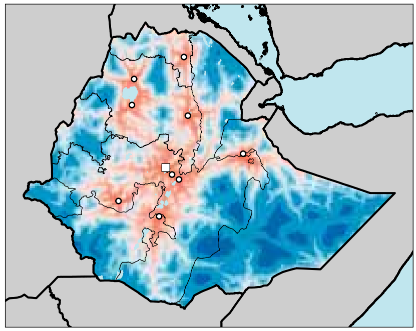
Agriculture

Agriculture remains the main activity in the Ethiopian economy and contributes, on average, 47 percent of GDP (down from 66 percent in the 1960s). Ethiopian agriculture employs over 85 percent of the population. Agriculture accounts for about 90 percent of the country's total export earnings.
About two-thirds of the total foreign exchange earnings are generated from

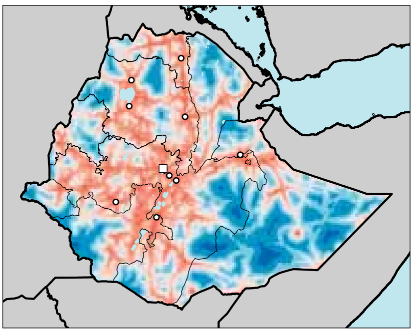
FIGURE 6.8 Travel time to urban areas of various sizes in Eritrea, circa 2000



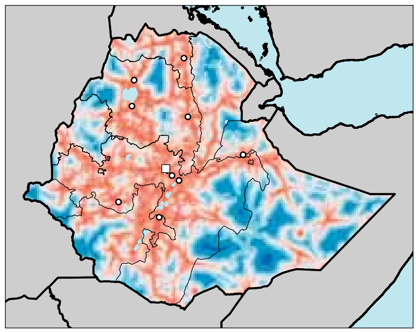
To cities of 500,000 or more people



To cities of 100,000 or more people



To towns and cities of 25,000 or more people



To towns and cities of 10,000 or more people

- Urban location
- < 1 hour
- 1–3 hours
- 3–5 hours
- 5–8 hours
- 8–11 hours
- 11–16 hours
- 16–26 hours
- > 26 hours

Source: Authors' calculations.

coffee exports (Wolde-Giorgis 1997). Smallholder households produce more than 90 percent of the agricultural output and cultivate more than 90 percent of the total cropped land. Crop production is the dominant subsector, accounting for more than 60 percent of agricultural GDP, followed by livestock with 20 percent. Widespread modes of production are subsistence mixed farming in the highlands, in which raising several crops is combined with livestock rearing, and nomadic pastoralism in the lowlands. It is estimated that 16.5 million hectares (14.8 percent) of 73.6 million hectares (66 percent) of the country's land area is potentially suitable for agricultural production. The potential irrigable land in the country is about 3.7 million hectares. Ethiopia has the largest livestock population in Africa and the tenth-largest in the world, with about 70 million head of livestock.

Tables 6.3–6.5 show key agricultural commodities in terms of area harvested, the value of the harvest, and food for human consumption (ranked by weight). Table 6.3 shows the harvest area of leading agricultural commodities in Ethiopia during 2006–2008. Teff and other cereals were produced over a larger area than other crops, reflecting teff's wider range of climatic adaptability, relatively higher prices, and easier storability, in addition to cultural food preferences. Maize also performs well in a wider range of agroecological settings. Wheat and maize were the commodities of highest monetary value (see Table 6.4). Although teff was the most important crop, it ranks only fourth in consumption (see Table 6.5) because most rural households sell teff for cash and consume more maize and wheat.

Figure 6.9 shows the estimated yield and growing areas for rainfed maize in 2000. Maize was produced over large areas of the country. However, yields were low, averaging around 2.2 tons per hectare but extending to close to

TABLE 6.3 Harvest area of leading agricultural commodities in Ethiopia, 2006–2008 (thousands of hectares)

Rank	Crop	Percent of total	Harvest area
	Total	100.0	13,035
1	Teff and other cereals	19.5	2,548
2	Maize	12.8	1,663
3	Sorghum	11.4	1,489
4	Wheat	11.1	1,453
5	Barley	7.7	1,001
6	Other roots and tubers	4.8	620
7	Broad beans and horse beans	3.6	469
8	Millet	3.0	388
9	Coffee	2.8	371
10	Chilies and peppers	2.3	293

Source: FAOSTAT (FAO 2010).
Note: All values are based on the three-year average for 2006–2008.

TABLE 6.4 Value of production of leading agricultural commodities in Ethiopia, 2005–2007 (millions of US$)

Rank	Crop	Percent of total	Value of production
	Total	100.0	4,548.0
1	Wheat	12.2	555.9
2	Maize	12.0	545.3
3	Teff and other cereals	11.7	532.1
4	Coffee	9.1	412.8
5	Sorghum	9.1	411.8
6	Other roots and tubers	8.8	400.3
7	Barley	6.2	280.2
8	Broad beans and horse beans	3.0	135.7
9	Sugarcane	2.8	129.3
10	Chilis and peppers	2.0	92.6

Source: FAOSTAT (FAO 2010).
Notes: All values are based on the three-year average for 2005–2007. US$ = US dollars.

TABLE 6.5 Consumption of leading food commodities in Ethiopia, 2003–2005 (thousands of metric tons)

Rank	Crop	Percent of total	Food consumption
	Total	100.0	20,228
1	Other roots and tubers	20.0	4,047
2	Maize	13.7	2,778
3	Wheat	12.4	2,515
4	Teff and other cereals	9.0	1,825
5	Sorghum	8.4	1,692
6	Barley	5.2	1,046
7	Other vegetables	3.5	718
8	Other pulses	3.5	699
9	Other fruits	3.2	647
10	Beer	2.6	521

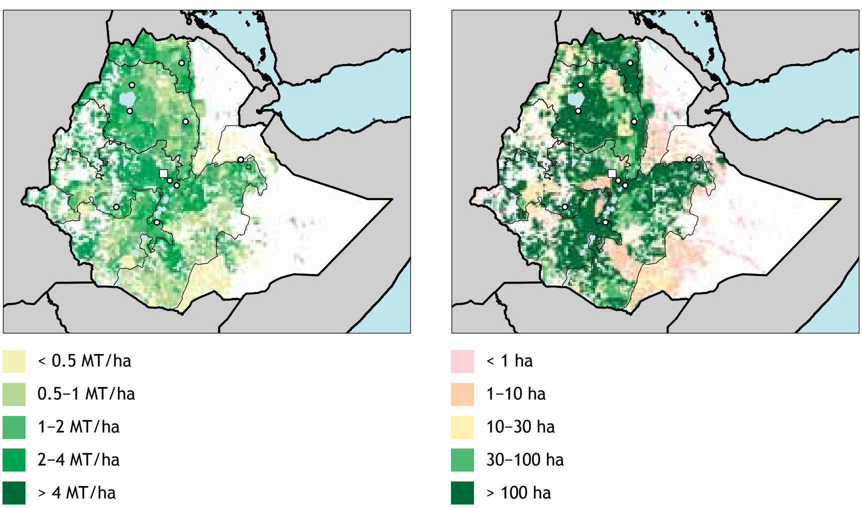
Source: FAOSTAT (FAO 2010).
Note: All values are based on the three-year average for 2003–2005.

4 tons per hectare in the higher-rainfall areas. The degraded and drier areas of the country produce less than 0.5 tons per hectare. In spite of the considerable potential, yields are low partly due to low levels of erratic rainfall, degraded soil of poor fertility, poor access to inputs, and high input prices resulting from high transport costs.

Figure 6.10 shows the wheat yield and harvest area in Ethiopia. Wheat is produced over a large area; however, its yield is quite low, ranging between 1 and 2 tons per hectare, with slightly higher yields in parts of the higher-rainfall areas in north, northwest, southwest, and central areas of the country. Most areas in the north, south-central, and eastern parts, however, produce 1–2 tons per hectare. The degraded and drier areas produce less than a half-ton per hectare.

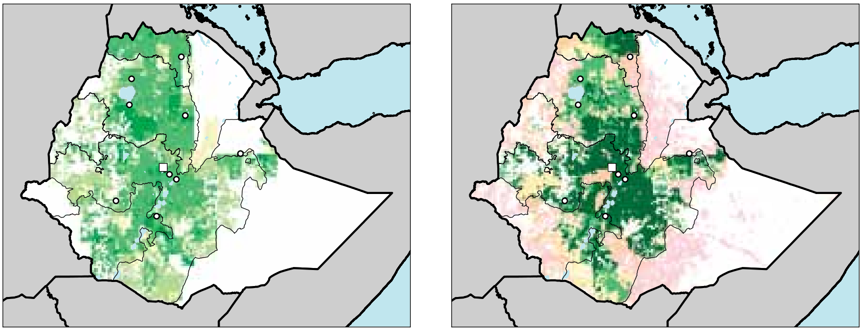
Figure 6.11 shows the results for rainfed sorghum. Sorghum is produced over large areas, but its yields are very low, ranging between 0.5 and 2 tons per hectare in most areas in the northern, south-central, western, and eastern parts of the country. More than 67 percent of the arable land is in drought-prone areas, and sorghum appears to be the crop best adapted to the adverse effects of climate. Removal of these drought-related problems as well as poor soil fertility, weeds, and disease is therefore crucial to ensure better yields and thereby food availability and income security for vulnerable zones of the country.

FIGURE 6.9 Yield (metric tons per hectare) and harvest area density (hectares) for rainfed maize in Ethiopia, 2000



Source: SPAM (Spatial Production Allocation Model) (You and Wood 2006; You, Wood, and Wood-Sichra 2006, 2009).
Note: ha = hectare; MT/ha = metric tons per hectare.

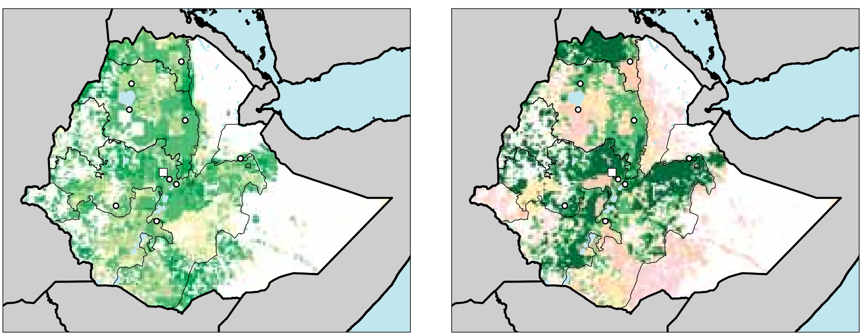
FIGURE 6.10 Yield (metric tons per hectare) and harvest area density (hectares) for rainfed wheat in Ethiopia, 2000



< 0.5 MT/ha	< 1 ha
0.5–1 MT/ha	1–10 ha
1–2 MT/ha	10–30 ha
2–4 MT/ha	30–100 ha
> 4 MT/ha	> 100 ha

Source: SPAM (Spatial Production Allocation Model) (You and Wood 2006; You, Wood, and Wood-Sichra 2006, 2009).
Note: ha = hectare; MT/ha = metric tons per hectare.

FIGURE 6.11 Yield (metric tons per hectare) and harvest area density (hectares) for rainfed sorghum in Ethiopia, 2000



Yield	Harvest area density
< 0.5 MT/ha	< 1 ha
0.5–1 MT/ha	1–10 ha
1–2 MT/ha	10–30 ha
2–4 MT/ha	30–100 ha
> 4 MT/ha	> 100 ha

Source: SPAM (Spatial Production Allocation Model) (You and Wood 2006; You, Wood, and Wood-Sichra 2006, 2009).
Note: ha = hectare; MT/ha = metric tons per hectare.

Scenarios for the Future

Economic and Demographic Indicators

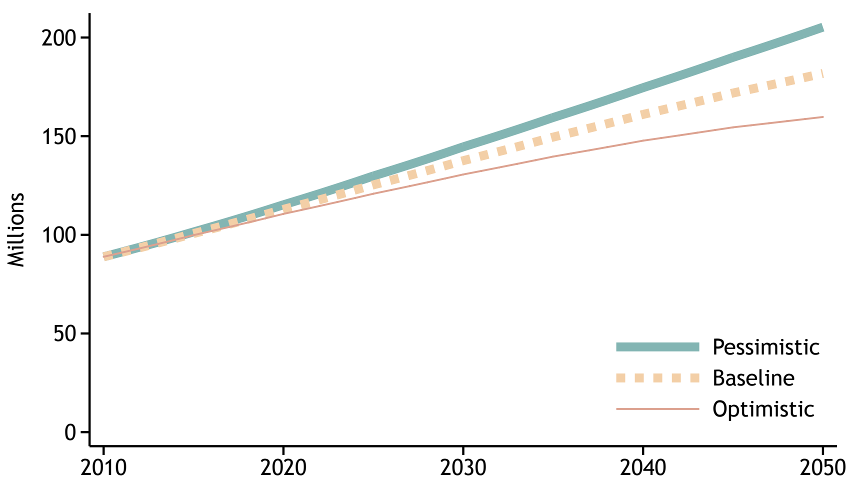
Population

Figure 6.12 shows population projections by the UN Population Division (UNPOP 2009) through 2050. The Ethiopian population may double by 2050. The population is expected to reach 180 million in the baseline scenario and 205 million in the pessimistic scenario. All the projections show a more or less linear increase in population. Population growth in Ethiopia since the past century has been at the expense of degradation of the natural resource base. Measures to address the rapid pace of population growth and to boost GDP are required to reduce economic vulnerability and increase the adaptive capacity of the people.

Income

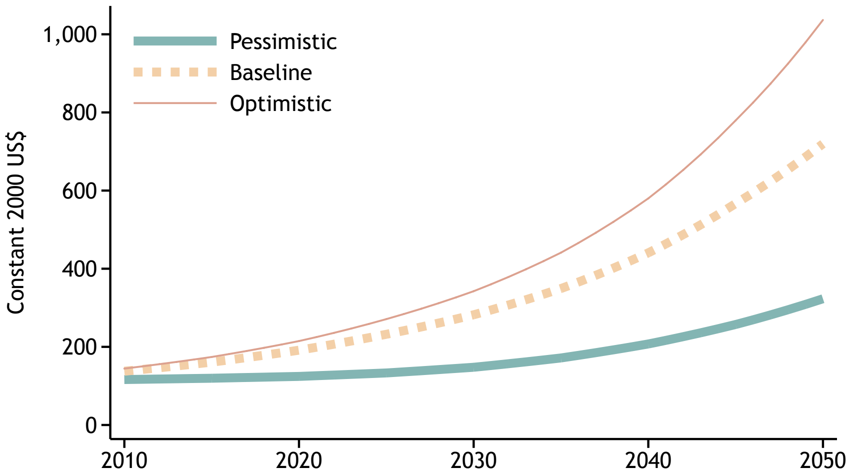
Figure 6.13 shows three scenarios for GDP per capita developed by combining three GDP projections with the three population projections of Figure 6.12. The optimistic scenario combines high GDP with low population, the baseline scenario combines the medium GDP projection with the medium

FIGURE 6.12 Population projections for Ethiopia, 2010–2050



Source: UNPOP (2009).

FIGURE 6.13 Gross domestic product (GDP) per capita in Ethiopia, future scenarios, 2010–2050



Sources: Computed from GDP data from the World Bank Economic Adaptation to Climate Change project (World Bank 2010), from the Millennium Ecosystem Assessment (2005) reports, and from population data from the United Nations (UNPOP 2009).

population scenario, and the pessimistic scenario combines the low GDP projection with the high population scenario.

Over the past decade, Ethiopia's economic growth has been fluctuating. The modeled results show a low expectation of GDP per capita under each of the three scenarios. The optimistic scenario, assuming the highest rate of GDP growth coupled with the lowest rate of population growth, shows GDP per capita exceeding $1,000 by 2050. The baseline scenario shows GDP per capita at about $700. The pessimistic scenario, assuming the lowest GDP and the highest rate of population growth, shows stunted growth through 2050 but nevertheless an almost doubling of per capita income from 2010. Such stunted growth would represent a vicious circle in which higher vulnerability would imply low adaptive capacity, hampering the growth of the agricultural sector.

Biophysical Analysis

Climate Models

Figure 6.14 shows projected precipitation changes in Ethiopia for 2000–2050 under the four downscaled climate models we use in this book with the A1B scenario.[1] CSIRO Mark 3 shows a decrease in annual precipitation in most highland areas of the country, while all the other models show normal to above-normal rainfall (though CNRM-CM3 shows decreased rainfall in the extreme western area).[2] Indeed, MIROC 3.2 shows a dramatic increase in precipitation over much of Ethiopia. In general, the maps show normal to above-normal levels for almost the entire country.

Figure 6.15 shows projected changes in average daily maximum temperature for the warmest month by 2050. All four GCMs agree that temperatures will rise, but they differ in how much. Two models, CNRM-CM3 and ECHAM 5, show a substantial increase in mean temperature, up to 2.5°C. CNRM-CM3 shows an increase in temperature over most of the west and the north—parts of the country projected to receive low to normal precipitation, indicating that water stresses are likely to increase. ECHAM 5 shows the greatest increase in the northeastern, northwestern, and central portions of the country. MIROC 3.2 and CSIRO Mark 3 show temperature increases for some parts of the country in the range of 1.5°–2°C, but both show that much of the temperature change will be lower, in the 1°–1.5°C range. Increases in temperature are likely to increase rates of evapotranspiration, likely leading to a deficit in the water balance and posing a major challenge to rainfed agriculture.

Extreme events such as droughts, floods, waterlogging, and erosion hazards may further degrade agricultural lands, reducing the quality of arable areas. Policymakers need to consider a mix of possible adaptation strategies to reduce the vulnerability of the agricultural sector and allow it to adapt to the challenges, including contingency plans designed to capitalize on any opportunities that may arise.

Crop Models

We used the Decision Support Software for Agrotechnology Transfer (DSSAT) software to compute crop yields under current temperature and precipitation regimes, and we repeated the simulation exercise for each of the future scenarios for the year 2050. The output for key crops is mapped in Figures 6.16–6.18, comparing crop yields for 2050 under climate change with the projected yields under an unchanged (2000) climate.

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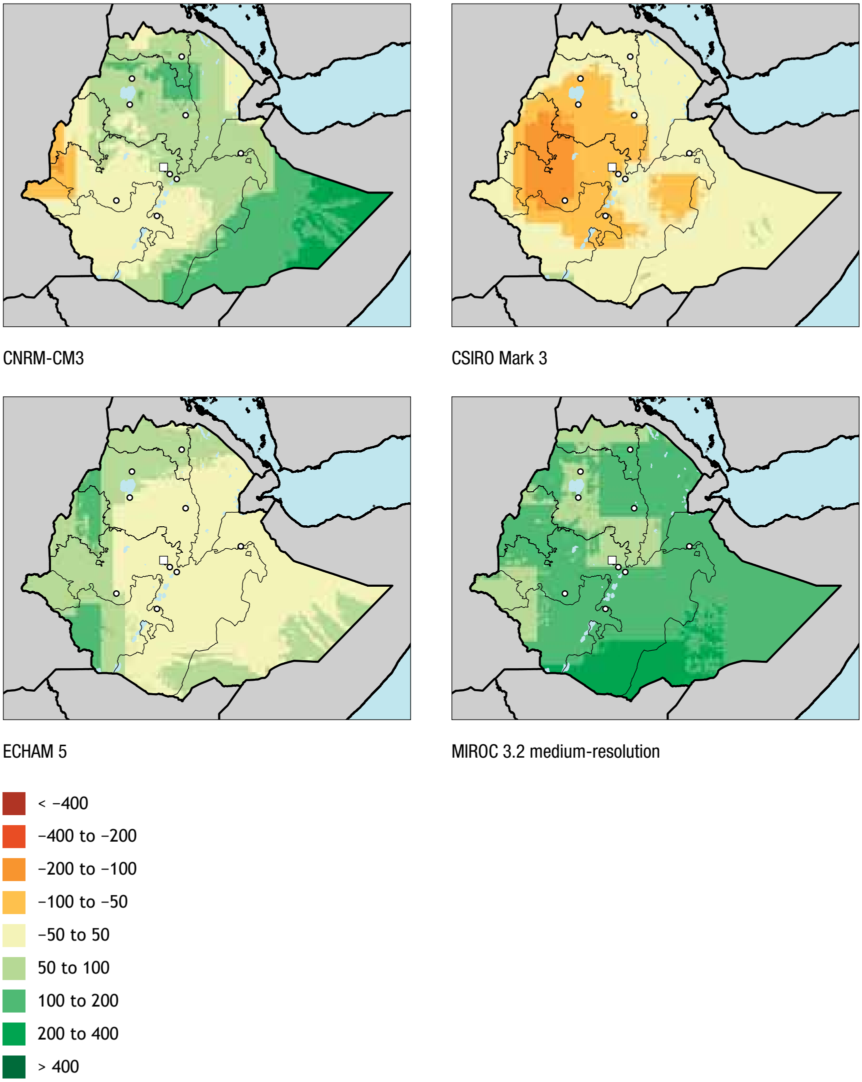
1 The A1B scenario is a greenhouse gas emissions scenario that assumes fast economic growth, a population that peaks midcentury, and the development of new and efficient technologies, along with a balanced use of energy sources.

2 CNRM-CM3 is National Meteorological Research Center–Climate Model 3. MIROC 3.2 is the Model for Interdisciplinary Research on Climate, developed at the University of Tokyo Center for Climate System Research. CSIRO Mark 3 is a climate model developed at the Australia Commonwealth Scientific and Industrial Research Organisation. ECHAM 5 is a fifth-generation climate model developed at the Max Planck Institute for Meteorology in Hamburg.

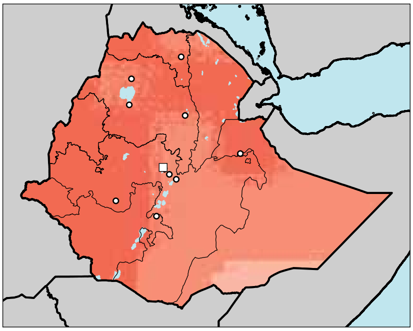
FIGURE 6.14 Changes in mean annual precipitation in Ethiopia, 2000–2050, A1B scenario (millimeters)



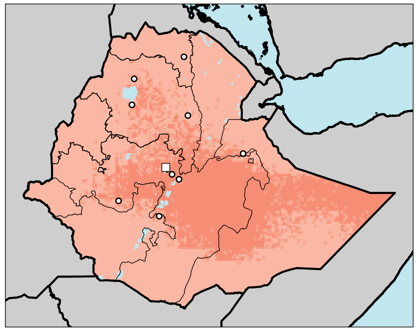
Source: Authors' calculations based on Jones, Thornton, and Heinke (2009).

Notes: A1B = greenhouse gas emissions scenario that assumes fast economic growth, a population that peaks midcentury, and the development of new and efficient technologies, along with a balanced use of energy sources; CNRM-CM3 = National Meteorological Research Center–Climate Model 3; CSIRO = climate model developed at the Australia Commonwealth Scientific and Industrial Research Organisation; ECHAM 5 = fifth-generation climate model developed at the Max Planck Institute for Meteorology (Hamburg); GCM = general circulation model; MIROC = Model for Interdisciplinary Research on Climate, developed by the University of Tokyo Center for Climate System Research.

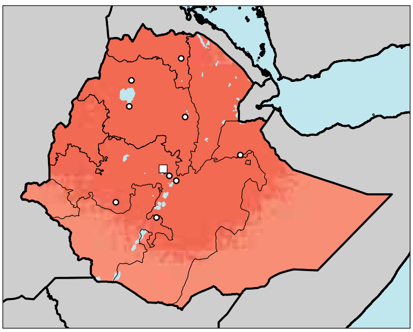
FIGURE 6.15 Change in monthly mean maximum daily temperature in Ethiopia for the warmest month, 2000–2050, A1B scenario (°C)



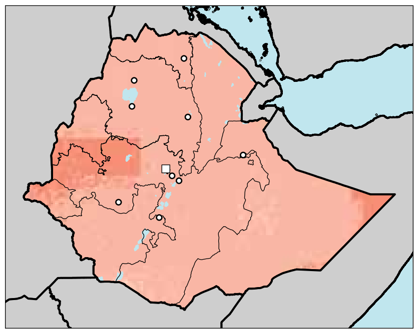
CNRM-CM3



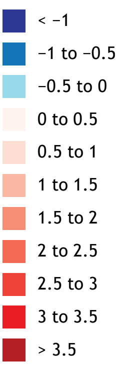
CSIRO Mark 3



ECHAM 5



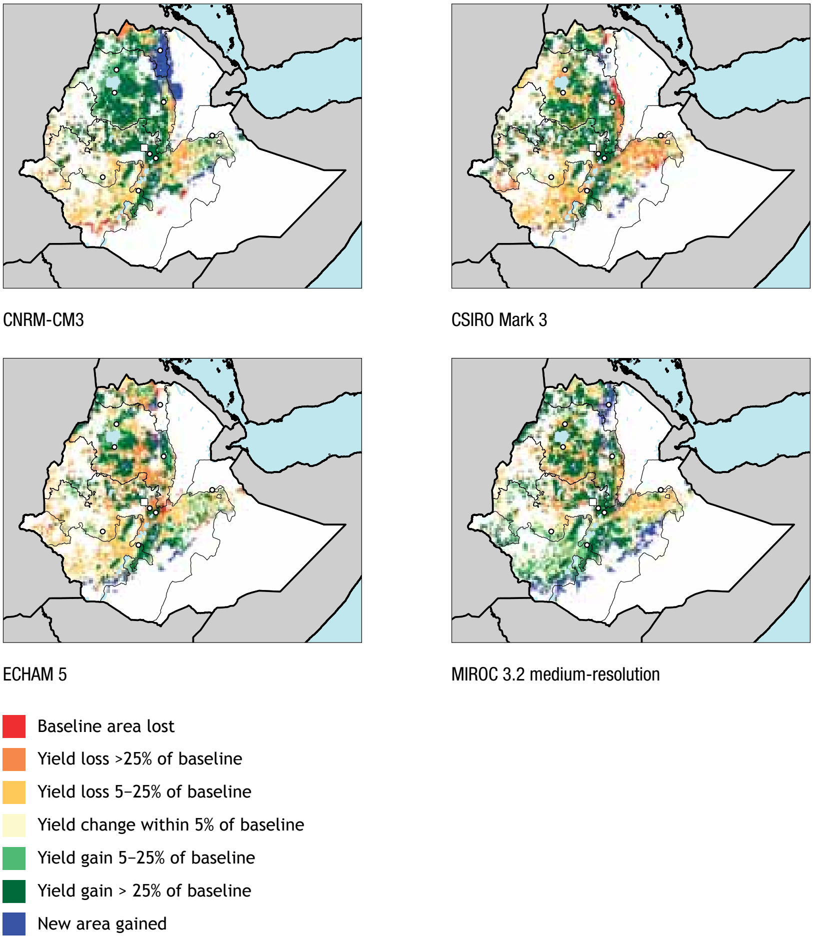
MIROC 3.2 medium-resolution



Source: Authors' calculations based on Jones, Thornton, and Heinke (2009).

Notes: A1B = greenhouse gas emissions scenario that assumes fast economic growth, a population that peaks midcentury, and the development of new and efficient technologies, along with a balanced use of energy sources; CNRM-CM3 = National Meteorological Research Center–Climate Model 3; CSIRO = climate model developed at the Australia Commonwealth Scientific and Industrial Research Organisation; ECHAM 5 = fifth-generation climate model developed at the Max Planck Institute for Meteorology (Hamburg); GCM = general circulation model; MIROC = Model for Interdisciplinary Research on Climate, developed by the University of Tokyo Center for Climate System Research.

FIGURE 6.16 Yield change under climate change: Rainfed maize in Ethiopia, 2000–2050, A1B scenario



Source: Authors' calculations.

Notes: A1B = greenhouse gas emissions scenario that assumes fast economic growth, a population that peaks midcentury, and the development of new and efficient technologies, along with a balanced use of energy sources; CNRM-CM3 = National Meteorological Research Center–Climate Model 3; CSIRO = climate model developed at the Australia Commonwealth Scientific and Industrial Research Organisation; ECHAM 5 = fifth-generation climate model developed at the Max Planck Institute for Meteorology (Hamburg); GCM = general circulation model; MIROC = Model for Interdisciplinary Research on Climate, developed by the University of Tokyo Center for Climate System Research.

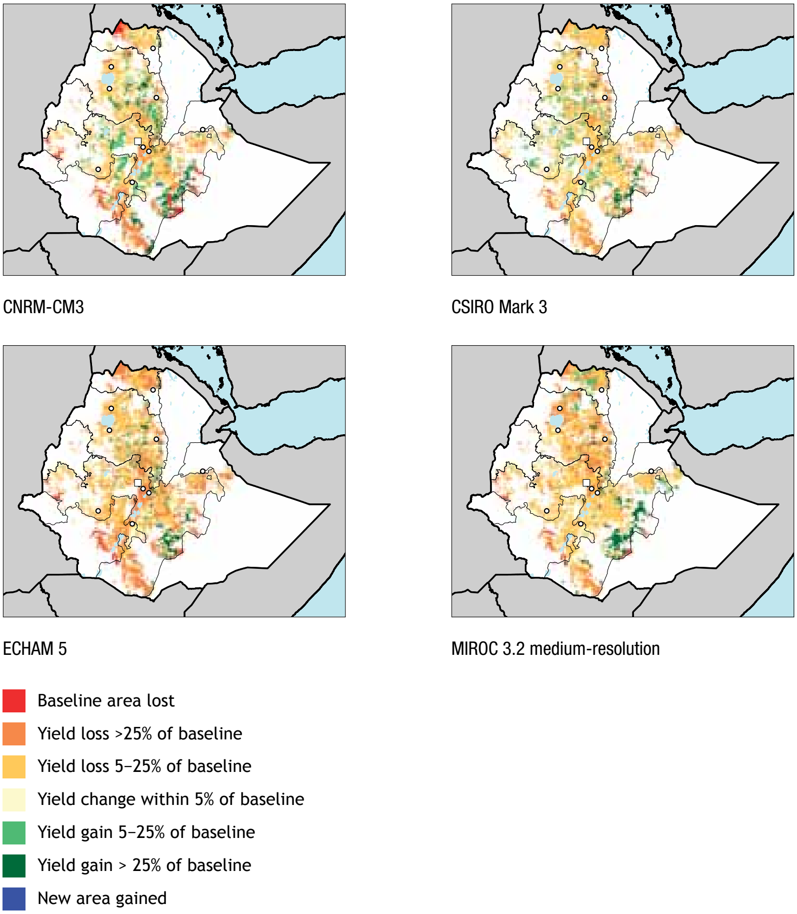
Figure 6.16 shows the modeled results for rainfed maize in Ethiopia. All models suggest that there will be a gain in maize yields of more than 25 percent in the eastern highlands at the edge of Great Rift Valley as well as in the north central highlands; to varying degrees they also show some patches of new area gained in the eastern parts of Amhara and Tigray. Three of the four models, however, show an equal amount of existing maize land marginalized or no longer suitable for maize, as well as a marked decrease in the maize yield over the southwestern and eastern parts of central Ethiopia. Both CNRM-CM3 and MIROC 3.2 suggest a considerable gain in maize production area, mainly in eastern Tigray. In contrast, CNRM-CM3 indicates that a strip along the southern periphery of Oromia may lose maize areas completely.

Maize is one of the most important foodcrops for the majority of the rural people in Ethiopia, and its potential vulnerability (indicated by the models) may cause a substantial food deficit. Hence, alternative strategies are needed for adapting maize to potential changes and to ensure the production of sufficient food. However, we can also clearly see that there may be significant gains as a result of climate change. It will be important to monitor areas that in the past have been poor for maize production but might become quite suitable in the future. If farmers are already located in those places, they can take advantage of the changes. If farmers are not present, and particularly if the area is under forest, policymakers have a much more difficult task of deciding whether they are willing to trade forest for agricultural production. It is not all a zero-sum game: policymakers could decide to help return to forest those areas lost to crop production.

Figure 6.17 shows the results of the crop simulation model for rainfed wheat. It suggests substantial reduction in wheat yields and some loss of area, even where rainfall is expected to increase—presumably due to heat stress. Wheat ranks as the most important crop in Ethiopia in terms of monetary value (see Table 6.4), as well as the third most important foodcrop by amount of consumption (see Table 6.5). It is especially disturbing, then, that all four models show future loss of wheat yield: all zones may lose the opportunity for spring wheat production, to levels far below the baseline; some wheat areas may still be available, but they would be very fragile and not so favorable. Also, there may still be possibilities for continued production of wheat in other areas, because Ethiopia offers a wide range of diverse agroecologies.

Figure 6.18 shows an increase in yield and an expansion in area in major sorghum-growing areas. All four models show a decreasing trend in the yield of rainfed sorghum over a very large area in the western and northwestern parts of the country but more than a 25 percent increase in central Ethiopia and isolated chains toward the north, including substantial crop area gained. However, the newly emerging production areas are all in fragile agroenvironments; tremendous work would be required to rehabilitate the degraded areas. Note that CNRM-CM3 and MIROC 3.2 give contrasting results for the southern

FIGURE 6.17 Yield change under climate change: Rainfed wheat in Ethiopia, 2000–2050, A1B scenario

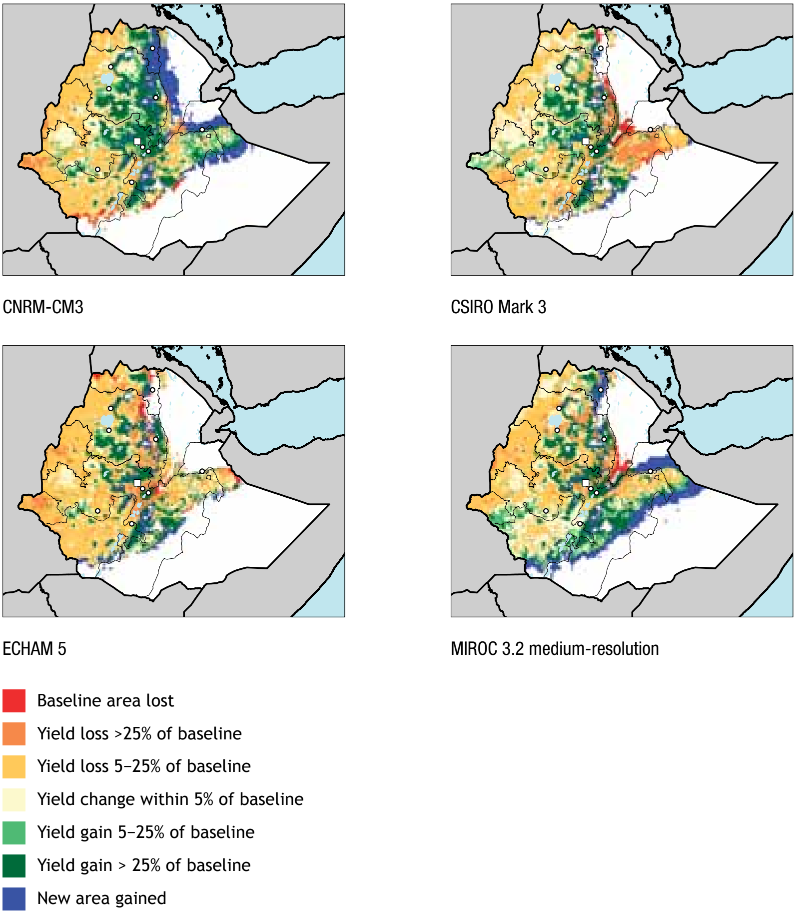


Source: Authors' calculations.

Notes: A1B = greenhouse gas emissions scenario that assumes fast economic growth, a population that peaks midcentury, and the development of new and efficient technologies, along with a balanced use of energy sources; CNRM-CM3 = National Meteorological Research Center–Climate Model 3; CSIRO = climate model developed at the Australia Commonwealth Scientific and Industrial Research Organisation; ECHAM 5 = fifth-generation climate model developed at the Max Planck Institute for Meteorology (Hamburg); GCM = general circulation model; MIROC = Model for Interdisciplinary Research on Climate, developed by the University of Tokyo Center for Climate System Research.

and southeastern regions: the former shows a loss of baseline sorghum production area, while the latter shows new opportunities for sorghum over the same area. The four models all show sorghum production declining by 5–25 percent in the western parts of Tigray, Amhara, Oromia, and SNNP, as well as the whole of Benishangul-Gumuz and Gambella states. In addition, two of the models show

FIGURE 6.18 Yield change under climate change: Rainfed sorghum in Ethiopia, 2000–2050, A1B scenario



Source: Authors' calculations.

Notes: A1B = greenhouse gas emissions scenario that assumes fast economic growth, a population that peaks midcentury, and the development of new and efficient technologies, along with a balanced use of energy sources; CNRM-CM3 = National Meteorological Research Center–Climate Model 3; CSIRO = climate model developed at the Australia Commonwealth Scientific and Industrial Research Organisation; ECHAM 5 = fifth-generation climate model developed at the Max Planck Institute for Meteorology (Hamburg); GCM = general circulation model; MIROC = Model for Interdisciplinary Research on Climate, developed by the University of Tokyo Center for Climate System Research.

yield declines exceeding 25 percent over large areas of Gambella, and CSIRO Mark 3 shows a considerable decline in most parts of northeastern Oromia.

The analytical results suggest significant impacts of climate change on the production and yields of major crops in terms of both altered production areas and total production. The new areas gained may be less favorable, moreover.

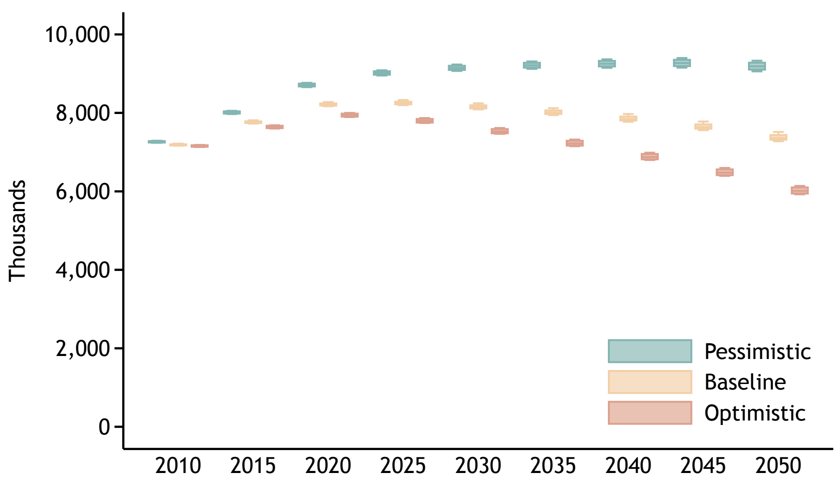
Increasing temperature, even when accompanied by an increase in annual rainfall, may create a higher risk of water deficits due to greater loss through evaporation, though the results in these three figures already reflect the impact of any potential water deficit.

It is unfortunate that DSSAT is not able to model coffee, because coffee is of particular importance to agricultural export earnings in Ethiopia. The effect of climate change on coffee in Ethiopia is ultimately unclear. Higher temperatures would likely adversely effect the yield of coffee in its current locations, yet by 2050, coffee could easily be planted in slightly different locations with cooler temperatures. In the short run, coffee may be adversely affected not only by higher temperatures but also by the coffee berry borer, which likes warmer temperatures. In the longer run, we would expect coffee to be relocated and yields to rise close to where they were prior to climate change.

Vulnerability

Figure 6.19 shows the impact of future GDP and population scenarios on the number of malnourished children under age five in Ethiopia. Figure 6.20 shows the share of children who are malnourished. The number of malnourished children decreases in the optimistic scenario, reflecting a lower

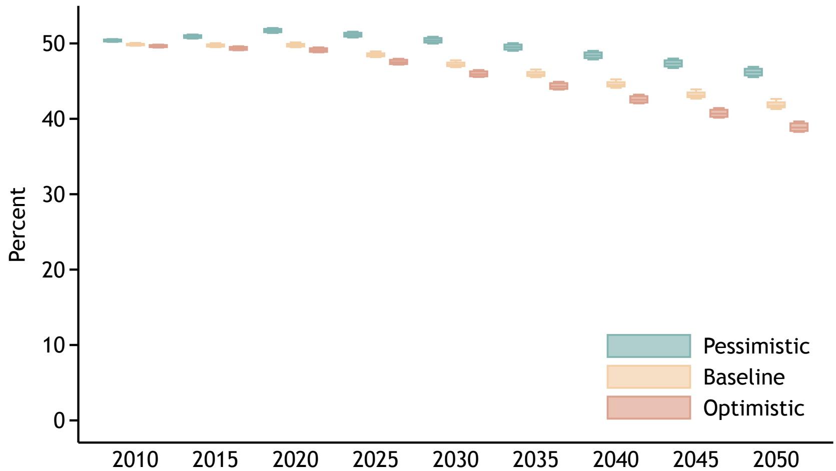
FIGURE 6.19 Number of malnourished children under five years of age in Ethiopia in multiple income and climate scenarios, 2010–2050



Source: Based on analysis conducted for Nelson et al. (2010).

Note: The box and whiskers plot for each socioeconomic scenario shows the range of effects from the four future climate scenarios.

FIGURE 6.20 Share of malnourished children under five years of age in Ethiopia in multiple income and climate scenarios, 2010–2050



Source: Based on analysis conducted for Nelson et al. (2010).

Note: The box and whiskers plot for each socioeconomic scenario shows the range of effects from the four future climate scenarios.

rate of population growth and improvement in GDP; the baseline scenario shows a more or less constant number of malnourished children. Even though the number of malnourished children increases in the pessimistic scenario between 2010 and 2050, the share declines due to population growth.

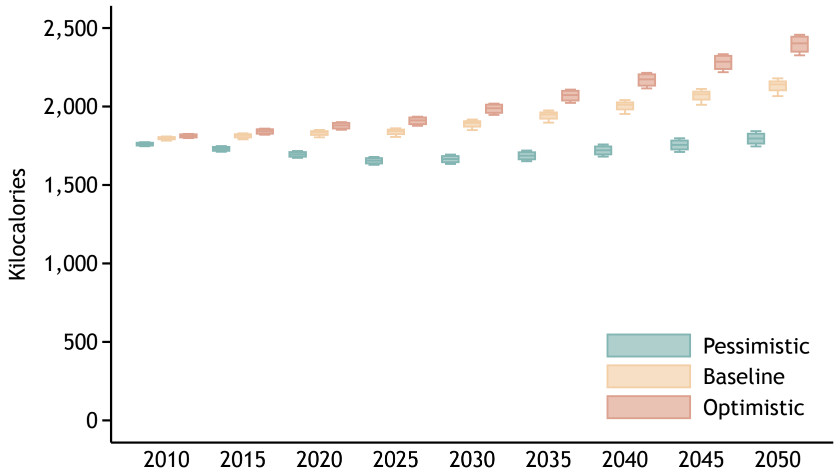
Figure 6.21 shows projections of available kilocalories per capita under multiple income and climate scenarios. Clear increases are shown in the optimistic scenario and modest increases in the baseline scenarios but no increase in the pessimistic scenario. The optimistic scenario would achieve the minimal per capita requirement (2,100 kilocalories per day) after 2040, but it will not be possible to attain this target if the pessimistic scenario proves correct.

Agricultural Outcomes

Figure 6.22–6.24 show simulation results from the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) associated with key agricultural crops in Ethiopia. Each featured crop has five graphs showing production, yield, area, net exports, and world price trends for 2010–2050.

The simulation results presented in Figure 6.22 show the maize yield rising somewhat by 2020 and then leveling off. At the same time, the cultivated

FIGURE 6.21 Kilocalories per capita in Ethiopia in multiple income and climate scenarios, 2010–2050



Source: Based on analysis conducted for Nelson et al. (2010).

Note: The box and whiskers plot for each socioeconomic scenario shows the range of effects from the four future climate scenarios.

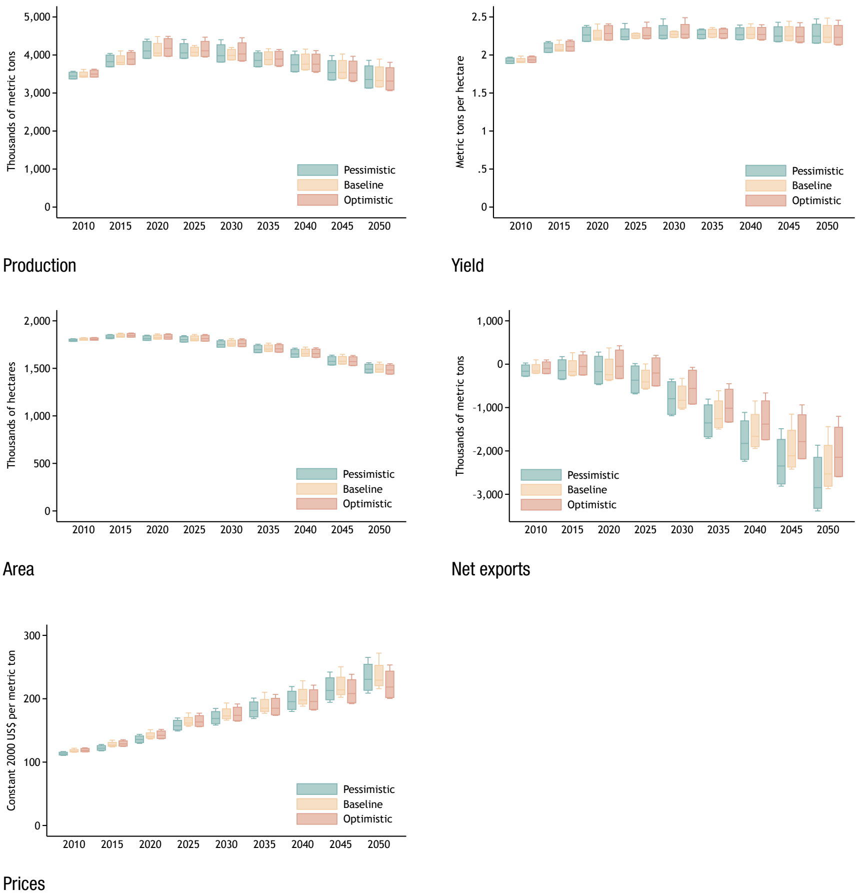
area of maize declines slightly after 2020. Together these lead production to rise by around 25 percent by 2020, then fall slightly thereafter, with levels in 2050 about the same as those in 2010. Note that some loss of maize area is indicated in the maps projected from DSSAT (see Figure 6.16), but there is some potential gain in maize area in other parts of the country.

The imports of maize into Ethiopia are projected to increase after 2020, despite the attractive world price suggested for maize. The box-and-whisker plots suggest that the interquartile range increases into the future, reflecting divergence of the yields from the climate models. This makes planning for the future more complex and challenging.

For wheat, Figure 6.23 shows that the yield is projected to more than double by 2050. With a slight increase in area, production by 2050 increases to around 2.5 times the 2010 level. Because the range for the production prediction is relatively small, the divergence of the net exports must reflect divergence in consumer demand for wheat. One scenario has Ethiopia as a net exporter, another as most likely a net importer, and the third is undecided as to which way Ethiopia will go.

There appears to be an increasing trend in the export of wheat in the pessimistic scenario. This is attributed to the low GDP in this scenario, which is

FIGURE 6.22 Impact of changes in GDP and population on maize in Ethiopia, 2010–2050



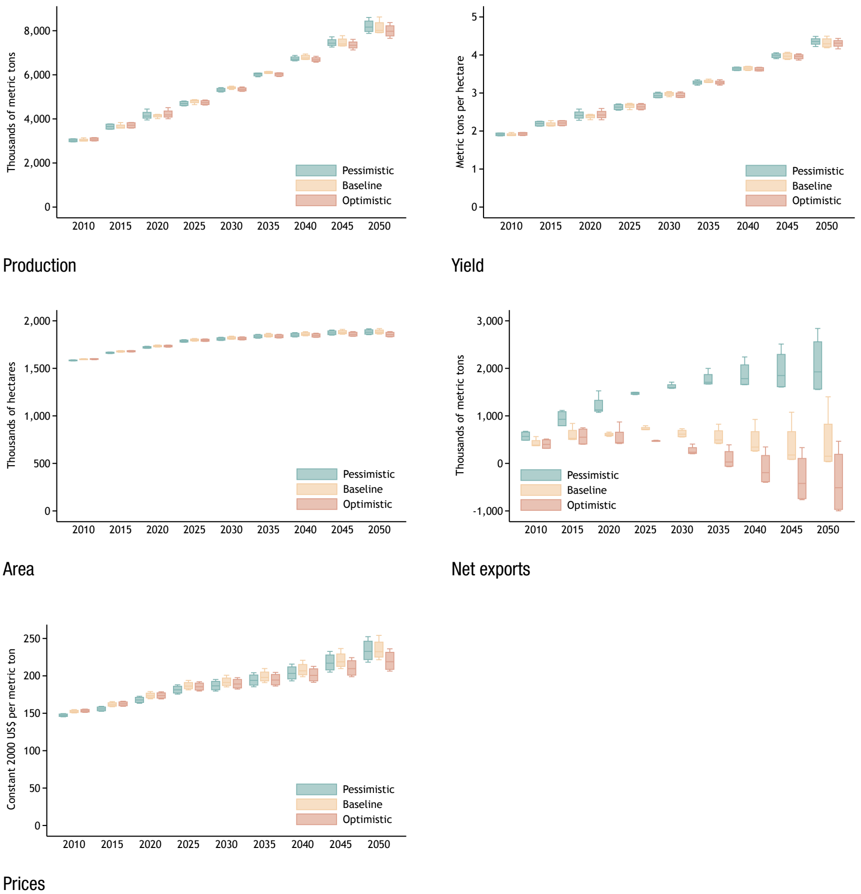
Source: Based on analysis conducted for Nelson et al. (2010).

Notes: The box and whiskers plot for each socioeconomic scenario shows the range of effects from the four future climate scenarios. GDP = gross domestic product; US$ = US dollars.

expected to make it more attractive to export wheat than to consume it. It is also likely that the consumption of maize-based food products will increase and that wheat will be sold. However, in the optimistic scenario, because the GDP is high and the population growth rate is low, consumers may be able to afford to purchase wheat for food, and the county may reduce its wheat exports toward 2050.

The productivity of all crops shows an increasing trend, probably attributed to an assumption of technological progress.

FIGURE 6.23 Impact of changes in GDP and population on wheat in Ethiopia, 2010–2050

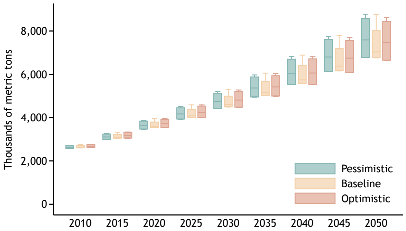


Source: Based on analysis conducted for Nelson et al. (2010).

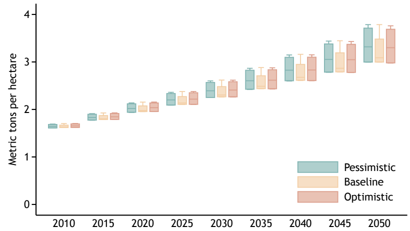
Notes: The box and whiskers plot for each socioeconomic scenario shows the range of effects from the four future climate scenarios. GDP = gross domestic product; US$ = US dollars.

Sorghum shows an increasing trend in production, yield, area, net exports, and world prices (Figure 6.24). This is somewhat in agreement with the result presented in Figure 6.11, showing an increase in yield and an expansion in area in major sorghum-growing areas. Sorghum is usually grown in drier areas to which most other high-value cereals and other crops are not adapted. This signals some advantage in sorghum production from expansion into the drier areas of Ethiopia, indicating that there is tremendous work ahead in balancing environmental management and food production needs.

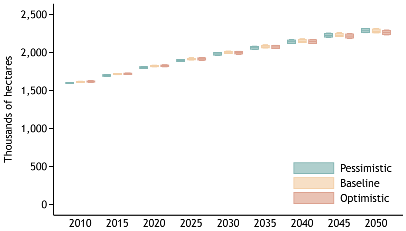
FIGURE 6.24 Impact of changes in GDP and population on sorghum in Ethiopia, 2010–2050



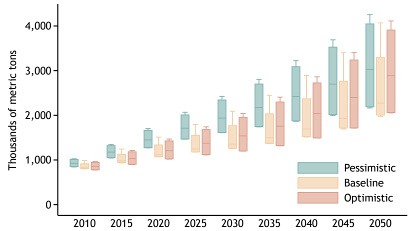
Production



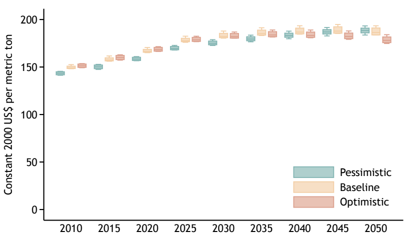
Yield



Area



Net exports



Prices

Source: Based on analysis conducted for Nelson et al. (2010).

Notes: The box and whiskers plot for each socioeconomic scenario shows the range of effects from the four future climate scenarios. GDP = gross domestic product; US$ = US dollars.

Conclusions and Policy Recommendations

Projections show Ethiopia's population increasing to as many as 205 million by 2050—more than 2.5 times the present level. Given that over 80 percent of the current population is living below the poverty line, serious problems must be expected from increased demand for food, water, and other basic needs under climate change. But the baseline and optimistic scenarios paint a brighter future for the country, in terms of both smaller population projections and larger GDP per capita projections.

Climate change affects biodiversity as well. Ethiopia, home to a rich and diverse flora and fauna, has already been critically affected by the loss of plant biodiversity. The potential loss of endemic bird species recorded in Ethiopia is of international concern. Protected areas play a role in mitigating climate change by providing buffers against extreme climate events as well as a network of natural habitats to provide pathways for rapid migration and space for evolution and adaptation. Protected areas are likely to be affected by climate change, potentially losing species and even ecosystems.

An essential priority must be conserving natural terrestrial and aquatic ecosystems (both freshwater and saline water bodies), along with restoring degraded ecosystems. These ecosystems play key roles in the global carbon cycle and in adapting to climate change while serving a wide range of functions essential for human well-being.

From the crop model projections it can be inferred that climate change might adversely affect production and cause certain growing areas to be no longer viable. On the positive side, there are areas of projected increases in yield and new areas that could be brought under cultivation in a warmer and sometimes wetter climate. The crop models show that wheat will be one of the hardest-hit crops, with significant losses and very few gains. The variation in outcomes of various models suggests the complexity of the problem of projecting future impacts on agriculture. There is an urgent need to develop alternative adaptation options that will fit into the various plausible scenarios and to design location-specific adaption programs to reach all vulnerable populations.

Many developmental institutions are currently trying to promote technologies for adaptation but in an uncoordinated manner. More collaboration among partners and harmonization of approaches will be required for effective scaling up of proven strategies in order to effectively address smallholders' technological adaptation needs. It is also necessary to adopt cross-sectoral programs that have strong ownership by stakeholders to effectively address climate change adaptation at different levels. There are some efforts underway to climate-proof development efforts and to institutionalize climate change adaptation into research for development as well as into poverty reduction and food security improvement efforts. Nevertheless, implementation of these policies and plans remains to be done.

To meet the challenges of climate change in Ethiopia, we recommend the following:

- Harmonize policies and institutional frameworks affecting climate change adaptation across different approaches and strategies.
- Develop alternative adaptation options for the various plausible scenarios and design multiple adaption programs for the diverse climates of Ethiopia so that all vulnerable populations can be reached.
- Provide rural financing to promote the adoption and use of proven technologies for climate-change adaptation.
- Encourage risk-insuring institutions to insure rainfall risks, especially for smallholder farmers as they adopt improved agricultural production technologies to benefit from potentially increased rainfall.
- Improve the road infrastructure in remote areas to increase farmers' opportunities and access to markets and market information.
- Manage rainwater to prevent potential flooding, waterlogging, erosion, and nutrient leaching under increased rainfall.
- Make reliable climate forecasts available to smallholders to reduce climate-induced risks.
- Integrate efficient agricultural water management practices with productivity-enhancing interventions.
- Integrate indigenous strategies and complex local technical knowledge with science-based knowledge to support adaptation to climate change.
- Promote new crop varieties adapted to drought, such as nutritionally enhanced maize varieties as well as drought-tolerant sorghum, teff, cassava, and market-preferred common bean varieties. Specific nutritionally enhanced crops—such as quality protein maize varieties with high lysine and tryptophan content—could alleviate protein-deficiency problems and under-five malnutrition, widely encountered in rural communities that depend on maize as their staple food.
- Promote dairy goat and poultry farming and silkworm rearing in appropriate agroclimatic conditions.

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