Technical Paper on socioeconomics and food security dimensions of climate change

Prepared for the African Group of Negotiators

by Claudia Ringler and Mark W. Rosegrant

International Food Policy Research Institute

April 2020

Technical Paper on socioeconomics and food security dimensions of climate change[1]

ABSTRACT

This paper examines the economic and food security implications of climate change in Africa with a focus on population and income growth, agricultural livelihoods and food security, and the role of gender and youth. Food security impacts include climate change risks to food production and agricultural value chains in Africa. The paper then identifies key entry points to address climate change and socioeconomic challenges, including the role of investment in agricultural research, irrigation investment, climate-smart agriculture, the role of ICT, trade as a buffer to climate change, crop insurance, as well as safety nets for the poorest and most vulnerable.

[1] Several sections draw heavily on De Pinto, A., E. Bryan, C. Ringler and N. Cenacchi. 2019. Adapting the global food system to new climate realities: Guiding principles and priorities. Washington, DC; Rotterdam, Netherlands: IFPRI; Global Center on Adaptation.

1. INTRODUCTION

Climate change is a significant and growing threat to food supply and food security globally and particularly in Africa. Adverse impacts from climate change already directly affect vulnerable populations across Africa and are expected to affect many more people in more areas in the future, even if remedial actions are taken today (IPCC 2018). Agriculture directly depends on climate as a key input into production; as such, climate change affects the agricultural sector more than any other sector. Africa, and particularly Sub-Saharan Africa, further stands out as the region with the largest share of rainfed agriculture in the world; the sector is thus largely left without the climate-buffering role of irrigated agriculture.

Moreover, Africa's populations and economies depend on agriculture more than any other region in the world, further heightening the impacts of climate change on farm families and overall economies. The share of employment in agriculture in Sub-Saharan Africa stood at 54 percent for men and 55 percent for women in 2018 and has been declining very slowly over the last decade, from 60 percent and 64 percent of total employment, respectively, in 2000. Employment shares are lower in North Africa but have also been declining slowly. As an example, in Egypt, 22 percent of men and 37 of women were employed in agriculture in 2018, down from 27 percent and 39 percent, respectively, in 2000. And while agriculture's contribution to GDP has declined in Sub-Saharan Africa—most GDP is generated in the (informal) service sector; agricultural GDP still contributes 16 percent to total GDP in the region; and substantially more in the most populous countries, such as Nigeria (21 percent of GDP) and Ethiopia (31 percent of GDP) (World Bank 2020). The share of the population engaged in agriculture and the contribution of agriculture to total national incomes is highest in the poorest African countries, where agriculture can contribute up to half of total national income. Finally as overall GPDs in Africa are lower than in much of the rest of the world, many countries in Africa have limited resources to prepare for and adapt to climate change, or to recover from adverse climate shocks.

This paper examines the economic and food security implications of climate change in Africa. It assesses key socioeconomic aspects of climate change, including population and income growth, agricultural livelihoods and food security, and the role of gender and youth. Next, the paper examines climate change risks to food production and agricultural value chains in Africa, beginning with climate change impacts on Africa's agricultural systems and value chains. Key entry points to address climate change and socioeconomic challenges are then identified, including the role of investment in agricultural research, the role of irrigation investment, and trade as a buffer to climate change.

2. KEY SOCIOECONOMIC DIMENSIONS OF CLIMATE CHANGE

2.1 Population and Economic Growth in Africa

Africa is experiencing the fastest population growth globally. According to the UN (2017), by 2050, the population of Africa will reach 2.5 billion people. Other estimates, i.e. those used by the IPCC medium-level Socioeconomic Scenario (SSP2), suggest that the population of Africa will reach 2.1 billion people by 2050 (see also Figure 2.1). Population is expected to grow most rapidly in the West and East African regions, while projected growth is lowest in southern Africa. Rapid population growth weakens the capacity of poor communities to adapt to climate change, endangering human development, provision of basic services and poverty eradication. Population growth works in tandem with climate change to deplete key natural resources, such as water, fuel and soil fertility. Rapid population growth can cause a significant increase in demand for and often mismanagement of natural resources that are compromised and in decline due to environmental variability and climate change (Stephenson et al. 2010). There is a close spatial connection strong connection between "hotspots" of projected rapid population growth and climate change "hotspots" in Africa (Hugo 2011).

Table 2.1 presents projected per capita income for Africa's regions. Per capita GDP is expected to grow in all African regions, but at a depressed level as a result of climate change. Moreover, income disparities across African regions are not expected to dramatically change. By 2050, per capita income is expected to be highest in the southern Africa region, followed by North Africa, while per capita incomes in East, Central and West Africa are projected to remain below US$10,000.

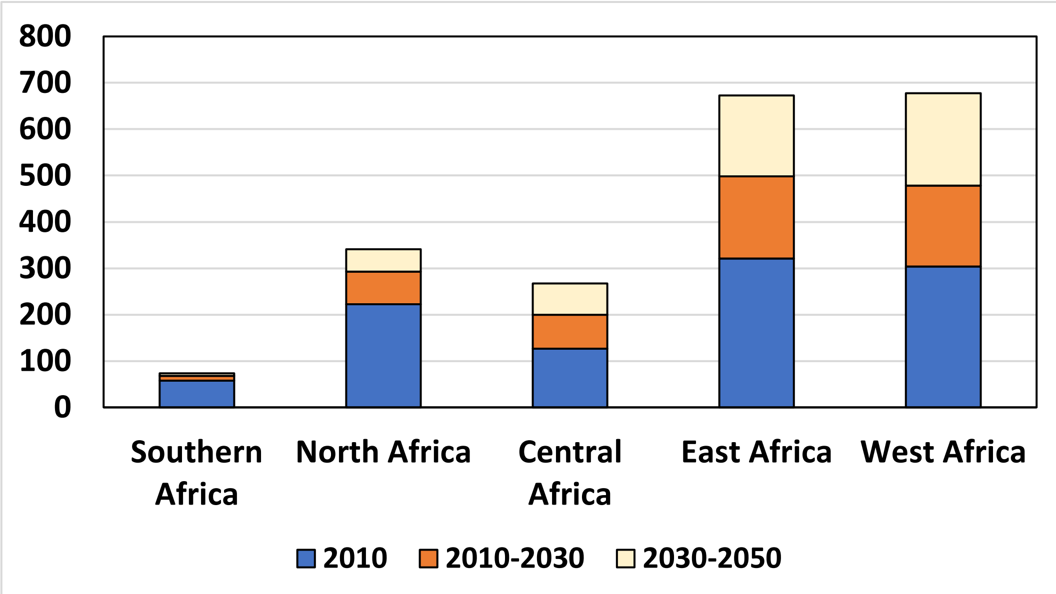
The 2015/16 ENSO (El Niño/ Southern Oscillation) drought in East Africa showed the economy-wide impacts of climatic shocks in that region. The event led to a drop in cereal production in Ethiopia's highly vulnerable lowlands by 10 percent while livestock herds shrank by 23 percent. Agricultural gross domestic product across the country fell by 3.6 percent, while gross domestic product across all sectors in the drought-prone lowlands fell dramatically, by over 11 per cent (Koo et al. 2019). Such direct impacts from climate extremes and also from longer-term climate change on the economies of Africa are expected to increase and need to be addressed through improved resilience strategies.

Table 2.1: Per capita GDP projections, African regions, using the IPCC SSP2 scenario

	2010	2030	2050
North Africa	5,180	9,820	17,640
East Africa	1,010	2,250	5,370
Central Africa	1,860	3,130	5,970
West Africa	1,710	3,790	8,120
Southern Africa	9,030	16,470	25,840

Note: SSP2 is Shared Socioeconomic Pathway 2 of the IPCC represents a "middle of the road" scenario historical patterns of development are continued throughout the 21st century.
Source: Dellink et al. (2017).

Figure 2.1: Projected growth in population in Africa, based on the IPCC SSP2 scenario (millions of people)



Note: SSP2 is Shared Socioeconomic Pathway 2 of the IPCC represents a "middle of the road" scenario historical patterns of development are continued throughout the 21st century.
Source: Jiang and O'Neill (2017); KC and Lutz (2017).

2.2 Agricultural Livelihoods are Key to Income and Food Security, but Investments are Lacking

As has been described in the introduction, about half the population in Africa is engaged in agriculture and even more if the entire food system is considered (i.e. including informal food vendors, food processing companies, etc.) making the sector the largest employer in Africa. But agriculture in Africa remains a risky business. Production systems on the continent are largely rainfed, even though the region faces the largest intra-annual variability in precipitation.

Farmers in Africa face a myriad of risks, such as production risk, market risk, institutional risk, personal risk, and financial risk. Given the lack of safety nets and other support systems, one single adverse climate event, such as a drought or flood, but also an illness or death in the family can put strains on families that they only slowly and sometimes never fully recover from. While primary climate change impact shocks are harvest and income losses, secondary impacts can include children, often girls, having to leave schools or never entering school, asset depletion, including the sale of agricultural tools to buffer harvest or income losses, reduction in the diversity of foods consumed as well as a reduction in the number of meals, migration of family members in search of work outside climate-shock affected areas, increased intimate partner violence, and early marriage of daughters, to name a few (Alston et al. 2014). Epstein et al. (2020), for example, find that drought was associated with measures of intimate partner violence towards women, particularly adolescent girls and unemployed women. Several of the responses to adverse climate change events have inter-generational implications, such as lower lifetime earning capabilities of girls prevented from attending schools or marrying early, increased stunting and wasting of children because of changes in food consumption resulting from climatic shocks, worse birth and health outcomes for babies from undernourished or early married mothers and those receiving fewer services because of climate change induced income shocks, which translates to potentially worse outcomes for their future offspring (Kumar and Quisumbing 2013).

Rural infrastructure, while improving, remains underdeveloped compared to the rest of the world. An example is rural electrification. Africa accounts for only 6 percent of global energy demand just over 3 percent of electricity demand. Bioenergy is the largest source of energy in Africa, accounting for more than half of final energy use-with devastating impacts of the continent's health, environmental sustainability and economy, and directly contributing to climate change. Where electricity is available, access is often unreliable. This severely limits economic activity. Lack of investment in electricity has also hindered the development of irrigation infrastructure, rural agro-processing centers and cold storage, which could help buffer adverse climate change impacts (Borgstein et al. 2020); secondary impacts of reduced investment are reduced availability of nutrient-dense crops, such as fruits and vegetables as well as animal-sourced foods, such as milk and eggs. Lack of investment in infrastructure has furthermore stymied the development of a vibrant manufacturing sector in Sub-Saharan Africa and has prevented labor absorption from rural areas keeping people locked in the highly climate-sensitive agricultural sector (Ringler et al. mimeo).

Lack of investment is similarly affecting water security. Annual per capita freshwater resources are particularly scarce in North Africa and intra-annual variability of water supply is highest in the Sub-Saharan African region. Climate change impacts on water resources include changes in the timing of water availability due to changes in rainfall; changes in the timing and intensity of water demands due to increased temperatures, evaporation, and changes in surface water availability and groundwater storage; an increased number and intensity of extreme climatic events (droughts and floods); and changes in water quality (Rosegrant 2019). Extreme hydroclimatic events such as floods and droughts—caused by climate change and naturally occurring water or hydrologic variability—damage crops, hurt livelihoods, and adversely affect economic growth and food security (Block et al., 2008; Brown and Lall, 2006; Thurlow et al., 2012). An analysis based on IPCC scenarios finds that for Africa as a whole, the mean total quantity of water resources is likely to increase. But assessment of the number of dry days and the frequency of their occurrences in much of Africa suggests an increase in the drought events and their duration in the future (Faramarzi et al. 2013). Based on the Fourth Assessment Report of the Intergovernmental Panel on Climate Change and the Coupled Model Intercomparison Project Phase 5 (CMIP5), both northern and southern Africa are projected to experience drying, such as decreasing precipitation, runoff and soil moisture in the 21st century, so will become more vulnerable to the impact of droughts (Gan et al. 2016).

Under-investment in water infrastructure heightens negative impacts from drought and flood shocks for both domestic and productive uses. The importance of accessing safe water of sufficient quality near the homestead has become heightened during the COVID-19 health crisis and is a further contributor to girls missing school. The World Health Organization (WHO) estimates economic losses associated with inadequate water supply and sanitation at 260 billion US dollars annually, or 1.5 per cent of Gross Domestic Product from reduced health costs and time savings for the countries studied. Other benefits from Water Supply, Sanitation and Hygiene (WASH), such as the potential of nutrient reuse, an overall cleaner environment and enhanced dignity were not valued in this analysis. More than one third of total investment needs are in sub-Saharan Africa.

Periodic droughts that dry up watering holes for animals affect availability of animal source foods in various parts of Africa and lead to severe income shocks of pastoralist households. Underinvestment in reservoir storage to address climate variability, including both droughts and floods, has contributed to the severe impacts on national economies from changes in precipitation patterns as well as higher temperatures. Moreover, most agricultural land in in sub-Saharan Africa is rainfed, as is two thirds of cropland in North Africa. This makes Africa the developing region with the lowest share of irrigation development on the globe. The effects of water insecurity are projected to worsen and expand as the effects of climate change intensify

Owing to agriculture's strong dependence on climate and water resources, management and investment in water is a key concern for food production. An analysis by Ringler et al. (2018) suggests that under a no-climate change scenario, the number of people at risk of hunger in the group of developing countries would be approximately 5 percent higher without additional irrigation investment by both 2030 and 2050. However, if climate change is considered, the number of people at risk of hunger would be 10 percent higher, an increase by 46 million people. Impacts are felt most in Sub-Saharan Africa where the share of people at risk of hunger would increase by 9 percent and where under-investment in irrigation would put 23 million people at risk of hunger by 2050. With urbanization rapidly proceeding on the continent, there is a high risk that investments in rural areas will be forgotten by both the public and the private sectors.

Even without climate change, Africa faces daunting food security and nutrition challenges. The number of undernourished people has been growing considerably in the region as a result of a combination of limited production growth compared to population growth, conflict and civil strife and climate variability and change. Other key challenges include high levels of childhood stunting and wasting, very high levels of micronutrient deficiencies and growing levels of obesity, caused by a myriad of factors including undernutrition and poor diets (FAO, IFAD, UNICEF and WHO 2019). Climate change puts further stress on agricultural growth, food security and nutrition, as will be discussed in Section 3 below.

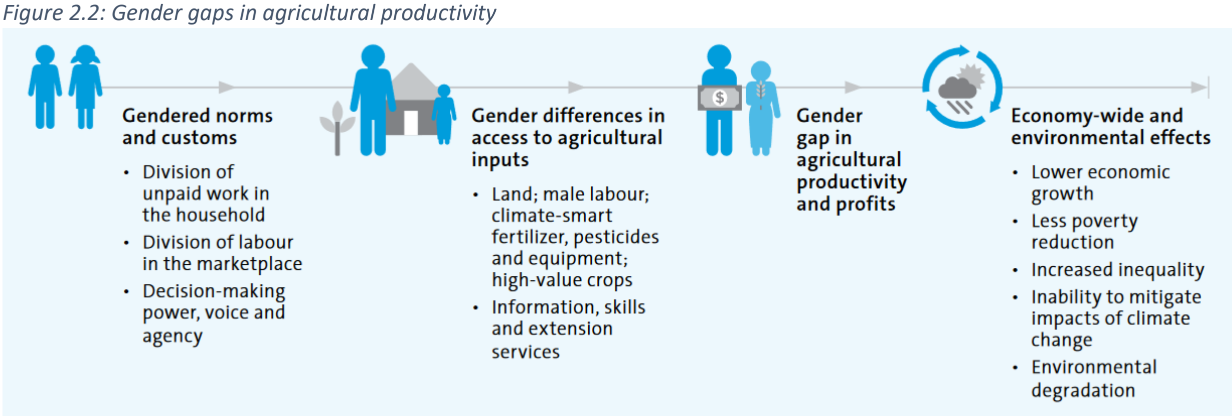
2.3 Gender and Youth

Women and men are roughly equally engaged in agriculture in much of Africa but severe gaps in agricultural productivity between women and men prevail. Women continue to experience inequitable access to agricultural inputs, in particular land, but also family labor, seed technologies and other agricultural inputs, such as agro-chemicals. Women's access to credit is similarly constrained as they often lack access to collateral, such as land, and tend to have lower education levels, particularly in rural areas (Meinzen-Dick et al. 2019); lower literacy and numeracy also affects women's access to information on advanced agricultural technologies. As women spend substantial time on domestic and care work, in additional to agricultural activities, providing technologies or other innovations that save time, is particularly critical for reducing gendered productivity gaps (Kristjanson et al. 2017).

Research suggests that paying attention to gender and involving youth in agriculture matters not only for equity of climate change adaptation programs but is also essential to increase program efficiency and effectiveness. Women perceive climate change differently from men and women experiences of climate change impacts similarly often differs from impacts experienced by men. In some places women's assets are sold first in response to a drought or other climate related shock, and in other places men's assets, such as agricultural tools are first sold to get through crises. Moreover, adaptive capacities, priorities, needs and preferences for climate change adaptation differ between women and men (Bernier et al., 2015; Twyman et al., 2014). Many organizations in Africa working to increase resilience to climate change with local communities have recognized the importance of gender, yet the degree to which women are not only reached and benefit from climate change adaptation but are also empowered through such project remains unclear. A recent study examined the extent to which organizations involved in climate change and resilience work in Sub-Saharan Africa have used gender-sensitive approaches in their programs using data collected through a knowledge, attitudes, and practices survey and key informant interviews (Bryan et al. 2018). The study found substantial potential to strengthen entry points for gender integration into climate change adaptation programs across a range of local contexts. Additional findings include a lack of capacity of organizations on gender, a lack of funding to support gender integration, and socio-cultural constraints that constraint gender integration, particularly in government agencies.

To reduce impacts of climate change on farm families, women and youth need to be fully integrated in the design of and information on climate change adaptation options. Key interventions include providing access to climate information and climate change adaptation strategies to women and youth; providing access to credit, agricultural technologies and knowledge to women and men; and removing gender gaps in agricultural decisions to address gendered gaps in adaptation strategies and associated outcomes (Bryan et al. 2017; see also Figure 2.2).

Figure 2.2: Gender gaps in agricultural productivity

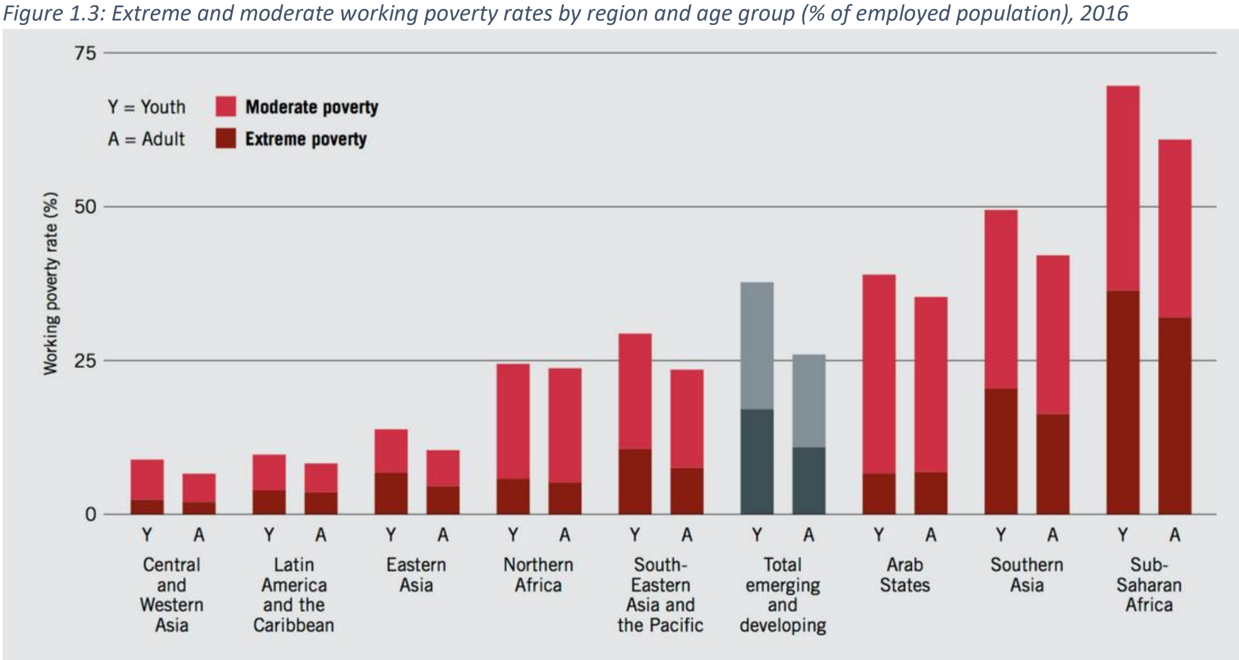


Source: UN Women 2019.

Countries with a high share of agriculture in GDP also tend to have high shares of youth (15–24 years old) in the total population. By 2030, two-thirds of the projected 500 million rural young people will be in Sub-Saharan Africa, where farming still employs more than half of the labor force and the absolute number of agricultural workers continues to grow (although the share of employment in agriculture as a portion of total employment is declining) (Brooks et al. 2019). However, those who left agriculture did generally not find jobs in manufacturing or other industries – unlike Asia where manufacturing provided jobs for many of those who left agriculture (Rodrik 2016). Instead, in Sub-Saharan Africa, many jobs are in labor-intensive service activities in the informal sector – with low labor productivity (street vending, transport services, etc.). These services will not be sufficient to raise living standards for most Africans (Diao et al. 2019) and will lock in many youth in either in climate-change impacted agriculture or other low-income employment that will be, in many cases, insufficient to quickly recover from adverse climatic shocks.

Climate change adaptation is highly knowledge intensive; it requires awareness of changes in the climate on agricultural systems, an understanding of which adaptation practices and strategies can reduce adverse impacts from climate change, knowledge on how to obtain appropriate technologies and sometimes credit to purchase these technologies, and then to appropriately apply the technologies or other adaptation practices. Such knowledge can be obtained in agricultural colleges or through linkages with extension staff who have attended such colleges, or through other information sources that are communicating appropriate knowledge. However, the number of students who study agriculture in African colleges is very limited (Goldin et al., 2015; Boshoff and Mouton 2010; Filmer and Fox. 2014.). This adds to the shortage of agricultural technical staff to support agriculture. While the share of youth unemployment is not higher in Africa than in other regions, the share of both adults and youth working in moderate and in extreme poverty is most pronounced in Sub-Saharan Africa (Figure 1.3) and is also large in Northern Africa.

Figure 1.3: Extreme and moderate working poverty rates by region and age group (% of employed population), 2016



Note: The chart displays the share of the employed youth (adult) population living in extreme and moderate poverty. The extreme working poverty rate is defined as the share of the employed population with per capita income or consumption of less than US$1.90 per day. The moderate working poverty rate refers to the share of the employed population with per capita income or consumption of between US$1.90 and US$3.10 per day.

Source: ILO calculations based on October 2015 update of the model in Kapsos and Bourmpoula (2013) and ILO Research Department's Trends Econometric Models, April 2016.

3. CLIMATE CHANGE RISKS TO FOOD PRODUCTION AND AGRICULTURAL VALUE CHAINS IN AFRICA

3.1 Climate Change Impacts on Africa's Agricultural Systems

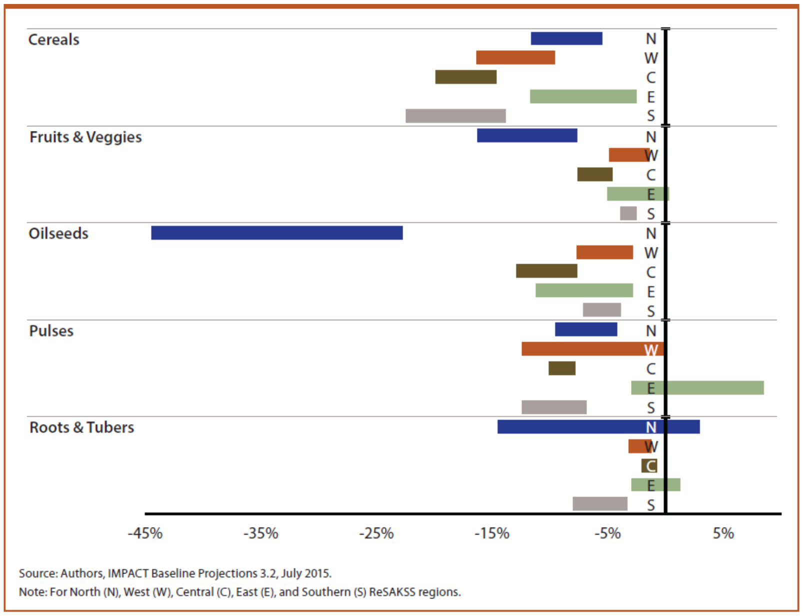
Climate change is a significant and growing threat to food supply and food security. Climate change is likely to affect the agricultural sector more than any other sector and those working in the agricultural sector and rural areas are often the most vulnerable and food-insecure populations. The IPCC base scenario projects negative consequences for most of the continent's agriculture, with the north and south particularly hard hit (Giordano and Bassini 2019). The highlands of east and north-east Africa are expected to benefit because of higher rainfall and carbon fertilization. However, with carbon fertilization increased plant growth is expected to be largely for biomass while the quality of grains might well decline (Beach et al. 2019).

Uncertainties in climate change scenarios, particularly regarding precipitation, make it difficult to determine the precise impacts on future agricultural productivity, but there is consensus that global food production will decline and that climate-change induced productivity declines, together with increasing global demand, will drive up food prices (Jalloh et al. 2013; Waithaka, Nelson, et al. 2013; Hachigonta et al. 2013). Pereira (2017) has summarized much of the research on future impacts of climate change on crops in Africa and the following results are from this paper. In most cases, high temperatures and changes in rainfall patterns are likely to reduce cereal crop productivity across Sub-Saharan Africa, ranging from a 2-percent decrease for sorghum to a 35-percent decrease for wheat (Nelson et al., 2009). Maize-based systems in southern Africa are particularly vulnerable to climate change, with yield losses for South Africa and Zimbabwe predicted to be in excess of 30 percent (Lobell et al. 2008; Schlenker and Lobell 2010). Wheat production in northern Africa is projected to be vulnerable to warming trends, and in western Africa the positive effects on millet and sorghum from increased precipitation are likely to be counteracted by temperature increases above 2°C (Niang et al. 2014). For noncereal crops, the evidence on the impact of climate change on yields is less conclusive. Cassava yields are projected to increase into the 2030s due to climate change assuming that there is a CO fertilization effect, but by 2050 negative impacts from climate change are expected to dominate (Schlenker and Lobell 2010; Lobell et al. 2008). Yields of beans are estimated to decrease by the mid-21st century (Jarvis et al. 2012; Thornton et al. 2011), while for peanuts some studies show a positive effect from climate change, especially in rainfed systems (Tingem and Rivington 2009; Dube et al. 2013) and a negative effect in other studies (Schlenker and Lobell 2010; Lobell et al. 2008).

Figure 3.1 presents a summary of projected yield impacts from climate change (relative to a no-climate-change baseline in 2050). Impacts vary across crops and subregions within Africa (SSP2 and RCP8.5).[2] Yield reductions of 5 percent to 15 percent are seen for most crops and subregions, with more severe yield impacts on oilseeds in North Africa while there is a small positive gain for pulses in East Africa.

[2] Four general circulation models (GCMs) were used to represent climate change in this analysis: HadGEM2-ES, IPSL-CM5A-LR, MIROC-ESM-CHEM, and GFDL-ESM2M.

Figure 3.1. Impact of climate change on crop yields in Africa

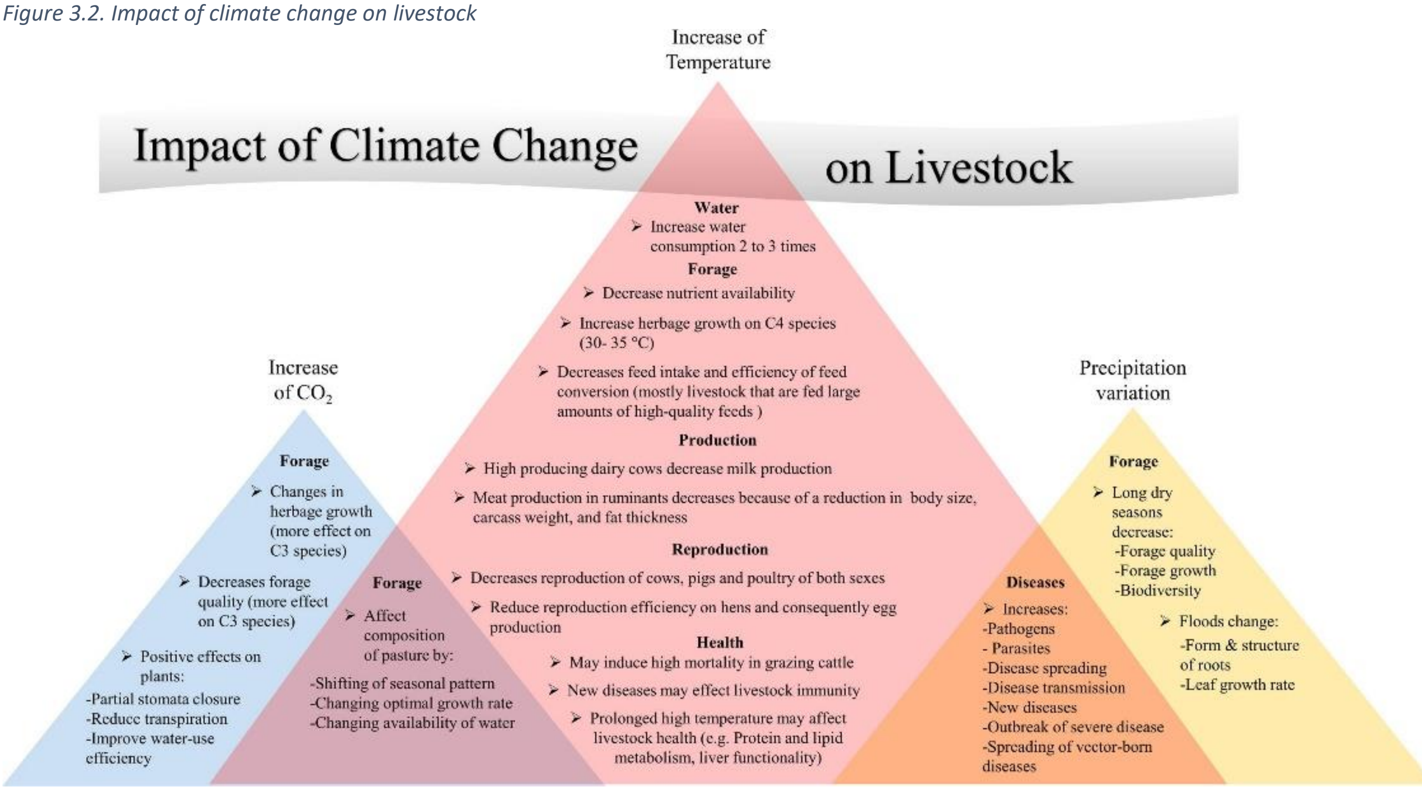


Source: Reproduced from Sulser et al. (2015).
Note: change is estimated for the year 2050, by subregion. N = North, W = West, C = Central, E = East, and S = Southern.

As a result of changes in crop yields, across all commodities, food production is projected to decline by 15 percent in North Africa, 7 percent in Eastern Africa, 11 percent in Central Africa and 8 percent in West Africa. Moreover, localized weather shocks and emerging pest and disease outbreaks are already compromising the stability of crop production, highlighting the urgency for immediate and adaptive management responses (FAO 2016).

Figure 3.2 summarizes climate change impacts on livestock. A separate AGNES paper will treat livestock-related impacts and solutions and thus the summary for this sector is brief. Conflicts between pastoralists and crop farmers have been recorded during El Niño–Southern Oscillation (ENSO) events in Sub-Saharan Africa and appear to be on the rise (NN 2018). While the IPCC provides little analysis of the critically important livestock sector, other projections suggest substantial, though uneven, negative effects due to direct physiological stress on animals from higher temperatures, reductions in forage availability and quality, and other factors (Thornton et al. 2015). The potential harm to herders is clear, but poor farmers often derive large shares of their incomes from livestock and could also be severely affected.

Figure 3.2. Impact of climate change on livestock



Source: Rojas-Downing et al. (2018).

3.2 Impacts of Climate Change on Value Chains

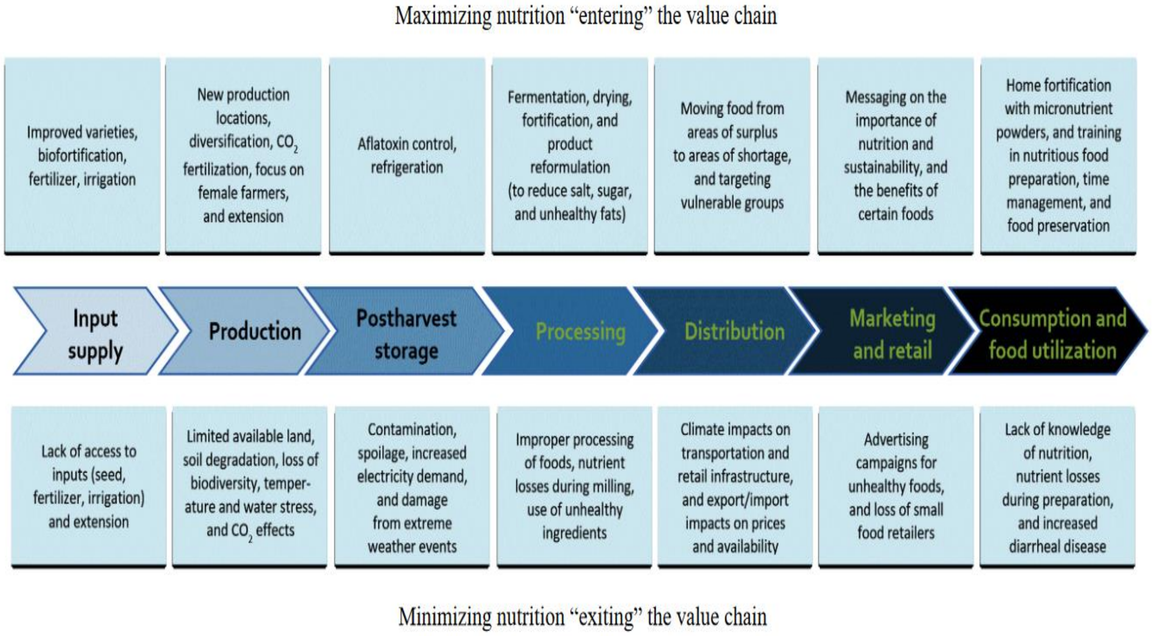
Climate change not only affects agricultural production but also has ripple effects throughout the food value chain and food systems. Increasing temperatures and changes in precipitation cause new food safety risks, especially contributing to increased prevalence of aflatoxins. These increased risks in storage need to be addressed to keep food safe. Rising temperatures will also increase demand for cold storage in order to maintain food safety and quality, and to prevent food waste. Extreme weather events also pose a risk for food storage and can lead to food waste. Climate change will impact methods of transportation, from roads to rail lines, through both long-term changes in climate and short-term extreme weather events (Fanzo et al. 2017). Transportation infrastructure will need to adapt to a more variable climate that will increase the likelihood of damages to the transportation network, such as flooded roads and port infrastructure or retail shops that lose power when hydroelectric dams run dry and the electrical grid fails. For example, Block et al. (2008) found that floods, which will increase in frequency and severity under climate change, damage rural roads, making it more difficult to move agricultural commodities to market, reducing income for farmers and for the broader economy. Finally, food security and nutritional outcomes can be affected directly by climate change, or indirectly as shocks move through the value chain (Figure 3.3). Adverse impacts from climate change were found in value chains as disparate as fish in Uganda (Timmers 2012) and rice in West Africa (Terdoo and Feola 2016).

Dealing with these climate change impacts is particularly important in Africa where storage, marketing, and retail systems are under-developed as has been discussed earlier. Value chains from farm to table have important implications for water, food, and nutrition security. The high costs to farmers and other actors of poor infrastructure, lack of information, insufficient credit, and policy distortions reduce the efficiency of value chains and impede producers' ability to connect to markets (Beamon 1999; Lohman et al. 2004). These costs and inefficiencies lead to postharvest losses that also waste the water used to produce and process food, to poor food quality, and to unsafe food. Improving the performance of value chains, therefore, can potentially benefit large numbers of people and help save water. As certain areas become hotter, greater investments in cold-storage options will be needed, but this requires investment in electricity.

Food losses can occur at any point in the value chain—from production (crop damage, spillage) and postharvest processing (attacks from insect or microorganisms during storage) to distribution (poor infrastructure, cold storage), retail sale, and consumption (e.g., spoilage, table waste). In Africa losses are mainly the result of inefficient harvesting methods and techniques, lack of storage and/or cooling facilities, and poor marketing and transport systems. In middle- to high-income countries, the biggest losses occur mainly after food reaches retail outlets, restaurants, and consumers where food is often thrown away due to spoilage and sell-by date expiration (Godfray et al. 2010; Rosegrant et al. 2018).

But the elongation of supply chains, as well as the increase in the consumption of perishables, has raised concerns internationally that waste and loss in African countries' food supply chains are even more substantial. For example, it is hypothesized that waste is as much as 20 to 30 percent for cereals, pulses, meat, milk, and fish; 40 percent for roots and tubers; and 50 percent for fruits and vegetables (FAO 2011). A recent review of empirical studies showed lower rates: 16 percent for cereals, 19 percent for oilseeds, 24 percent for roots and tubers, and 27 percent for fruits and vegetables (Rosegrant et al. 2018). Whatever the final losses, in the absence of value chain adaptation, climate change is likely to worsen post-harvest losses and to reduce market access for smallholder farmers. Climate-proofed infrastructure and transportation can reduce these adverse impacts, protect nutritional value, and reduce food waste through improved connections between farmers and consumers and through increased access of retailers to cold storage (Fanzo et al. 2017). Advanced ICT linking farmers with aggregators and increased investment in rural infrastructure (both discussed below) are important elements in value chain adaptation. Other value chain policies for climate change adaptation include increased investment in electricity, in many cases, through decentralized distributed renewable energy (DRE) systems that cannot only unlock billions of dollars of value in agriculture (Borgstein et al. 2020) but can also buffer adverse climatic shocks.

Figure 3.3: Climate-Change-Nutrition Linkages along Food Value Chains



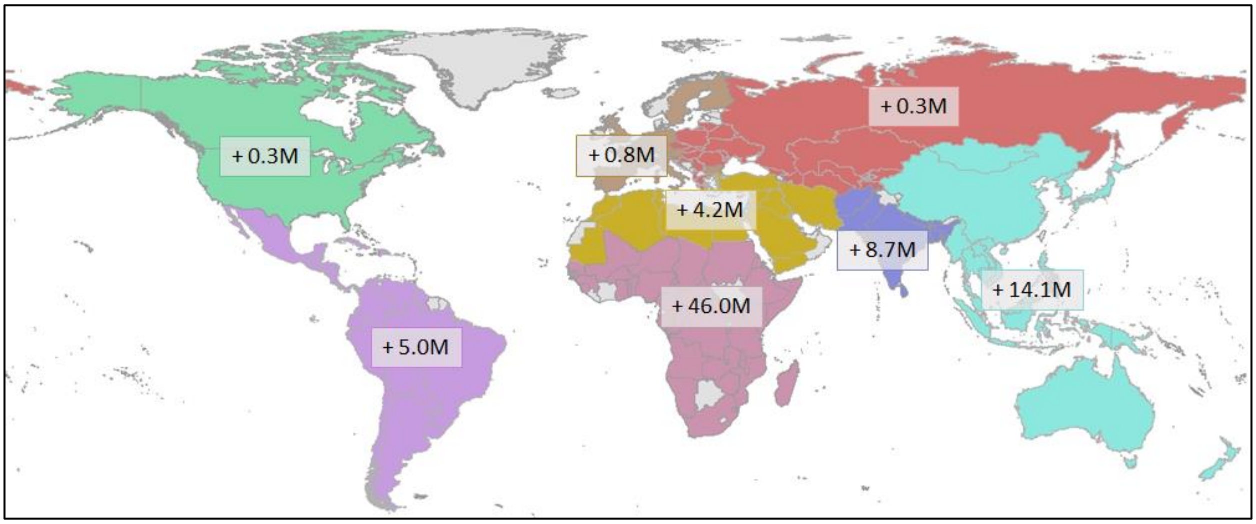
Source: Fanzo et al. 2017.

3.3 Impacts of Climate Change on Food Security and Nutrition

Climate Change will likely make it impossible to reach several Sustainable Development Goals in Africa, putting out of reach SDG2 on zero hunger and slowing progress toward global equality (SDG 10), with direct and indirect negative effects on the goal of ending poverty (SDG 1) and furthering economic growth (SDG 8). Sub-Saharan Africa is particularly hit with an expected 46 million people at risk of hunger in 2050 due to climate change (over and above other factors) out of the total increase of 80 million people due to climate change (Figure 3.4). Moreover, in North Africa, an additional 4.2 million people are expected to be at risk of climate change as a result of climate change—which shows the extent to which climate change increases inequality. Adverse impacts from climate change on food security and hunger are also calculated for 2030, when it is projected that an additional 16 million people in Africa will be at the risk of hunger due to climate change (Mason D'Croz, et al. 2019)

Temperature, carbon dioxide, and ozone also directly and indirectly affect the production and quality of fruit and vegetable crops and other foods. Increases in temperatures can be expected to have a significant impact on postharvest quality by altering important quality parameters, such as synthesis of sugars, organic acids, antioxidant compounds, and firmness. Adverse climate impacts on health, including through malnutrition, is gaining increased attention. Studies indicate that the nutritional quality of key food crops in Africa and elsewhere could suffer from climate change. Higher carbon dioxide concentration (CO_2) is shown to lower concentrations of zinc, iron and protein and raise starch and sugar content in C3 crop plants such as wheat, rice and soybeans (Elbehri 2015; Beach et al. 2019). The most severely affected people would be the poor and food insecure, especially poor children (McMichael et al. 2003). These effects will exacerbate the malnutrition challenges, including obesity and nutrition deficits in poor communities.

Figure 3.4. Change in the number of people at risk of hunger in 2050, by region.



Source: Authors, IMPACT model data

Notes: Figures show the difference in the estimated population at risk between a climate change scenario (HadGem GCM [general circulation model] run under [representative concentration pathway] RCP8.5) and a reference scenario without climate change (NoCC). Results are based on simulations, which do not include any explicit and specific adaptation strategy.

4. KEY ENTRY POINTS TO ADDRESS CLIMATE CHANGE AND SOCIOECONOMIC CHALLENGES

4.1 The Role of Investment in Agricultural Research

After a period of modest growth, investment in agricultural research in Africa declined by 5 percent during 2014–2016 due to reduced government and donor commitments. In 2016, Sub-Saharan Africa invested only 0.39 percent of its agricultural GDP into agricultural research. This is far below the 1 percent target recommended by the African Union and United Nations. Investing at recommended levels would boost agricultural productivity gains—essential to combat climate change and achieve important food security and nutrition targets while safeguarding the environment—at 26 percent above levels projected otherwise (www.asti.cgiar.org).

In addition to more investment in agricultural research, new strategies for research are needed. The Green Revolution that brought tremendous improvements to food security to Asia largely bypassed Africa. Reasons for this include lack of a dominant farming system, predominantly rainfed rather than irrigated agriculture, poor soil fertility, underinvestment in agricultural R&D and infrastructure, lack of competitive markets and conducive enabling environments, low labor productivity, and the predominance of customary land tenure (InterAcademy Council 2004).

Advancement in productivity and profits from improved agricultural research and extension and market liberalization can contribute to substantial increases in income and improved food security, as noted above. Investments in conventional breeding and tools of biotechnology such as marker-assisted selection and cell and tissue culture techniques can boost crop yield growth in rainfed environments and can be targeted to the micro-environments that characterize much of African agriculture. Input from farmers, local farmer groups, and NGOs can stimulate innovations and adaptations and then promote their impact. Agricultural research should have greater focus on climate change-related traits, including drought and heat tolerance, and pest and disease resistance. Increased research funding should be accompanied by reform of technology support policies and regulatory systems. Intellectual property rights must be addressed to ensure that the benefits of modern science and technology reach smallholder farmers in Africa. Resource-poor farmers could be excluded from the benefits of modern science, including biotechnology, if measures are not taken to avoid social exclusion in dissemination of new agricultural technologies. In addition, harmonization of regulatory standards in the development and dissemination of innovations, including biosafety standards, would reduce the time between development and adoption of new varieties.

Improved partnerships between international and national agricultural research efforts would also be valuable. The CGIAR already works closely with African research institutes and ministries but expanded networks for testing varieties in multiple local agroclimatic environments would be valuable. Private international companies can also become more effective working with African institutions. In some cases where the market offers little opportunity for fully private participation, some companies have chosen to make genes and intellectual property rights available for poor farmers through public private partnerships (PPP's) in Africa. For example, the Bill and Melinda Gates Foundation has funded PPP's to allow access to genes developed in the private sector for drought tolerance in the Water Efficient Maize for Africa program, which has included Monsanto, national agricultural research systems (NARS), and CIMMYT.

Finally, given the small size of most NARS in Africa, the establishment of regional centers of excellence could also be beneficial. A successful example of this approach is the Biosciences Eastern and Central Africa (BECA) regional hub located on the International Livestock Research Institute (ILRI) campus. BECA has state-of-the art facilities and laboratories for biosciences R&D in areas of crops and livestock.

Increased and targeted livestock research is also needed in the face of climate change. Achieving productivity gains in the livestock sector is also important. The sustainable expansion of livestock production to meet the growing demand for animal-source foods must allow poorer consumers to benefit from a nutritional perspective while reducing the impact on the environment. This means balancing trade-offs among food and nutrition security, poverty, equity, environmental sustainability, and economic development. Key innovations are needed in breeding and feeding programs that will focus not only on productivity but also on product quality, animal welfare, disease resistance, reduced water and land use, lower greenhouse gas emissions, and reduction of other environmental impacts. Areas for research and development include optimizing livestock diets to reduce greenhouse gas emissions, improving feed digestibility, improving water management, developing high-quality grain concentrates, and improving pasture quality. Other areas include improved waste management, use of by-products for energy production, and recycling. Integrated management of mixed livestock-crop systems could provide substantial water savings and livestock productivity. Innovative, intensive grazing practices that lead to soil creation and soil health are exciting strategies for enhancing soil moisture retention and fighting desertification (Thornton 2010).

Is it possible to reverse these negative impacts of climate change on hunger in Africa through higher investments in agriculture? Rosegrant (2017) and Mason D'Croz (2019) explore this question through simulations of an investment scenario for agriculture and the rural sector that includes increased investments in agricultural R&D, irrigation expansion, water use efficiency, soil and water management, and rural infrastructure in developing countries. Rural infrastructure includes rural roads, rail, and rural electrification. This investment portfolio has a total annual additional cost over the baseline for all developing countries of US$52 billion per year from 2015 to 2030 (Mason-D'Croz et al. 2019). The additional annual investment cost for Africa is almost US$15 billion per year, or 29 percent of additional investments across all developing countries. These investments generate economic benefits through several pathways. Increased agricultural R&D boosts crop and livestock yields, reduces food prices, and increases farm income and economy-wide GDP through multiplier effects on the non-agricultural sectors. Irrigation and water use efficiency investments increase crop yields and reduce prices, thereby generating higher incomes. Enhanced rural infrastructure reduces post-harvest losses and marketing margins, improving the profitability of farm production, and boosting supply to consumers for any given level of production. These effects also increase farm and broader income.

This aggressive investment scenario dramatically reduces the number and prevalence of hunger in Africa by 2030 with the population at risk of hunger falling from 21 percent in 2010 to about 10 percent by 2030, a reduction of about 55 million people, compared to a 16 million increase by 2030 in the climate change scenario (Mason D'Croz, et al. 2019). Enhanced investments in agriculture and the rural sector can thus more than compensate for the negative effects of climate change on food security and make serious inroads on hunger in Africa.

These investments in agricultural R&D and rural infrastructure also generate very large total economic benefits. Even with the high cost of physical infrastructure such as roads, electricity, and irrigation, the benefit-cost ratio (BCR) of a comprehensive package of these investments is lower than for increased investments in agricultural R&D, although it still has a substantial BCR of 10:1. Given the high impacts on economic growth, these investments warrant serious consideration as necessary complements to agricultural R&D and targeted investments in hunger and nutrition programs. As a stand-alone investment program, increased spending on agricultural R&D has a very high BCR of 52:1 (Rosegrant et al. 2019).

4.2 The role of irrigation investment

Irrigated agriculture supports food production in dry seasons and in areas that receive too little rainfall to grow food and increasingly supplements production in areas with uncertain rainfall as a result of climate change. Irrigated yields are generally 30–60 percent higher than those of rainfed crops, as irrigation supports higher-yielding seeds and stimulates application of other inputs, such as fertilizers (Rosegrant et al. 2009). In Africa, irrigated area has been evolving differently in Northern and Sub-Saharan Africa. Given the arid and semi-arid nature of Northern Africa, irrigation has long been a key avenue for food production and food security, but severe water resource constraints have led to a slow-down in expansion, converting the focus toward efficiency, reuse and productivity improvements. In Sub-Saharan Africa, on the other hand, economic water scarcity has prevented the profitable exploitation of existing water resources and the region has remained largely rainfed.

Creating access to water for productive uses for Africa's population requires investments that are linked to conducive enabling conditions, such as strong water rights systems that allow smallholder farmers and other marginal water users access to increasingly contested water resources.

Where rainfall can be stored for agricultural purposes, rainwater harvesting, which alters the runoff of rain, allowing for rainfall to infiltrate the soil and be stored for plant use, is a key intervention that not only supports food production but can also control soil erosion. In other areas, low-cost irrigation technologies, such as manual and, increasingly motorised pumps, including solar irrigation pumps as well as low-cost irrigation scheduling tools such as wetting-front detectors, can help farmers access and manage water resources.

You et al. (2011) estimate total irrigated area expansion potential for Africa over the next 50 years of 24 million hectares, a 177 percent increase over existing equipped irrigated area of 13 million hectares. As expected, they calculate limited economic expansion potential in northern Africa, at 1.8 million hectares (on top of the existing 6.3 million hectares equipped for irrigation) based on water resource availability, food demand, and production costs. At the same time, they calculate substantial irrigated area expansion potential of 22 million hectares in Sub-Saharan Africa (in addition to the existing 7 million hectares of equipped area).

In small-scale, farmer-managed or farmer-led systems of Africa, individual water lifting devices have advanced from shallow, hand-dug wells and manual water lifting methods, such as buckets, to deep tubewell-supported solar irrigation pump technologies. Farmers tend to prefer solar irrigation technologies over labor-intensive manual technologies, and diesel and electric pumps where variable fuel or electricity costs can be high. However, solar-irrigation technologies, like other advanced irrigation technologies can also contribute to water degradation and depletion. Unlike in large-scale irrigation systems, ensuring collective action around agricultural water is challenging, but not impossible, in individually managed systems. The emerging spread of affordable solar-pump technologies in Africa may enable irrigation access to the more than two-thirds of Africa's rural areas that are not yet linked to the electric grid, but could also lead to much more rapid drawdown of groundwater resources as well as to depletion of associated surface water resources and aquatic biodiversity. Given the substantial cost of solar systems, several pay-as-you-go solar irrigation systems are currently being tested in various African countries, such as Uganda to reach a larger number of lower-income farmers.

Like in other regions of the world, irrigation has multiplier effects in the African region. Beyond its contribution to crop production and food security, it has tampered the high net food import dependency in North Africa and can reduce the growing net food import dependency in Sub-Saharan Africa. Xie et al. (2018), for example, found that accelerated irrigation investment can effectively reduce growing food import dependency from 54 percent in 2050 under a business-as-usual scenario to a much smaller 17–40 percent depending on irrigation technology cost and other factors; and can also reduce the population at risk of hunger and child undernutrition.

Additionally, potential benefits of irrigation include the production of more diverse, nutrient-dense crops, such as vegetables and fruits, the generation of higher incomes, the co-provision of water supply for domestic uses and sanitation and strengthened women's empowerment if women own or can drive decisions on irrigation technologies or irrigated land or if their time spent on fetching domestic water or on agricultural activities declines as a result of irrigation (Domenech 2015). All these additional benefits can only be achieved if irrigation is developed with these goals in mind.

Supporting low-cost agricultural water management approaches also requires increased investment in agricultural research and development for complementary technical and institutional innovations that counter adverse impacts from climate-change induced, larger crop water requirements, increased heat and drought stress and more concentrated, shorter-duration precipitation events that are linked to flash floods, soil erosion and reduced soil water storage.

Realization of this potential depends on policies, incentives, and local enabling conditions. The potential for long run success of new investments in small-scale irrigation (and to improve the performance of existing systems) can be increased by improving market access for high-valued crops such as fruits and vegetables at local, regional, national, and international scales (Burney and Naylor 2012). Support for small-scale irrigation should include investing in smallholder farmers' capacity to irrigate their land with groundwater or nearby surface water, and to collectively manage these resources in decentralized ways. This includes creating opportunities for private investment in small-scale irrigation systems and making distributed irrigation technology affordable. It also requires focused investments in input and output markets, transportation infrastructure, cold-chain storage, drought insurance programs, legal support, and education (Rosegrant 2019; Rosegrant 2020).

4.3 The role of climate-smart agriculture

In addition to irrigation expansion, improved, climate-smart agriculture (CSA) is needed to help adapt farmers adapt to the effects of climate change. Improved cropping systems for the predominant rainfed agriculture is particularly important. For example, water harvesting in rainfed farming can have substantial benefits through storing water in surface areas, in the soil profile, or by facilitating recharge of aquifers can reduce vulnerability to dry spells, reducing yield losses and allowing farmers invest in other inputs, such as fertilizers and high-yielding varieties (FAO 2017). The evidence of the benefits of water harvesting is mixed, as shown in Rosegrant (2020). A review study of the published literature found that water harvesting improves crop yields significantly, and that the relative impact of water harvesting on crop yields is largest in low rainfall years. However, especially in low productivity areas in Africa, small farmers may not invest in water harvesting, because the returns to investment can be limited (Bouman et al. 2016). A study of rainwater harvesting for agricultural production in selected semi-arid areas of Tanzania found that the practice improved gross margins and returns to labor. Maize production with rainwater harvesting had an internal rate of return (IRR) of 57 percent and rice production with rainwater harvesting had an IRR of 31 percent. Where output markets are available, rainwater harvesting enabled some farmers to switch to high value crops, with significant improvement of incomes (Senkondo et al. 2004). Given the potential for water harvesting, smart subsidies could be targeted to also cover labor and installation costs for water harvesting structures. Temporary subsidies during the early stage of input and technology adoption may be effective in overcoming the fixed costs related to the adoption of new technology and in inducing farmer experimentation and learning during periods of rapidly changing technological potential (Rosegrant 2020).

Water harvesting is just one example of CSA. CSA practices seek to achieve gains across three key climate change related goals by considering three foundational outcomes and by fully accounting for the trade-offs and synergies among them. The framework is composed of agricultural systems that contribute to (1) sustainable and equitable increases in agricultural productivity and incomes, (2) greater adaptation and resilience to climate change of food systems from the farm to the national level, and (3) the reduction or removal of GHG emissions where possible (de Pinto et al. 2019). As noted by the Global Commission on Adaptation (2019), climate-smart agriculture is not so much a specific set of practices, but rather a way of combining measures so that they have a greater emphasis on addressing climate change impacts.

Key emphases for adaptation include putting more focus on yield and income stability rather than just yield levels alone; more focus on efficiency in the use of inputs, such as water and fertilizer; and more focus on long-term sustainability by properly caring for soil and water resources. Climate smart measures need to be tailored to local conditions, rather than taking single steps, and need to extend improvements from the farm to the overall value chain. Broader agroecological approaches to conserve land and water resources at the landscape scale would also be beneficial. Climate change is likely to increase soil erosion and losses of soil carbon, among other threats to soil quality. These threats can be addressed with agroecological approaches, such as enhanced use of agroforestry, increased retention of crop residues, and larger numbers and types of crops used in rotations, especially more use of legumes. Integrated pest management will also be vital to address the likely increase of pest pressures from a hotter world (Global Commission on Adaptation 2019).

4.4 The role of ICT and information exchange

ICT can help to improve agricultural production systems and value chains in Africa deal better with climate change. Use of affordable smart phones is expanding rapidly in rural areas of Africa, further improving access to market and crop information. Smart phones can also allow for the transfer of funds, and they can provide access weather forecasts and online software to make irrigation more precise and cost effective. FarmDrive, a Kenyan enterprise, connects unbanked and underserved smallholder farmers to credit, while helping financial institutions cost-effectively increase their agricultural loan portfolios. Kenyan startup M-Farm and Cameroon's AgroSpaces provide pricing data to remove price asymmetry between farmers and buyers, making it possible for farmers to earn more (Ekekwe 2017). Farmerline, a social enterprise that uses mobile technology to connect farmers to information and services, provides daily weather updates, assistance on getting seeds and fertilizer on credit, and access to market prices in local languages in 11 African countries (DWFI 2018). Scaling up these innovations will be a critical next step for achieving large benefits (Rosegrant 2019).

In addition to pricing services, advanced technologies can help value chains better serve small farmers in other ways. Sensors linked to digital information systems have the potential to improve links between farmers and processors; reduce postharvest losses with digitally enabled harvest loans and digitally warehoused receipts; inform on-farm harvest practices; monitor storage conditions along the value chain; track provenance for supply chain optimization and grading; reduce the cost of transport; increase transport options for farmers; and increase access to timely information so that farmers know if and when transport is arriving (USAID 2017). Many of these advanced technologies need to come down in cost to broadly benefit African farmers and value chains, but innovations along these lines are underway.

Given that many of the new technologies are knowledge-intensive, extension services, education, and training will be crucial. Education can focus on strengthening human resource capacity, especially within local government agencies, to improve the delivery of rural services and extension. In addition, for agricultural extension programs to be effective and efficient, local government agencies should be given active roles in increasing the adaptive capacity of vulnerable farmers through training and other capacity building activities. Innovative forms of extension—through radio, mobile phone and other advanced information and communication technologies—should be implemented. To achieve the full potential impact, it will be crucial to ensure that information reaches both women and men.

Precision agricultural technologies, such as soil moisture sensors, yield sensors and other technologies to support a detailed, field-level understanding of crop variability support improved decision making and can lead to higher productivity and stability of yields, which is key for climate resilience (de Pinto et al. 2019). Public, private, and NGO extension efforts should be better coordinated (Rosegrant 2019). Particular attention should be given to preserving access to these technologies by poorer producers and consumers (De Pinto et al. 2019).

4.5 Trade as a Buffer for Climate Challenges

Under business-as-usual agricultural trends, Africa will continue to import a growing share of foods over the coming decades, including a doubling of net imports of cereals (Rosegrant 2017). At the same time, more frequent extreme weather patterns can adversely impact trade by disrupting transportation, supply chains, and logistics. Trade is an important measure to smooth food production declines from adverse climate change events. While global markets can play a stabilizing role for prices and supplies and provide alternative food options for regions negatively impacted by changing conditions, trade alone is not a sufficient adaptation strategy. A relatively open trade policy should be balanced with domestic adaptation strategies, such as the enhanced investment options described below. Judicious investments and policies can avoid too much dependence on imports which may increase a country's risk and exposure to higher market and price volatility expected under climate change (Elbehri 2015). Trade policy plays an important role in affecting future trade flow patterns. Progress on climate-compatible trade policies requires ensuring that climate change policies do not distort trade.

Improvements can also be made in agricultural export potential. Agricultural exports from Africa have been hampered by poor infrastructure and food safety concerns, such as aflatoxins in maize and groundnut. However, there has been considerable success in exporting nontraditional crops, especially to the European market. Vegetables commonly exported from Africa include asparagus, snow peas, fine beans, round beans, baby carrots, baby corn, hard-shell garden peas, Brussels sprouts, broccoli, chilies, and globe artichoke. Avocado, mango, passion fruit, and pineapple make up the bulk of the fruit export. African countries also ship roses and some other flowers to the EU. Several factors have contributed to the success of fruit, vegetable, and flower exports from Africa that can also support broader agricultural exports. African governments have engaged in privatization of government enterprises, enacted less restrictive business laws, and provided incentives for export. International corporations have tied up with African counterparts and transferred technology, provided logistics, and created market identity and penetration for African products. African countries have formed regional economic groups combining business activities, technical knowledge, market information, and manpower to increase their competitiveness (Singh 2002).

Badiane, et al. (2019) note that growth in exports and the agribusiness sector more broadly is likely to be particularly effective in reducing poverty, given its geographic dispersion and strong linkages to upstream and downstream value chain actors. Policies to boost enterprise growth should aim to strengthen markets to lower transaction costs; increase access to management-skills training to enable innovation; facilitate the transfer and adaptation of knowledge and technologies from abroad; and increase access to credit (Sonobe and Otsuka 2011; Badiane and McMillan 2015). Several African countries have invested in comprehensive place-based strategies to increase private investment in agriculture, sometimes referred to as agribusiness parks or staple crop processing zones." The African Continental Free Trade Agreement (AfCFTA), which was signed in Kigali, Rwanda, on 21 March 2018 and now has more than 50 members should help to increase intra-African trade for increased food security in the face of climate change.

4.6 The role of crop insurance and safety nets

Climate change will increase the risk inherent in agricultural production and associated household incomes. Key options to reduce the risk that farmers face, including rapidly growing climate and weather risk, are crop insurance and safety net programs. The range and scope of multiple-peril or all-risk crop insurance has rapidly expanded over the past several decades, but primarily in developed countries. However, this type of crop insurance is expensive, so few farmers are willing to pay the full commercial cost. Some developing countries, such as India and Mexico, have established large-scale, highly subsidized insurance programs like those in developed countries. But the heavy subsidies paid by agricultural insurance programs for multiple-peril insurance in developed countries are usually not fiscally sustainable for governments in Africa with limited financial resources (Smith and Glauber 2012).

An alternative to all-risk insurance is index-based insurance, usually based on rainfall. It pays out to farmers based on the observed value of rainfall. Because index insurance relies on publicly available information, is standardized and transparent, and cannot be manipulated by the insured, it is less costly to administer than general insurance. However, index insurance suffers from “basis risk,” which is the difference between the losses actually incurred and the losses insured. Since the indemnity provided by index insurance is based on an index rather than on verifiable losses, the insured can suffer a significant loss without an insurance contract payout. Others may receive payouts without suffering losses, at a financial loss to the program. Because of basis risk, significant uptake of index insurance has usually occurred only if subsidies are provided or if it is bundled with other benefits, such as low-interest loans (Miranda and Farrin, 2012; Rosegrant et al. 2020a). However, some index insurance innovations have started to overcome the problem of basis risk. Dercon et al. (2014) examine the potential of offering weather insurance contracts to groups, rather than to individuals, in Ethiopia. Groups could improve understanding of the product, could be better placed to enforce insurance contracts, and could be a means to manage basis risk, if basis risk is not perfectly correlated among its members. They found that that the demand for insurance was increased when groups were provided training that encouraged sharing of insurance within groups; and that one mechanism for this higher demand may come from the ability of groups to mitigate some of the basis risk inherent in these products.

The entry of the private sector into index insurance in Africa is also promising. The WINnERS index-based insurance scheme was launched in 2017 and has reached 25,000 farmers in Tanzania with insurance and has expanded to ten countries in sub-Saharan Africa (EIT Climate-KIC 2020). The program is mainly targeted at local, small scale farmers, with payments under the insurance policies met by investment capital, rather than the reinsurance market and the product is. Policies such as these present a challenge for the industry in ensuring its policies are affordable and easily available. As a new generation of commercially oriented farmers emerges, with greater access to technology and the internet, innovative new products with novel features such as agreements and payments being made via handheld devices may become more attractive. Partnerships between telecoms and insurance providers, such as the Safaricom/Changhamka partnership in Kenya, allow for high market penetration (Kilgour and McArdle 2017). Long-term government investments, such as weather-reporting stations and basic data collection and analysis, can help to create the conditions and infrastructure for robust insurance markets. Complementary investments are also needed in basic methods of mitigating risk through low-cost irrigation, drought-resistant seed varieties, improved sanitation, and preventive health care (Meyer et al., 2011).

To further reduce hunger and improve nutrition in Africa, investments in health, nutrition, clean water and sanitation, and education are also essential. Safety nets can also provide an incentive for farmers to adopt new climate-smart technologies because they protect against downside risk in the case of early adjustment problems with new technologies. Even with the key climate resilience strategies identified here, some of the poor will be reached slowly if at all and many of them will remain vulnerable to climatic shocks, particularly rural populations and those dependent on agriculture. These groups can be reached through income transfers, or through safety nets that will alleviate their nutritional needs and socioeconomic conditions during short-term shocks. As an example, when failed and erratic rains in 2015/16 in Ethiopia caused acute and widespread crop failure, asset depletion, food insecurity, and acute malnutrition, more than 10 million people needed food relief in addition to the 7.9 million people already under the country's Productive Safety Net Programme (PSNP). The government responded quickly, along with a number of international organizations, including through expanding its reach through the existing food safety net program. Research suggests that households participating in Ethiopia's food safety program recovered faster from climatic shocks (Koo et al. 2019).

5. CONCLUSIONS

Climate change is increasingly impacting the economies, food security and nutrition, and overall livelihoods of Africa's populations. Climate change will make agricultural growth and development more difficult, increasing the risks to farming and food security and the costs of achieving development goals such as the SDGs. Climate change is a threat multiplier that makes more urgent the need to reform agricultural policies and promote investments and new technologies for adaptation. This paper reviewed key socioeconomic aspects of climate change, including population and income growth in Africa, agricultural livelihoods and food security, and the role of gender and youth. The paper also examined climate change risks to food production and agricultural value chains in Africa, beginning with climate change impacts on Africa's agricultural systems and value chains. Key entry points to address climate change and socioeconomic challenges were then identified, including the role of investment in agricultural research, irrigation investment, climate-smart agriculture, the role of ICT, trade as a buffer to climate change, crop insurance, and the role of safety net for the poorest and most vulnerable. Key conclusions can be summarized as follows:

1) Spending on agricultural research and development, especially crop and livestock breeding, should be increased significantly and targeted to African micro-environments and climate change-related traits such as drought and heat tolerance, and pest resistance. Legal and regulatory reforms should be implemented to reduce barriers to the adoption of new seed varieties and other agricultural technologies, increasing the scope and speed of adoption by farmers.

2) Infrastructure investments, including rural roads, electricity cell phone towers, markets, cold chains, and processing facilities, should be expanded, in partnership with the private sector where feasible. These investments can also support the development of a stronger rural non-farm and service sectors to allow rural populations who cannot make a living from agriculture as a result of climate change and other factors to transition to other livelihood opportunities.

3) Increased investment in irrigation expansion, especially smallholder groundwater irrigation, and in improvement of existing irrigation systems is warranted, with careful attention to cost-effectiveness. The emerging spread of affordable solar-pump technologies in Africa may enable irrigation access to the more than two-thirds of Africa's rural areas that are not yet linked to the electric grid, but could also lead to much more rapid drawdown of groundwater resources as well as to depletion of associated surface water resources and aquatic biodiversity. Together with improved irrigation investment, policies should encourage effective management of rainfed cropping systems.

4) New digital technologies have the potential to transform agriculture and increase the climate resilience of farmers. Investments in these technologies and in building the capacity to use them must be facilitated. Extension services and agricultural education need to be upgraded to expand the adoption of both conventional and advanced agricultural technology such as precision farming. Particular attention needs to be provided to women farmers.

5) Expand the implementation of risk-reducing policies such as crop insurance and social safety nets to ensure that the poorest and most vulnerable to extreme climate events, including pregnant women and small children, can recover from such events without permanent negative impacts on intellectual capacity, lifelong earning capacity and overall livelihood security.

REFERENCES

Alston, M., K. Whittenbury, A. Haynes and N. Godden. 2014. Are climate challenges reinforcing child and forced marriage and dowry as adaptation strategies in the context of Bangladesh? Women's Studies International Forum Vol 47 Part A. Nov-Dec: 137-144.

Badiane, O. and M. S. McMillan, "Economic Transformation in Africa: Patterns, Drivers, and Implications for Future Growth Strategies," in *Beyond a Middle Income Africa: Transforming African Economies for Sustained Growth with Rising Employment and Incomes,* ReSAKSS Annual Trends and Outlook Report 2014, edited by O. Badiane and T. Makombe (Washington, D.C: International Food Policy Research Institute, 2015).

Badiane, O. J. Collins, T. Makombe, and J. Ulimwengu 2019. 2019 Global Food Policy Report—Africa. International Food Policy Research Institution, Washington DC.Beamon, Benita M. "Measuring Supply Chain Performance." *International Journal of Operations and Production Management* 19, no. 3 (1999): 275–92. https://doi.org/10.1108/01443579910249714.

Beach, R. H., T.B. Sulser, A. Crimmins, N. Cenacchi, J. Cole et al. 2019. Combining the effects of increased atmospheric carbon dioxide on protein, iron, and zinc availability and projected climate change on global diets: a modelling study. Lancet Planetary Health 3(7): e307-e317. https://doi.org/10.1016/S2542-5196(19)30094-4

Bernier, Q., Meinzen-Dick, R., Kristjanson, P., Haglund, E., Kovarik, C., Bryan, E.,…Silvestri, S. (2015). Gender and institutional aspects of climate-smart agricultural practices: Evidence from Kenya (CCAFS Working Paper No. 79). Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Block, Paul J., Kenneth Strzepek, Mark W. Rosegrant, and Xinshen Diao. 2008. Impacts of Considering Climate Variability on Investment Decisions in Ethiopia. *Agricultural Economics* 39, no. 2 (2008): 171–81. https://doi.org/10.1111/j.1574-0862.2008.00322.x.

Borgstein, E., D.K. Mekonnen and K. Wade. 2020. Capturing the productive use dividend: Valuing the synergies between rural electrification and smallholder agriculture in Ethiopia. Insight Brief April 2020. https://rmi.org/insight/ethiopia-productive-use/

Boshoff N. and J. Mouton. 2010. Africa Regional Perspectives on Engineering. In. UNESCO. Engineering: Issues Challenges and Opportunities for Development.

Bouman, J.A., S.S. Hegde and R. Lasage. 2016. Assessing the returns to water harvesting: A meta-analysis. Agricultural Water Management 163 (1): 100-109

Brooks, K., S. Dunston, K. Wiebe, C. Arndt, F. Hartley, and R. Robertson. 2019. Climate and Jobs for Rural Young People. 2019 Rural Development Report Background Papers. Rome: IFAD.

Brown, Casey, and Upmanu Lall. 2006. Water and Economic Development: The Role of Variability and a Framework for Resilience. *Natural Resources Forum* 30, no. 4 (2006): 306–17. https://doi.org/10.1111/j.1477-8947.2006.00118.x

Bryan, E., Q. Bernier, M. Espinal and C. Ringler. 2018. Making climate change adaptation programmes in sub-Saharan Africa more gender responsive: insights from implementing organizations on the barriers and opportunities. Climate and Development 10(5): 417-431

Bryan, E., S. Theis, J. Choufani, A. De Pinto, R.S. Meinzen-Dick, and C. Ringler. 2017. Gender-sensitive, climate-smart agriculture for improved nutrition in Africa south of the Sahara. In A thriving agricultural sector in a changing climate: Meeting Malabo Declaration goals through climate-smart agriculture, eds. A. De Pinto and J.M. Ulimwengu. Chapter 9, pp. 114-135. Washington, D.C.: IFPRI.

Burney, J., and R. Naylor. 2012. "Smallholder Irrigation as a Poverty Alleviation Tool in sub-Saharan Africa." *World Development* 40 (1): 110–123

Dellink, R., J. Chateau, E. Lanzi and B. Magne. 2017. Long-term economic growth projections in the Shared Socioeconomic Pathways. Global Environmental Change 42 (January): 200-214.

De Pinto, A., E. Bryan, C. Ringler and N. Cenacchi. 2019. Adapting the global food system to new climate realities: Guiding principles and priorities. Washington, DC; Rotterdam, Netherlands: IFPRI; Global Center on Adaptation.

Dercon S, Vargas Hill R, Clarke D, Outes-Leon I, Taffesse AS (2014) Offering Rainfall Insurance to Informal Insurance Groups: Evidence from a Field Experiment in Ethiopia. Journal of Development Economics, 106:132–143.

Diao, X., P.A. Dorosh, K.J. Mekamu, A. Kennedy and J. Thurlow. 2019. Employment and livelihoods: Connecting Africa's rural and urban areas for rural revitalization. In 2019 Global food policy report. Chapter 4, Pp. 36-43. Washington, DC: International Food Policy Research Institute (IFPRI). https://doi.org/10.2499/9780896293502_04.

Domènech, L. 2015. Improving irrigation access to combat food insecurity and undernutrition: A review. *Glob Food Sec* 6:24–33. Available from: https://www.sciencedirect.com/science/article/pii/S2211912415300067?via%3Dihub

Dube, S., et al. 2013. South African food security and climate change: Agriculture futures. Economics: The Open-Access, Open-Assessment E-Journal, 7, 2013–2035.

DWFI. "Pathways to Increasing Farmer-Led Investments in Sustainable Agricultural Water Management in Sub-Saharan Africa." Working Paper. Lincoln, Nebraska, 2018.

EIT Climate-KIC. 2020. Success Stories: WINnERS. https://www.climate-kic.org/success-stories/winners/

Elbehri, Aziz, ed.. 2015. Climate Change and Food Systems: Global assessments and implications for food security and trade, pp. 146 - 175. Rome, Italy: Food and Agricultural Organization of the United Nations (FAO). http://www.fao.org/3/a-i4332e.pdf

Elver, H. 2015. "Interim Report of the Special Rapporteur on the Right to Food." New York: United Nations General Assembly. http://www.un.org/en/ga/search/view_doc.asp?symbol=A/70/287.

Epstein, A., E. Bendavid, D. Nash, E.D. Charlebois and S.D. Weis. 2020. Drought and intimate partner violence towards women in 19 countries in sub-Saharan Africa during 2011-2018: A population-based study. PLoSMed 17(3):e1003064.https://doi.org/10.1371/journal.pmed.1003064

Fanzo, Jessica; McLaren, Rebecca; Davis, Claire; and Choufani, Jowel. 2017. Climate change and variability: What are the risks for nutrition, diets, and food systems? http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/131228

Food and Agriculture Organization of the United Nations (FAO). 2017. Water for Sustainable Food and Agriculture: A report produced for the G20 Presidency of Germany. Rome, Italy. 33 pp IPCC. 2014. *Climate change 2014: impacts, adaptation, and vulnerability*. In V.R. Barros, C.B. Field, D.J. Dokken, M.D. Mastrandrea, K.J. Mach, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea & L.L. White, eds. Part B: Regional aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge, UK, and New York, USA, Cambridge University Press.

FAO. 2016. *The State of Food and Agriculture: Climate Change, Agriculture and Food Security*. Rome: FAO.

FAO. 2011. *The State of the World's Land and Water Resources for Food and Agriculture*. Rome and London: FAO and Earthscan, 2011.

FAO, IFAD, UNICEF, WFP and WHO, "The State of Food Security and Nutrition in the World 2019. Safeguarding against economic slowdowns and downturns", Rome, FAO, 2019.

Faramarzi, Monireh, Karim C. Abbaspour, Saeid Ashraf Vaghefi, Mohammad Reza, Farzaneh Alexander, J.B.Zehnder, Raghavan Srinivasan, Hong Yang. 2013. Modeling impacts of climate change on freshwater availability in Africa. Journal of Hydrology. Volume 480, 14 February 2013, Pages 85-101

Filmer D. and L. Fox. 2014. Youth Employment in Sub-Saharan Africa. World Bank, Washington DC.

Gan, T.Y. Mari Ito, S. Hülsmann, X Qin, X.X. Lu, S.Y. Liong, P. Rutschman, M. Disse & H. Koivusalo. 2016. Possible climate change/variability and human impacts, vulnerability of drought-prone regions, water resources and capacity building for Africa, Hydrological Sciences Journal, 61:7, 1209-1226, DOI: 10.1080/02626667.2015.1057143

Giordano, Mark and Elisabeth Bassini 2019. Climate Change and Africa's Future, Governance in an Emerging New World, Winter Series, Issue 119. Hoover Institution.

Global Commission on Adaptation. 2019. Adapt Now: A Global Call for Leadership on Climate Resilience. Global Center on Adaptation and World Resources Institute. September 2019

Godfray, C.H.,Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, Pretty J, Robinson, S, Thomas SM, Toulmin C (2010) Food Security: The Challenge of Feeding 9 Billion People. Science, 327(5967):812–818.

Goldin, N., Hobson, M., Glick, P., Lundberg, M., & Puerto, S. (2015). "Toward Solutions for Youth Employment: A Baseline for 2015." Solutions for Youth Employment, Washington D.C. Washington, D.C.: S4YE.

Hugo, Graeme. Future demographic change and its interactions with migration and climate change. Global Environmental Change. Volume 21, Supplement 1, December 2011, Pages S21-S33. https://doi.org/10.1016/j.gloenvcha.2011.09.008

IPCC. 2018. "Summary for Policymakers." In V. Masson-Delmotte, P. Zhai, H. O. Portner, D. Roberts, J Skea, P. R. Shukla, A. Pirani, et al., eds., *Global Warming of 1.5°C: An IPCC Special Report on the Impacts of Global Warming of 1.5°C above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways.* Geneva: IPCC.

Hachigonta, S., G. Nelson, T. S. Thomas, and L. M. Sibanda, eds. 2013. *Southern African Agriculture and Climate Change: A Comprehensive Analysis.* IFPRI Research Monograph. Washington, D.C.: IFPRI. http://www.ifpri.org/publication/southern-african-agriculture-and-climate-change.

InterAcademy Council. 2004. *Realizing the Promise and Potential of African Agriculture. Science and Technology Strategies for Improving Agricultural Productivity and Food Security in Africa (*Amsterdam).

International Energy Agency (IEA). 2019., "World Energy Outlook 2019", Paris, 2019.

Jalloh, A., G. C. Nelson, T. S. Thomas, R. Zougmoré, and H. Roy-Macauley, eds. 2013. *West African Agriculture and Climate Change: A Comprehensive Analysis*. IFPRI Research Monograph. Washington, D.C.: IFPRI.

Jarvis, A., et al. 2012. Is cassava the answer to African climate change adaptation? Tropical Plant Biology, 5(1), 9–29.

Jiang, L., & O'Neill, B.C. (2017). Global urbanization projections for the Shared Socioeconomic Pathways. *Global Environmental Change*, 42: 193-199. DOI: 10.1016/j.gloenvcha.2015.03.008

Kilgour, S. and M. McArdle. 2017. The rise of agricultural index-based insurance in Africa. CMS Cameron McKenna Nabarro Olswang LLP Law Firm, UK. https://www.lexology.com/library/detail.aspx?g=e1e7002f-6292-4432-b816-cc9001159ddd

KC, S., & Lutz, W. (2017). The human core of the shared socioeconomic pathways: Population scenarios by age, sex, and level of education for all countries to 2100. *Global Environmental Change*, 42: 181-192. DOI: 10.1016/j.gloenvcha.2014.06.004

Koo, J., J. Thurlow, H. Eldidi, C. Ringler, and A. De Pinto. 2019. Building resilience to climate shocks in Ethiopia. Washington, D.C.: IFPRI.

Kristjanson, P., E. Bryan, Q. Bernier, J. Twyman, R. S. Meinzen-Dick, C. Kieran, C. Ringler, C. Jost and C. Doss. 2017. Addressing gender in agricultural research for development in the face of a changing climate: Where are we and where should we be going? International Journal of Agricultural Sustainability 15(5): 482-500. http://www.tandfonline.com/doi/full/10.1080/14735903.2017.1336411

Kumar, N. and A. Quisumbing. 2013. Gendered impacts of the 2007-2008 food price crisis: Evidence using panel data from rural Ethiopia. Food Policy 38 (February): 11-22.

Lobell, D. B., et al. 2008. Prioritizing climate change adaptation needs for food security in 2030. Science, 319(5863), 607–610.

Lohman, Clemens, Leonard Fortuin, and Marc Wouters. "Designing a Performance Measurement System: A Case Study." *European Journal of Operational Research* 156, no. 2 (2004): 267–86. https://doi.org/10.1016/S0377-2217(02)00918-9.

Mason-D'Croz, D., Sulser, T. B., Wiebe, K., Rosegrant, M. W., Lowder, S. K., Nin-Pratt, A., Willenbockel, D., Robinson, S., Zhu, T., Cenacchi, N., Dunston, S., and Robertson, R. D. (2019). *World Development*, *116*, 38–53. https://doi.org/10.1016/j.worlddev.2018.12.006

McMichael, A., D. Campbell-Lendrum, S. Kovats, S. Edwards, P. Wilkinson, T. Wilson, R. Nicholls, S. Hales, F. Tanser, D. Le Sueur, et al. 2003. "Global Climate Change." In Comparative Quantification of Health Risks: Global and Regional Burden of Disease Attributable to Selected Major Risk Factors. Geneva: World Health Organization.

Meinzen-Dick, R.S., A.R. Quisumbing, C. Doss and S. Theis. 2019. Women's land rights as a pathway to poverty reduction: Framework and review of available evidence. Agricultural Systems 172(June 2019): 72-82. https://doi.org/10.1016/j.agsy.2017.10.009

Meyer, R., R. Zander, and H. Fritsche. 2011. Subsidies as An Instrument in Agriculture Finance A Review. Joint Discussion Paper. The World Bank, BMZ, FAO, GIZ, IFAD, and UNCDF. https://www.researchgate.net/publication/235942005_Subsidies_as_An_Instrument_in_Agriculture_Finance_A_Review

Miranda MJ, and Farrin K (2012). Index insurance for developing countries. Applied Economic Perspectives and Policy 34(3): 391–427.

Myers, S. S., A. Zanobetti, I. Kloog, P. Huybers, A. D. B. Leakey, A. J. Bloom, E. Carlisle, et al. 2014. "Increasing CO2 Threatens Human Nutrition." Nature 510, 139–42.

NN. 2018. “Pastoralism and Conflict in the Horn of Africa and the Sahel.” *Population and Development Review* 44, no. 4, 857–60.

Niang, I., et al. (2014). Africa. In V. R. Barros et al. (Eds.), Impacts, adaptation, and vulnerability. Part B: Regional aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change (pp. 1199–1265). Cambridge, U.K.: Cambridge University Press.

Pereira, L. 2017. Climate Change Impacts on Agriculture across Africa. Framing Concepts in Environmental Science, Environmental Issues and Problems, Agriculture and the Environment. Online Publication Date: Mar 2017. DOI: 10.1093/acrefore/9780199389414.013.292

Ringler, C. G. Collins, B. Scanlon, L. Yaseen, W. Brent, P. Orengoh and A.M. Alqarawy. 2020. Enhanced water security and energy access: Key investments for Africa. T-20 policy note. Mimeo.

Rodrik, D., 2016. An African growth miracle? *Journal of African Economies*, 27(1):10-27.

Rojas-Downing, M., A. P. Nejadhashemi, T. Harrigan, and S. A. Woznicki. 2017. “Climate Change and Livestock: Impacts, Adaptation and Mitigation.” Climate Risk Management 16, 145–63.

Rosegrant, M.W., S. Fan, and K. Otsuka. 2020a. Global Issues in Agricultural Development. Chapter 2 in K. Otsuka and S. Fan, *Agricultural Development: New Perspectives in a Changing World.* IFPRI, Washington DC, 2020 forthcoming.

Rosegrant, M.W., K. Wiebe, T. B. Sulser, D. Mason-D’Croz, and D. Willenbockel. 2020b. Climate Change and Agricultural Development. Chapter 19 in Keijiro Otsuka and Shenggen Fan, *Agricultural Development: New Perspectives in a Changing World.* IFPRI, Washington DC, 2020 forthcoming.

Rosegrant, M.W. 2020. Water management for sustainable irrigated and rainfed agriculture: opportunities, challenges, impacts and the way forward. Background Paper for FAO State of Food and Agriculture 2020, *Managing water for a sustainable food system.* April 2020.

Rosegrant, M.W. 2019. From Scarcity to Security: Managing Water for a Nutritious Food Future. Chicago Council on Global Affairs. Chicago.

Rosegrant, M.W., S. Dunston, D. Mason D’Croz, T.B. Sulser, K. Wiebe, and D. Willenbockel. 2019. The Economic Benefits of Agricultural Investments in Africa. Background paper for the Copenhagen Consensus.

Rosegrant, M.W., Sulser, T.B., Mason-D’Croz, D., Cenacchi, N., Nin-Pratt, A., Dunston, S., Zhu, T., Ringler, C., Wiebe, K., Robinson, S., Willenbockel, D., Xie, H., Kwon, H-Y., Johnson, T., Thomas, T.S., Wimmer, F., Schaldach, R., Nelson, G.C., and Willaarts, B. (2017). *Quantitative Foresight Modeling to Inform the CGIAR Research Portfolio*. Project Report, Washington DC, USA: International Food Policy Research Institute (IFPRI).

Rosegrant, M.W., E. Magalhaes, R.A. Valmonte-Santos, and D. Mason-D’Croz. “Returns to Investment in Reducing Postharvest Food Losses and Increasing Agricultural Productivity Growth.” In *Prioritizing Development: A Cost Benefit Analysis of the United Nations’ Sustainable Development Goals*, edited by B. Lomborg, 322–38. Cambridge: Cambridge University Press, 2018.

Rosegrant, M.W., C. Ringler, and T. Zhu. 2009. Water for agriculture: Maintaining food security under growing scarcity. *Annual Review of Environment and Resources*. 2009. 34:205–223. doi: 10.1146/annurev.environ.030308.090351.

Schlenker, W. and Lobell, D. B. (2010). Robust negative impacts of climate change on African agriculture. Environmental Research Letters, 5(1), 014010–014018.

Senkondo, E. M. M., A. S. K. Msangi, P. Xavery, E. A. Lazaro and N. Hatibu. 2004. Profitability of Rainwater Harvesting for Agricultural Production in Selected Semi-Arid Areas of Tanzania. Journal of Applied Irrigation Science, Vol. 39. No 1/2004, pp. 65 – 81. ISSN 0049-8602

Singh, B.P. 2002. Nontraditional crop production in Africa for export. p. 86–92. In: J. Janick and A. Whipkey (eds.), Trends in new crops and new uses. ASHS Press, Alexandria, VA.Tacoli, C., B. Bukhari, and S. Fisher. 2013. *Urban Poverty, Food Security and Climate Change.* Human Settlements Working Paper no. 37. London: International Institute for Environment and Development.

Smith VH, Glauber JW (2012) Agricultural Insurance in Developed Countries: Where Have We Been and Where Are We Going? Applied Economic Perspectives and Policy, 34(3):363–390.

Sonobe, T. and K. Otsuka, *Cluster-Based Industrial Development - A Comparative Study of Asia and Africa*, 1st ed. (London, UK: Palgrave Macmillan UK, 2011)

Stephenson, Judith, Karen Newman, Susannah Mayhew. 2010. Population dynamics and climate change: what are the links? *Journal of Public Health*, Volume 32, Issue 2, June 2010, Pages 150–156, https://doi.org/10.1093/pubmed/fdq038

Terdoo, Fanen and Giuseppe Feola. 2016. The Vulnerability of Rice Value Chains in Sub-Saharan Africa: A Review. Climate 2016, 4, 47; doi:10.3390/cli4030047Thornton PK, Boone RB, Ramirez-Villegas J. 2015. Climate change impacts on livestock. CCAFS Working Paper no. 120. Copenhagen, Denmark: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS).

Thornton, P. K., et al. 2011. Agriculture and food systems in sub-Saharan Africa in a 4C + world. Philosophical Transactions of the Royal Society: A, 369, 117–136.

Thornton PK (2010) Livestock Production: Recent Trends, Future Prospects. Philosophical Transactions of the Royal Society B Biological Sciences, 365(1554):2853–2867.

Timmers, B. 2012. Impacts of Climate Change and Variability on Fish Value Chains in Uganda. World Fish Center, Project Report 2012-18

Tingem, M. and Rivington, M. 2009. Adaptation for crop agriculture to climate change in Cameroon: Turning on the heat. Mitigation and Adaptation Strategies, 14, 153–168.

Twyman, J., Green, M., Bernier, Q., Kristjanson, P., Russo, S., Tall, A.,…Ndourba, Y. (2014). Adaptation actions in Africa: Evidence that gender matters (CCAFS Working Paper, 83). Copenhagen: CGIAR Research Program on Climate Change, Agriculture, and Food Security (CCAFS).

United Nations, Department of Economic and Social Affairs, Population Division. 2017. World Population Prospects: The 2017 Revision, DVD Edition.

UN Women. 2019. The gender gap in agricultural productivity in Sub-Saharan Africa: Causes, costs and solutions. Policy Brief No. 11. Accessed at https://africa.unwomen.org/en/digital-library/publications/2019/06/gender-gap-policy-brief

USAID 2017. How Digital Tools Impact the Value Chain. https://www.usaid.gov/sites/default/files/documents/15396/Why_Where_and_How_Digital_Tools_Impact_the_Value_Chain.pdf

Waithaka, M., T. S. T. Gerald Nelson, and M. Kyotalimye, eds. 2013. *East African Agriculture and Climate Change: A Comprehensive Analysis*. IFPRI Research Monograph. Washington, DC: IFPRI. http://www.ifpri.org/publication/east-african-agriculture-and-climate-change.

World Bank. 2020. World Development Indicators. Access April 24, 2020.

Wiebe, K. D., H. Lotze-Campen, R. D. Sands, A. Tabeau, D. van der Mensbrugghe, A. Biewald, and B. Bodirsky, et al. 2015. "Climate Change Impacts on Agriculture in 2050 Under a Range of Plausible Socioeconomic and Emissions Scenarios." *Environmental Research Letters* 10, 85010. https://doi.org/10.1088/1748-9326/10/8/085010.

Xie, H., N. Perez, C. Ringler, W. Anderson and L. You. 2018. Can Sub-Saharan Africa feed itself? The role of irrigation development in the region's drylands for food security. *Water International* 43(6): 796-814.

Xie, H., L. You, B. Wielgosz, C. Ringler. 2014. Estimating the potential for expanding smallholder irrigation in Sub-Saharan Africa. *Agricultural Water Management* 131: 183-193

You, L, C. Ringler, U. Wood-Sichra, R. Robertson, S. Wood, T. Zhu, G. Nelson, Z. Guo, and Y. Sun. 2011. What is the Irrigation Potential for Africa? A combined biophysical and socioeconomic approach. Food Policy 36(6): 770-782. http://dx.doi.org/10.1016/j.foodpol.2011.09.001