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Climate Change, Global Food Security and the U.S. Food System

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EXECUTIVE SUMMARY

CLIMATE CHANGE
GLOBAL FOOD SECURITY
AND THE U.S. FOOD SYSTEM

U.S. GLOBAL CHANGE RESEARCH PROGRAM

Climate Change, Global Food Security, and the U.S. Food System

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Climate Change, Global Food Security, and the U.S. Food System

Executive Summary

Food security—the ability to obtain and use sufficient amounts of safe and nutritious food—is a fundamental human need. Achieving food security for all people everywhere is a widely agreed upon international objective, most recently codified in the United Nations Sustainable Development Goals for 2030. This report describes the potential effects of climate change on global food security and examines the implications of these effects for the United States.

Food-security challenges are widely distributed, afflicting urban and rural populations in wealthy and poor nations alike. Food-security challenges are particularly acute for the very young, because early-life undernutrition results in measurably detrimental and lifelong health and economic consequences. Food insecurity affects people through both under- and overconsumption. Much of the scientific literature to date addresses the former issue, though the latter is now receiving more attention. For an individual, food insecurity may manifest as a reduced capacity to perform physically, diminished mental health and development, and an increased risk of chronic disease. Collectively, food insecurity diminishes global economic productivity by 2%–3% annually (USD 1.4–2.1 trillion), with individual country costs estimated at up to 10% of country GDP.

The last several decades have seen significant progress in overcoming the obstacles of population growth, food waste, inefficient distribution, and ineffective social-safety nets to improve global food security. There are currently about 805 million people, or 11% of the global population, who are undernourished according to the Food and Agriculture Organization of the United Nations, down from about 1.01 billion, or 19%, in 1990–1992. At least 2 billion people currently receive insufficient nutrition. The fundamental issue addressed by the *Climate Change, Global Food Security, and the U.S. Food System* assessment is whether progress can be maintained in the face of a changing climate.

Relationships between climate and agriculture are well documented. Agricultural production is governed in large part by climate conditions and is a central consideration for food availability. It is less widely appreciated that climate conditions also affect access to food, its utilization, and the overall stability of each. These effects occur through climate's influence on global food-system activities, including food processing, packaging, transportation, storage, waste, and consumption (Figure ES-1).

Climate change is a long-term trend in the state of the climate, usually described as changes in the average and/or variability of properties such as temperature and precipitation. Since 1750, rapidly growing human-induced emissions of greenhouse gases have caused increases in global average temperatures, changes in precipitation timing and intensity, rising sea levels, and many other changes, including direct physiological effects of changing greenhouse-gas concentrations on crop development. This report considers how all of these changes are affecting global food systems and food security.

Table ES-1: The Components of Food Security. *For food security to be achieved, all four components must be attained and maintained, simultaneously. Each is sensitive to climate change.*

Component	Definition
Availability	The existence of food in a particular place at a particular time.
Access	The ability of a person or group to obtain food.
Utilization	The ability to use and obtain nourishment from food. This includes a food's nutritional value and how the body assimilates its nutrients.
Stability	The absence of significant fluctuation in availability, access, and utilization.

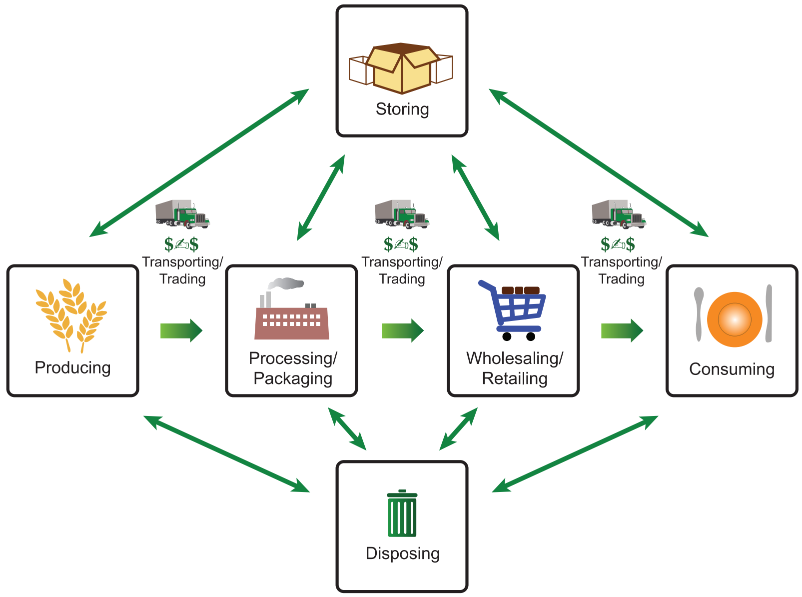

Figure ES- 1. Food-system activities and feedbacks. *Food-system activities include the production of raw food materials, transforming the raw material into retail products, marketing those products to buyers and product consumption. Food transportation, storage and waste disposal play a role in each of these activities.*

Many factors aside from climate change influence future food systems and food security. The most relevant include technological and structural changes in food production, processing, distribution, and markets; increasing population, demographic changes, and urbanization; changes in wealth; changes in eating habits and food preferences; disasters and disaster response; and changes in energy availability and use. Some of these amplify the effects of climate change and increase the risks to food security (e.g., population growth), while others appear likely to diminish risk and to help offset damaging climate-change impacts (e.g., increasing levels of wealth).

Food security, food systems, and climate change are each multifaceted topics. Their interactions are likewise complex and are affected by a wide range of environmental and socioeconomic factors. It is nevertheless clear that there are multiple connections between changing climate conditions and food systems and that climate change affects food systems in ways that alter food-security outcomes.

Report Findings

Climate change is very likely to affect global, regional, and local food security by disrupting food availability, decreasing access to food, and making utilization more difficult. Climate change is projected to result in more frequent disruption of food production in many regions and in increased overall food prices. Climate risks to food security are greatest for poor populations and in tropical regions. Wealthy populations and temperate regions that are not close to limiting thresholds for food availability, access, utilization, or stability are less at risk. Some high-latitude regions may actually experience near-term productivity increases due to high adaptive capacity, CO_2 fertilization, higher temperatures, and precipitation increases. However, damaging outcomes become increasingly likely in all cases from 2050–2100 under higher emissions scenarios.

The potential of climate change to affect global food security is important for food producers and consumers in the United States. The United States is part of a highly integrated global food system: climate-driven changes in the United States influence other nations, and changes elsewhere influence the United States. The United States appears likely to experience changes in the types and cost of foods available for import. The United States is similarly likely to experience increased demand for agricultural exports from regions that experience production difficulties yet have sufficient wealth to purchase imports; the United States is likely to be able to meet increased export demand in the near term. Demand for food and other types of assistance from the United States could increase in nations that lack purchasing power. In the longer term and for higher-emissions scenarios, increased water stress associated with climate change could diminish the export of "virtual water" (the water that is embodied throughout the entire production process of a traded commodity) in agricultural commodities. Climate change is likely to increase demand from developing nations with relatively low per-hectare yields for

advanced technologies and practices, many of which were developed in the United States.

Climate change risks extend beyond agricultural production to other elements of global food systems that are critical for food security, including the processing, storage, transportation, and consumption of food. Production is affected by temperature increases; changes in the amount, timing, and intensity of precipitation; and reduced availability of water in dry areas. Processing, packaging, and storage are very likely to be affected by temperature increases that could increase costs and spoilage. Temperature increases could also make utilization more difficult by increasing food-safety risks. Sea-level rise and precipitation changes alter river and lake levels, and extreme heat can impede waterborne, railway, and road transportation. Constraints in one component of food security may sometimes be compensated through another—for example, food insecurity may be avoided when production decreases *(availability)* are substituted with food acquired through purchase *(access)*. Alternatively, constrictions at one point within the food system may be so severe, or have no feasible alternative possibilities within a local context, that food security may be compromised. As a consequence of these interactions and dependencies, a systems-based approach is needed to understand the implications of climate change on food security.

Climate risks to food security increase as the magnitude and rate of climate change increase. Higher emissions and concentrations of greenhouse gases are much more likely to have damaging effects than lower emissions and concentrations. Worst-case projections based on high greenhouse-gas (GHG) concentrations (~850 ppm), high population growth, and low economic growth imply that the number of people at risk of undernourishment would increase by as much as 175 million above today's level by 2080. The same socioeconomic conditions with GHG concentrations of about 550 ppm result in up to 60 million additional people at risk, while concentrations of about 350 ppm—less than today's level—do not increase risk. Scenarios with lower population growth and more robust economic growth result in large reductions in the number of food-insecure people compared to today, even when climate change is included, but higher emissions still result in more food insecurity than lower emissions.

Effective adaptation can reduce food-system vulnerability to climate change and reduce detrimental climate-change effects on food security, but socioeconomic conditions can impede the adoption of technically feasible adaptation options. The agricultural sector has a strong record of adapting to changing conditions. There are still many opportunities to bring more advanced methods to low-yield agricultural regions, but water and nutrient availability may be limiting in some areas, as is the ability to finance expensive technologies. Other promising adaptations include innovative packaging and expanded cold storage that lengthen shelf life, improvement and expansion of transportation infrastructure to move food more rapidly to markets, and changes in cooking methods, diets, and purchasing practices.

The complexity of the food system within the context of climate change allows for the identification of multiple food-security intervention points, which are relevant to decision makers at every level. The future need for, and cost of, adaptation is lower under lower-emissions scenarios. Trade decisions could help to avoid large-scale price shocks and maintain food availability in the face of regional production difficulties such as drought. Improved transportation systems help to reduce food waste and enable participation in agricultural markets. Public- and private-sector investments in agricultural research and development, coupled with rapid deployment of new techniques, can help to ensure continued innovation in the agricultural sector. Refined storage and packaging techniques and materials could keep foods safer for longer and allow for longer-term food storage where refrigeration is absent and food availability is transient.

Accurately projecting climate-change risks to food security requires consideration of other large-scale changes. Ecosystem and land degradation, technological development, population growth, and economic growth affect climate risks and food security outcomes. Population growth, which is projected to add another 2 billion people to Earth's population by 2050, increases the magnitude of the risk, particularly when coupled with economic growth that leads to changes in the types of foods demanded by consumers. Sustained economic growth can help to reduce vulnerability if it reduces the number of poor people and if income growth exceeds increases in food costs in vulnerable populations. Analyses based on scenarios of sustained economic growth and moderate population growth without climate change suggest that the number of food-insecure people could be reduced by 50% or more by 2040, with further reductions over the rest of the century. Such analyses should not be misinterpreted as projections, since climate change is already occurring, but they clearly indicate that socioeconomic factors have large effects on food insecurity.

Report Background and Scope

This report is a consensus-based assessment developed by a team of technical experts and based on the peer-reviewed scientific literature. The report supports the National Climate Assessment activities of the U.S. Global Change Research Program. This report represents a consensus of authors and contributors from 19 Federal, academic, nongovernmental, and intergovernmental organizations in four countries, identifying climate-change effects on global food security through 2100, and analyzing the United States' likely connections with that issue.

Climate Change, Global Food Security, and the U.S. Food System is a technical, scientific, and economic analysis of climate-change effects on global food security and food systems. The report's scope is global, due to the interdependencies within and among food systems and the shifting geography of food supplies and demands. Policy recommendations are outside the scope of this report. Discussion of the secondary effects of changes in food security upon other sectors (e.g., human health, national security) is outside the scope of this report. Domestic U.S. food security has been detailed elsewhere and is not the topic of this report. This assessment considers anticipated changes 25 and 100 years into the future to the degree supported by the available literature or through explicit inference based on information established by the scientific record.

Scenarios and Projections of Climate and Socioeconomic Changes

Vast observational evidence demonstrates that human activities, such as burning fossil fuels and deforestation, have increased global greenhouse-gas concentrations; atmospheric carbon dioxide levels increased from 280 ppm in the late 1700s to today's level of about 400 ppm. This has, in turn, increased global average temperature by about 0.8 °C since 1900.

Scenarios and Projections of Climate Change

In order to investigate how climate might change in the future, scientists use different levels of greenhouse-gas emissions as inputs to earth-system modeling experiments that project future climate conditions. The most recent set of inputs, called Representative Concentration Pathways (RCPs), was developed through the Coupled Model Intercomparison Project (CMIP) for use in climate modeling experiments and assessment efforts, such as those conducted by the Intergovernmental Panel on Climate Change (IPCC). The RCPs are the basis for the climate projections in the recent 5th Assessment Report of the IPCC and are used in this document, except for occasional instances where we consider results based on previous widely used scenarios such as those developed in the IPCC Special Report on Emissions Scenarios (SRES). This report focuses primarily on the climate implications of two possible emissions futures.

- RCP 2.6 is a low-emissions scenario with extensive mitigation and a CO_2 concentration of about 421 ppm by 2100. This results in a global average temperature increase of about 1 °C by 2050, with no further change by 2100, and global average sea-level rise of about 0.17–0.32 m by mid-century and 0.26–0.55 m by late century. Referred to as "low emissions" in this report.

- RCP 8.5 is a high-emissions scenario, where emissions continue to increase rapidly, producing a CO_2 concentration of 936 ppm by 2100. This results in a global average temperature increase of about 2 °C by 2050 and 4 °C by 2100, and global average sea-level rise of about 0.22–0.38 m by mid-century (2046–2064) and 0.45–0.82 m by late century. Referred to as "high emissions" in this report.

The range of 0.26–0.82 m for late-century sea-level rise projected by the IPCC and used in this document is slightly less than the estimated range of 0.3–1.2 m by 2100 used by the latest U.S. National Climate Assessment.

There is considerable regional variability within these broad global averages. Figure ES-2a shows the global distribution of projected temperature changes in mid- and late-century for low and high emissions. Warming is greater at high latitudes and in continental interiors. Figure ES-2b shows the precipitation based on the same emissions and in the same time frames. In general, wet areas become wetter over time and dry areas drier. For both temperature and precipitation, the differences between scenarios become larger as time progresses.

Scenarios of Socioeconomic Change

One of the challenges of projecting the societal effects of various emissions scenarios is the complexity and rapid rate of societal change. As an illustration, from 1950 to today, global population increased from about 2.5 billion to over 7 billion and global GDP from about USD 5.3 trillion to USD 77.6 trillion. We know that future society and adaptive capacity will differ in many respects from today, but it is not yet possible to determine the relative likelihood of many possible societal changes. It

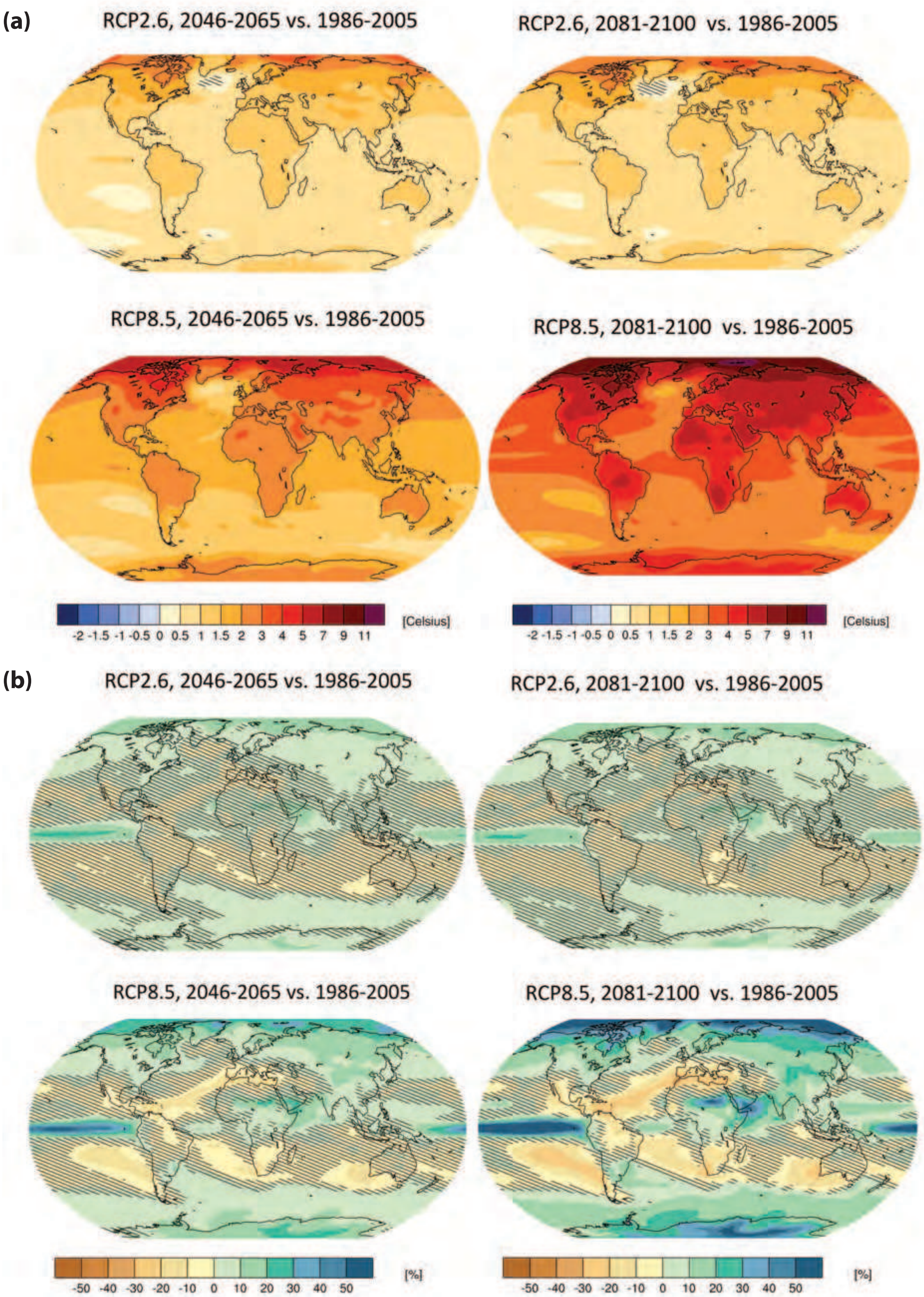

Figure ES- 2. Projected changes in global surface temperature (a) and precipitation (b). *Mid (left) and late (right) 21st century changes are compared with the period 1986 to 2005 for low emissions (RCP 2.6 – top) and high emissions (RCP 8.5 – bottom) scenarios. Multimodel ensemble-mean changes are shown, where gray dashes indicate areas for which changes have less than one standard deviation compared to natural variability. This figure was produced using CMIP5 model output through the web application "Climate Explorer," available at http://climexp.knmi.nl/.*

is, however, possible to identify alternative sets of internally consistent future changes that could occur together. Scientists can then compare plausible future climates to plausible future societies and determine likely effects of different combinations.

The scientific community has developed new scenarios called Shared Socioeconomic Pathways (SSPs) to facilitate this work. The five SSPs are designed to span a range of societal conditions in two particular dimensions: (1) challenges to mitigation and (2) challenges to adaptation, defined by different combinations of socioeconomic elements. SSP1 assumes low challenges to mitigation and adaptation; SSP2 assumes medium challenges to both; SSP3 assumes high challenges to both; SSP4 assumes adaptation challenges dominate; and SSP5 assumes mitigation challenges dominate. Each SSP has a qualitative narrative that describes general trends in societal conditions and how and why these trends unfold together over time, along with quantitative projections of key elements; none is considered more or less likely than another.

Taken together, the set of RCPs and SSPs provides a basis for the scientific community to conduct systematic and comparable analyses of future vulnerability, risks, and effects of climate change in the context of other environmental and socioeconomic changes. Most of the integrated modeling results examined in this assessment used combinations of SSP1, SSP2, and SSP3 with RCP 2.6 and RCP 8.5. This report occasionally includes results based on the socioeconomic conditions in the SRES scenarios developed previously in the IPCC process. In some cases, SSPs are also used as a frame for qualitative assessment of likely future risks to food security.

Integrated Assessment Modeling of Agriculture and Food Systems

These studies use climate and socioeconomic scenarios like RCPs and SSPs to study how the food system responds to stresses and project climate-change effects. They do not usually produce direct calculations of food-security outcomes (i.e., numbers of undernourished people), but do provide insights about possible changes in food prices, consumption, and trade, in addition to changes in yield, cultivated area, and production.

Most assessments use a structure like that outlined in Figure ES-3, which links climate models, biophysical models of agricultural systems, and economic models. Such integrated assessments help explain food-system changes that affect food security. Outputs are too aggregated to assess all of the important food-security concerns related to food availability, access, utilization, and stability, but have been used for statistical calculation of childhood malnutrition and number of people at risk of hunger. More detailed data and models and additional model intercomparisons are needed to fully assess climate-change effects on all dimensions of food security at subnational, local, and household levels.

Results reviewed in this assessment show that climate-change effects on overall global food production are likely to be detrimental, particularly later in the century. Figure ES-4 shows recent global modeling results across three different scenarios for 2050. Yields are reduced, area in production has increased, prices are higher, and production and consumption are slightly reduced relative to a baseline projection for 2050 that does not include further climate change between now and then.

It is important to recognize that effects vary substantially by region due to differing biophysical and socioeconomic conditions that determine both the effects of climate change and the potential for adaptation. The most adverse effects are likely to be in the tropics and subtropics, and some near-term benefits are possible at higher latitudes, due to the combined effects of CO_2 fertilization, higher temperatures, precipitation increases, and stronger adaptive capacity.

Integrated assessment studies clearly show that technological, economic, and policy decisions each play a major role in the global food system and future

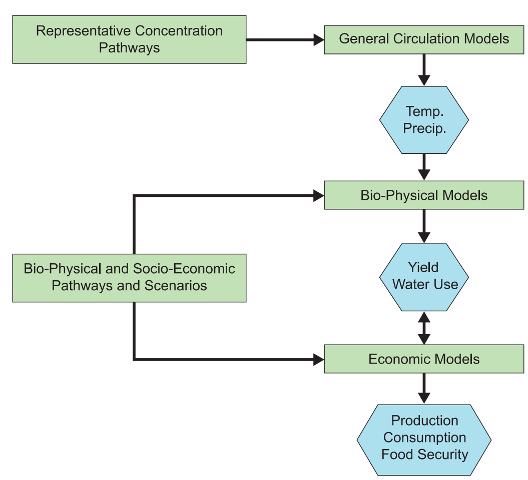

Figure ES-3. Framework for integrated agricultural and food system impact assessments. *Models of global economic and biophysical system, driven by climate-model outputs for different RCPs, are linked to assess outcomes under different future scenarios.*

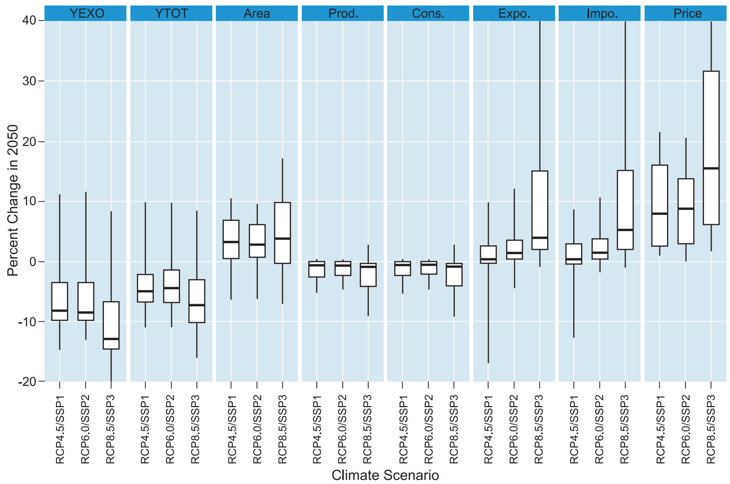

Figure ES-4. Climate-change effects on agricultural commodities in 2050 under different SSPs and RCPs. *The more pessimistic "high concentration/low international cooperation" scenario (RCP8.5/SSP3) shows much larger and more variable climate-change effects for the five commodities (coarse grains, rice, wheat, oilseeds and sugar), than the "medium concentration/middle of the road" (RCP6.0/SSP2) and "low concentration/sustainable development" (RCP4.5/SSP1) scenarios. All are compared to baseline of SSPs with no climate change. Results are from three GCMs and five economic models, aggregated across thirteen regions (n = 75). YEXO = yield effect of climate change without technical or economic adaptation, YTOT = realized yields after adaptation, AREA = agricultural area in production, PROD = total production, CONS = consumption, Expo = exports, IMPO = imports, PRICE = prices.*

global food security, demonstrating that climate assessments need to be made in the context of plausible future socioeconomic scenarios.

Many studies indicate that these technological and socioeconomic factors are likely to be more important to food security than climate change under low-to-medium emissions and concentration scenarios in the near term to mid-century. Under less-optimistic socioeconomic scenarios, higher-emissions scenarios, and longer time frames, climate effects are projected to be equal to or greater than the effects of socioeconomic change.

Food Availability and Stability

The first component of food security, *availability*, addresses the question of whether food exists locally. Where food is, or is not, is in part a function of production types, rates, and locations. Food production occurs through the cultivation of crops and livestock, fishing, and hunting outside of cultivated systems. Production forms the foundation of food availability, providing calories and nutrients for human consumption. The processing, packaging, and storage of food also contribute to food availability, as do trade and the transportation systems that enable it.

Climate change influences food availability and stability through each food-system activity. Climate can also interact with external stressors (e.g., conflict) and with the natural-resource base (e.g., soils) to alter the stability of food supplies. Increased risk can also result from agricultural expansion into less optimal lands in response to climate trends. The literature suggests that world food production needs to increase by 60%–100% to feed a larger, wealthier, and more urban global population.

Crop yields have increased globally by about 1.8% per year on average since 2000, while the area of per-capita–cultivated land has decreased by 9% over the same period, leading to an 8% increase in total per-capita global cereal production since 2000. Yield increases appear to be diminished by up to 2.5% per decade, globally, due to climate change. Local production is particularly important in the tropics, where crops' biophysical thresholds are already closer to their limitations and where higher temperatures are likely to result in diminished yields. In addition to the direct physical effects of temperature and precipitation changes, climate change influences the range and infestation intensity of crop pests and pathogens.

Livestock production provides a livelihood for over a billion people, including 600 million households in less-developed areas of the world, and contributes the equivalent of over USD 1 trillion to the global economy. Heat stress from higher temperatures diminishes food intake and physical activity for livestock, leading to lower growth, survival, and reproductive rates, as well as lower production of meat, milk, and eggs. Climate change also affects livestock indirectly through changes in the incidence of disease and pests, pasture and forage crop quality and quantity, and feed-grain production.

Fisheries, both cultivated and capture, as well as wild game, are important protein sources for large segments of the global population and are subject to multiple stressors that affect food availability, stability, and incomes (food access). Current methodological techniques cannot distinguish the importance of climate change relative to other influences upon food supplies from fisheries and wild game.

Processing, packaging, storing, trading, and transporting food are frequently prerequisites for food to reach its ultimate consumers. The influence of climate change on which crops are grown where in the world affects the location of storage, processing, and packaging facilities, as well as that of the underlying transportation infrastructure for moving food from producer to consumers or to trade hubs. Higher temperatures require more postharvest cooling for fresh fruits and vegetables, which is likely to result in additional energy expenditures and costs. Temperature and precipitation, along with extreme events, directly influence transportation systems (e.g., flooding of roads, storm surge in ports) and can impair just-in-time food distribution networks. One-sixth of global agricultural production (by mass) is traded internationally, which can act to stabilize food supplies when local or regional production fails due to climate or other factors.

Food production, processing, packaging, storage, transport, and trade all have dependencies upon climate variables. The agricultural sector is highly adaptive but limited in many regions by financial or other restrictions of local producers to realistically adopt relevant technologies and practices for responding to changing conditions. In addition, some adaptations can have undesirable side effects, requiring a systemic approach when implementing adaptive strategies. Adaptation via effective food packaging, higher levels of food processing, increased and improved cold storage and cold-chain continuity, and greater redundancies in transportation options each represent adaptive food-system approaches to help ensure food availability and its stability.

Future climate-change effects on food availability and its stability are considered using the SSP and emissions futures frameworks, and reflect the informed judgment of the authors. The risks posed by climate change to food production are greatest under SSPs 2, 3, and 4, where yield increases weaken due to reduced agricultural investment and increasing land degradation. This trend exposes more production to variable climate influences and therefore can lead to local availability challenges under these SSPs. Under SSPs 3 and 4 this challenge could be particularly pronounced, given that, under these scenarios, those living in the poorest countries lack access to agricultural technologies that could offset some climate-variability effects on production in arid and marginal lands. The risks posed by climate change to food production are lowest under the economic conditions described in SSPs 1 and 5 for a given scenario of climate change. Under these SSPs, gradual intensification is likely to be the principal means of increasing crop yields.

Climate change influences food availability and stability throughout the food system. Understanding systemic connections allows decision makers to identify strengths, vulnerabilities, and compensatory mechanisms to help to ensure food availability and stability. The condition of the natural-resource base and adaptive capacity are important to agricultural production and strongly influence food-security outcomes. Now and in the future, climate influences on food availability and stability depend on the relative balance of changes being experienced within localized conditions; at the global scale, however, such changes are increasing challenges to food security.

Food Access and Stability

The second component of food security—*access*—addresses whether an individual or community has the resources necessary to acquire food. Access involves prices (trading); proximity to food *(availability)*; retail outlets (wholesaling/retailing) or farmable lands (producing); and the social and cultural norms that shape food distribution and preferences.

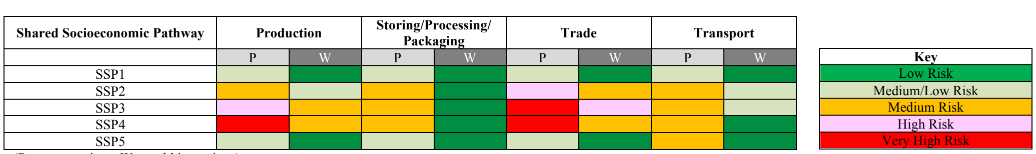

Figure ES- 5. Relative risks to food availability for different SSPs. *The risks to food availability would be lowest under the economic conditions described in in SSP 1 and SSP 5 for a given scenario of climate change, with poorer nations being at higher risk across all food production, distribution and trade categories for all SSPs. Shading represents higher or lower risks for each SSP from climate change. Risks reflect the informed judgment of the authors of this report based on the available literature.*

Global real food prices generally decreased over the second half of the 20th century and have been increasing since 2000. Price affects food affordability, which integrates food prices with income for purchasing food and can originate outside of the food system.

Trade in agricultural commodities and food can reduce price volatility and enhance stability for both producers and consumers by enabling areas of food production surpluses to supply areas of deficit. Food prices are affected by the balance between supply and demand, which is a function of food production, global population, and consumption rates. Price volatility has risen in recent years due to a combination of factors, including the widespread occurrence of extreme climate events, competition for land, and changes in commodity markets as global demand for commodities from nonfood sectors increases. Low-income households, whose food budgets represent a larger portion of their incomes, are generally more vulnerable to price spikes.

Extreme temperatures, heavy rainfall events, drought, sea-level rise, and storm surge can damage road, rail, and shipping infrastructure. Climate's effects upon transportation infrastructure can hinder the movement of food from its place of production to consumers, altering food prices in response to changes in the cost of transportation and disrupting the timing and operation of logistical supply systems between producers and distributors.

Rapid changes already underway in the food retail sector can improve or reduce resilience to climate change, depending on specific adaptive capacities. Adaptation to higher temperatures may be accomplished with increased refrigeration, for example, though that often comes with increased costs for wholesalers, retailers, and consumers. Repairs, modifications, changes to shipping logistics, and transportation substitutions may be used to adapt to changing conditions.

There is high uncertainty about future changes in real food prices, even in the absence of climate change. Socioeconomic models that include climate change generally show an increase in food prices, implying that climate change is likely to diminish other gains in food accessibility that might be achieved under any socioeconomic development scenario.

Using the SSP and emissions futures, we can examine how climate change is likely to affect food access in the future. This discussion reflects the informed judgment of the authors. Under SSPs 1 and 5, highly integrated and well-functioning world

Figure ES-6. Relative risks to food access for different SSPs. *The risks to food access would be lowest under the economic conditions described in SSP 1 and SSP 5 for a given scenario of climate change, with poorer nations being at higher risk across almost all food affordability and allocation categories for all SSPs. Shading represents higher or lower risks for each SSP from climate change. Risks reflect the informed judgment of the authors of this report based on the available literature.*

markets suggest that climate change alone would be unlikely to generate the exceptional price shocks that compromise widespread food availability. SSPs 2, 3, and 4 each present various futures under somewhat constrained global trade. SSP2 would likely experience many stresses and shocks in availability, and issues of price increases and affordability are prevalent in poorer countries. Under SSPs 3 and 4, this pattern and outcome are accentuated.

Climate and weather have demonstrable effects on food prices, transportation infrastructure, and the costs and operations of food distributors, affecting food access and stability. Food access is strongly influenced by additional factors outside of the food system, such as household income. The adaptive capacity of food access to changes in climate is potentially very high but varies enormously between high-income and low-income countries and individuals, between urban and rural populations, and the ways in which each of these develops in the future.

Food Utilization and Stability

Food *utilization* is the ability of individuals to make use of the food otherwise available and accessible to them. Nutritional outcomes are frequently measured in terms of malnutrition, which manifests as undernutrition or overnutrition. The prevalence of child stunting in the developing world decreased from approximately 47% in 1980 to 29.2% in 2000 and is expected to further decrease to 23.7% by 2020. The prevalence of obesity since 1970 has increased for all developed countries and for a number of developing countries, with the largest increases seen in urban populations and in the lowest income groups.

Climate has a number of potential and observed effects on food utilization, which include contamination of the food supply, the nutritional composition of food, and a body's ability to assimilate available nutrients. Climate change

affects food safety by influencing vectors of food contamination and levels of toxins in food. Elongated supply chains expose food products to greater risk of contamination and make it harder to verify the quality of food at various stages, but also allow more diversity in consumption and more stability over time. Temperature increases are associated with bacteria-caused illness related to poor food storage and handling practices in the supply chain. Fungal contamination resulting in the increase of mycotoxins in the food supply occurs due to high temperature and moisture levels during pre- and post-harvest and during storage, transportation, and processing, as well as pre-harvest practices and timing, the handling of agricultural products, and insect damage. Aquatic and fishery food sources can be affected by climate when more frequent or widespread harmful algal blooms lead to high toxin levels and uptake rates within the food supply.

Elevated atmospheric carbon dioxide leads to lower protein content in important global food staples.

Elevated atmospheric carbon dioxide leads to lower protein content in important global food staples. Disease burden, the status of women, and water, sanitation, and hygiene factors each influence nutritional outcomes as well and are affected by changing climate.

Food waste that occurs as a result of climate-sensitive activities during food storage, processing, packaging, and trade affects utilization rates. Estimates suggest that 30%–50% of total global food production by mass is lost globally as waste. Food waste in retail, in food service, and at home accounts for most food waste in developed regions; in developing nations, the absence of adequate food system infrastructure is a primary cause.

Diminished food utilization or utilization stability can result when the food system fails to adapt to changes in climate. Food safety and waste vulnerabilities are particularly apparent during extreme weather events when time is critical. Adaptive options can include increased and improved cold storage, varietal selection, biological control, storage structures, chemical treatments, botanical and inert dusts, and improved handling and processing to reduce vulnerabilities.

The influence of climate change on food utilization depends on how the food system responds under differing socioeconomic and climate futures; this section reflects the informed judgment of the authors. Rates of economic growth and environmental quality are expected to be high or improve in poor countries under SSPs 1 and 5, expanding their capacity to manage changes in climate and respond quickly to climate-related disasters. Under SSP2, technology transfer and economic growth would be somewhat lower than under SSP1, but globalized trade might compel investment in, or transfer of, food safety technologies to meet international certification requirements, limiting significant challenges to food safety. Environmental quality is expected to deteriorate under SSPs 2, 3, and 4, leading to more illness-based diseases that affect a body's capacity for absorbing nutrients from food. In SSPs 3 and 4, poor countries will experience low rates of economic growth and technology transfer, limiting adaptive capacity in these cases. Under SSP4, high levels of intracountry inequality could produce highly variable outcomes within a country, with the wealthy largely insulated and the poor experiencing increasing exposure to food utilization and stability challenges posed by climate change.

Biological contaminants in the food supply are highly sensitive to changing temperature and humidity, affecting food-spoilage rates and human health, the latter of which in turn affects a body's capacity to absorb nutrients. Adaptive capacity is potentially very high but is also highly variable, and depends on decisions made at multiple levels throughout a diverse food system. Climate variability has already affected the stability of food utilization through extreme-weather events; to the degree that more extreme events may be anticipated in the future, food utilization stability should be expected to be challenged.

The United States as a Global Food-System Actor

The United States makes significant contributions to global food security through trade, assistance

Shared Socioeconomic Pathway	Food Safety		Health Status	
	P	W	P	W
SSP1	Medium/Low Risk	Low Risk	Medium/Low Risk	Low Risk
SSP2	Medium Risk	Medium/Low Risk	Medium Risk	Low Risk
SSP3	High Risk	Low Risk	Medium Risk	Low Risk
SSP4	Medium Risk	Medium/Low Risk	Medium Risk	Low Risk
SSP5	Medium/Low Risk	Low Risk	Medium/Low Risk	Low Risk

(P: poorer nations, W: wealthier nations)

Key
Low Risk
Medium/Low Risk
Medium Risk
High Risk
Very High Risk

Figure ES- 7. Relative risks to food utilization for different SSPs. *The risks to food utilization would be lowest under the economic conditions described in SSP 1 and SSP 5, with poorer nations being at higher risk across all food utilization categories for all SSPs. Shading represents higher or lower risks for each SSP from climate change. Risks reflect the informed judgment of the authors of this report based on the available literature.*

programs, technology transfer, and export of environmental-management systems used in agriculture. The U.S. agriculture sector is responsive to the main drivers of global food demand, including population and income growth. The trend of rapidly rising global incomes is expected to be a significant source of increasing demand for food, though this may be tempered somewhat as the growth in global population is expected to slow in the coming decades, bringing with it a lowering of the growth rate of food consumption. Three major challenges to meeting this demand and achieving broader global food security that are likely to involve the U.S. food system include (1) closing yield gaps, (2) increasing food production, and (3) reducing food waste.

Increasing food production is a key to providing continued upward growth in food supplies and is particularly important for producers for whom agriculture represents both a food and an income source. Yield gaps are the difference between the actual crop productivity of a place and what might otherwise be attained using the best genetic material, technology, and management practices. Yield gaps are typically caused by lack of access to contemporary technology and management knowledge. Genetically modified crop varieties and the technological advances that produce them could play a significant role in increased food production in nations with large yield gaps, if they are suited to the local cultural, ecological, and economic situation. Other technologies, such as high-efficiency irrigation systems and advanced mechanization and fertilization methods, can also contribute to reducing the yield gap.

The United States is the largest global exporter of corn, is among the top wheat and rice suppliers, and is responsible for one-quarter of the world's meat exports. These exports represent "virtual water" that can compensate for the effects of climate change on water resources in arid and semiarid regions around the world. Underlying food transportation, storage, processing, and related facilities will need to change to accommodate the shifting production areas for major export crops. Vulnerabilities in transportation infrastructure in the United States and around the world are evident in the available scientific literature and may impede export capacity in a changing climate.

The United States imports food to meet consumer demand for variety, quality, and convenience. Globally, the United States is the third-largest importer of agricultural products such as coffee and fresh fruit, which influences the production choices and incomes of overseas producers and food systems. Climate change affects the production of key food imports due to their specific climatic and ecological requirements.

Trade benefits the United States by contributing to the economy, bringing investment, and providing incomes across multiple economic sectors. Modeling shows that the U.S. trade balance in agricultural goods in the coming decades might be expected to change in a changing climate, with imports expected to increase slightly more than exports by 2050.

These results, however, do not account for potential vulnerability in transportation infrastructure, which affects access to trade markets for many actors in the U.S. food system.

In addition to helping countries meet agricultural development and long-term food security objectives, U.S. international food assistance is an important instrument for meeting the needs of vulnerable populations. Food assistance will likely continue to be an important tool for ameliorating food insecurity in the early stages of climate change, particularly in response to extreme climate events, while many low-income nations are just beginning to experience rising incomes. The consequences of climate change on food security in different global regions will influence, and be influenced by, development efforts. Technological development in the United States has demonstrably benefited global food production over the last century, the result of concerted investment in agricultural research and investment. Continued advancement could provide critical climate-change adaptation possibilities for developing countries, and demand for advanced technologies could grow as economic development proceeds. Proactive and targeted management is necessary, however, for technology and information products to be effective in reducing future food insecurity.

The United States maintains many important connections with the rest of the world, including trade, food and developmental assistance, and technological development. Each is essential for global food security and will be challenged by climate change. Climate change has the ability to disrupt food security by making it more difficult to get food from one region that is able to produce a food to another region that wants to consume it, due to vulnerabilities in transportation infrastructure and related trade arrangements. The United States will likely be directly and indirectly affected by changing global conditions but is expected to maintain strong food imports, exports, and assistance programs and be the source of new technologies and information products for addressing global food insecurity.

Increasing food production is particularly important for producers for whom agriculture represents both a food and an income source.

EXECUTIVE SUMMARY

CLIMATE CHANGE **GLOBAL FOOD SECURITY** AND THE U.S. FOOD SYSTEM

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