Fifth National Climate Assessment: Chapter 11

Agriculture, Food Systems, and Rural Communities

Chapter 11. Agriculture, Food Systems, and Rural Communities

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Introduction

A changing climate, characterized by more frequent and severe extremes events, such as heatwaves, droughts, and extreme rainfall (KM 2.2), will affect US agriculture, food systems (a topic not addressed in previous National Climate Assessments [NCAs]), and rural communities. Climate change has increased risk to agricultural production, for example, by disrupting growing zones, growing days, and seasonality, making adaptation necessary to increase resilience in an evolving landscape (KM 11.1). Climate change is projected to reduce the availability and affordability of nutritious food, with impacts being unevenly distributed across society (KM 11.2). Rural communities, which manage much of the Nation's land and natural resources, face unique challenges and opportunities due to climate change (KM 11.3).

Agriculture has always faced unpredictable weather, but a changing climate poses additional challenges. Examples highlighted in NCA5 include extreme precipitation events damaging crops, delaying planting and harvesting, and expanding pest ranges in the Northeast (KM 21.1); increased average and extreme temperatures adversely affecting farmworker health in the Southeast and Southwest (Figure 11.1; KM 22.3); reductions in corn yield due to both excessive water and extreme drought in the Midwest (KM 24.1); greater incidence of heat stress on livestock in the Southwest (KM 28.3); and collapse of major fisheries in Alaska (KM 29.3).

Disruptions to food systems and supply chains within them (see Focus on Risks to Supply Chains) are expected to increase with climate change (KM 19.1). These disruptions are projected to make some food items more expensive and less accessible, particularly for lower-income individuals and households, including those in rural settings. Food insecurity affected 10.2% (13.5 million) of US households in 2021.[1] Historical structural inequities have influenced the distribution of resources, participation, accessibility, benefits, and burdens within the food system (Figure 20.1), and climate change will exacerbate these inequities (Figure 18.2). For example, many food system workers are both food insecure and disproportionately exposed to the effects of climate change, intensifying the socioeconomic impacts of these intertwined inequities.[2]

Rural communities supply labor for agricultural production and other economic sectors and often serve as stewards of the Nation's soil and water resources, having unique knowledge of rural landscapes. Climate change increases existing risks in rural communities, some of which have limited resources and infrastructure to adapt (KM 22.3). Many risks are disproportionately greater in some Black, Indigenous, Latino, and lower-income communities, and among some small-scale, beginning, and underrepresented farmers (KMs 15.2, 16.2, 22.4, 26.4, 31.2).

In summary, climate change poses significant challenges to US agricultural production, food systems, and rural communities—from primary producers to supporting industries to consumers. Climate-smart practices based on agroecological approaches are needed to both mitigate greenhouse gas emissions and adapt to ongoing climatic changes. Significant mitigation can occur through reductions in nitrous oxide emissions using precision technologies that target the right amount, source, placement, and timing of nitrogen fertilizer applications; formulation of methane-reducing diets in ruminant livestock systems; and conservation management with no-till, cover cropping, and perennial crop rotations to store more soil carbon. Many of these same agroecological approaches will support adaptation to climate change by improving soil health, increasing biological diversity, and making more efficient use of fertilizers, feed, water, and energy. Agricultural production is a complex web of biophysical and socioeconomic features interacting with environmental conditions, some of which are stable and some that are becoming less reliable with climate change. Reliance on more agroecological approaches is expected to help stabilize agricultural production while preserving the integrity of natural resources that are vital to support continued agricultural production in the future (KM 32.2). Agroecological approaches seek to achieve beneficial agricultural outcomes while promoting ecosystem services and rural livelihoods (Box 11.1).

Farmworker Exposure to Extreme Heat and Smoke

Climate change increases farmworker exposure to extreme heat and wildfire smoke.

Figure 11.1. Farmworkers, for example, shown here in Salinas, California, face compounding health risks from extreme heat, wildfire smoke, and COVID-19 (see Ch. 15; KM 28.4; Focus on Western Wildfires; Focus on COVID-19 and Climate Change). Photo credit: ChuckSchugPhotography/iStock via Getty Images.

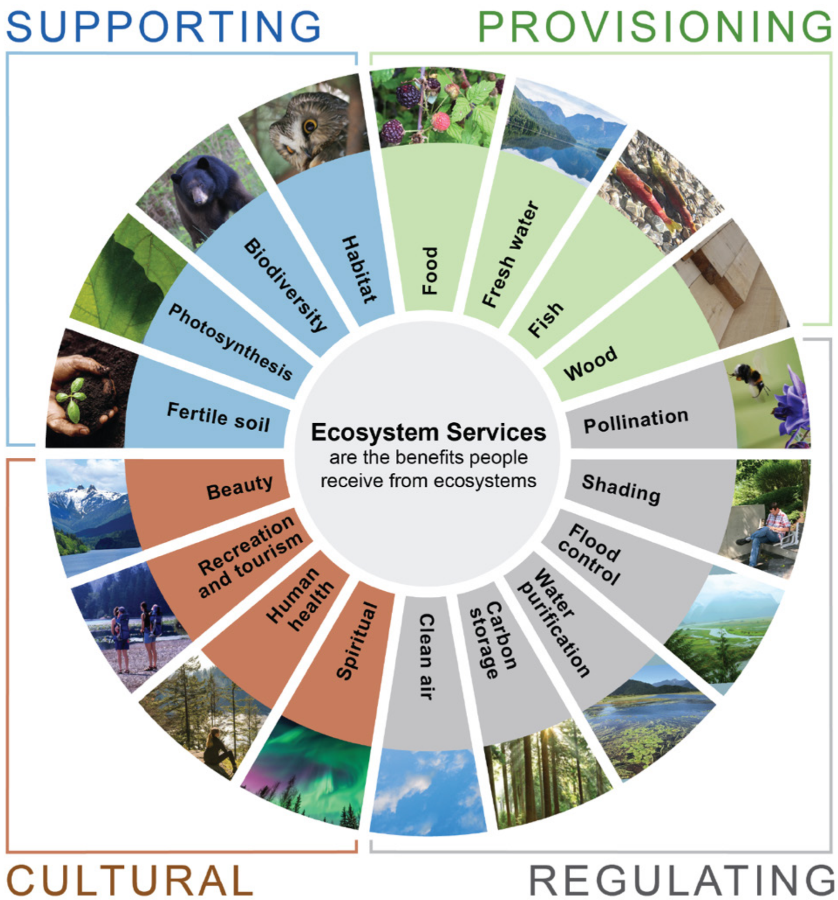
Key Message 11.1

Agricultural Adaptation Increases Resilience in an Evolving Landscape

Climate change has increased agricultural production risks by disrupting growing zones and growing days, which depend on precipitation, air temperature, and soil moisture (*very likely*, *very high confidence*). Growing evidence for positive environmental and economic outcomes of conservation management has led some farmers and ranchers to adopt agroecological practices (*very high confidence*), which increases the potential for agricultural producers to limit greenhouse gas emissions (*likely*, *medium confidence*) and improve agricultural resilience to climate change (*high confidence*).

Agriculture focuses on the provision of food, feed, fiber, and fuel. Modern agriculture provides essential products engineered for mass production to serve the nutritional, clothing, construction, and energy needs of society. Historically, excessive tillage, heavy reliance on agrochemicals, and simplified cropping systems have led to environmental degradation; therefore, using adaptive conservation management approaches and diversifying agricultural landscapes[3] can build resilience—the ability to anticipate, prepare for, adapt to, withstand, and recover from disruptions like climate change—and improve ecosystem services that affect plant, animal, and human health and well-being (Figure 11.2). Indigenous Knowledge can also play a role in these adaptive approaches (KMs 16.3, 30.5).[4,5]

Ecosystem Services: Hub of the Wheel

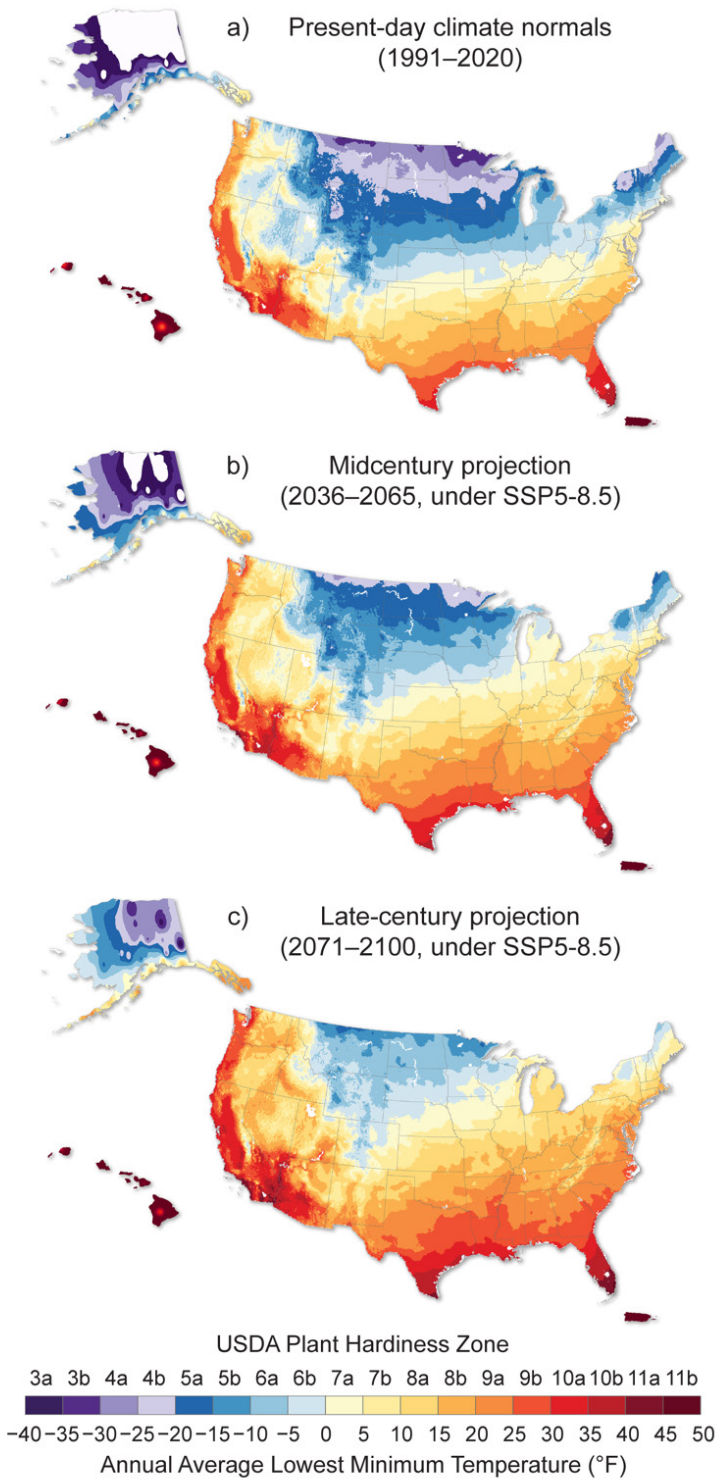


Ecosystem services have wide-ranging benefits for plants, animals, and human well-being.

Figure 11.2. People receive many benefits from the ecosystem, including provisioning, regulating, supporting, and cultural services. Adaptive management practices (see Figure 8.1) foster resilience to climate change and related disturbances in these ecosystem services (see Figure 8.18). Adapted with permission from MetroVancouver 2018.[6]

Agricultural systems depend on soil, water, air, and sunlight, which vary seasonally and may fluctuate as much as daily. Climate change disrupts these fundamental natural resources. Plant hardiness zones, a common metric for plant appropriateness for a given local climate, have shifted as climate change lengthens frost-free periods (Figure 11.3).[7] Climate shifts, along with greater expected weather volatility, require changes in agricultural practices, including crop selection, use of equipment, and management approaches.

Projected Changes in Plant Hardiness Zones

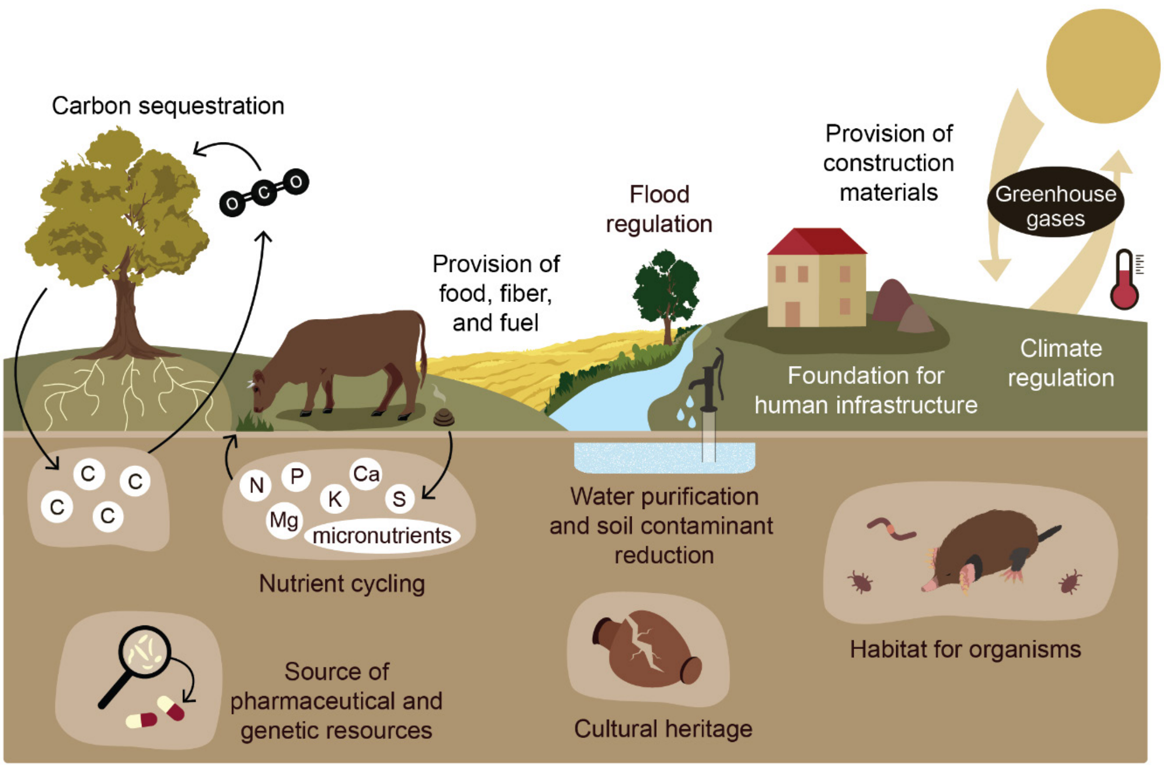


Plant hardiness zones are projected to shift northward throughout this century.

Figure 11.3. Plant hardiness zones help local farmers and gardeners identify optimal crops to plant and when to plant them. Hardiness zones are projected to migrate northward as the climate warms. The maps show plant hardiness zones for (**a**) present-day (1991–2020) climate normals, and (**b**) midcentury (2036–2065) and (**c**) late century (2071–2100) under a high emissions scenario (SSP5-8.5). Figure credit: USDA, NOAA NCEI, and CISESS NC.

Climate change exacerbates soil degradation through drought, flooding, and excessive heat events that disrupt normal plant production and ecosystem processes. Excessive tillage, overgrazing, and overreliance on agrochemicals can further deplete soil organic matter and impair soil health.[8,9,10,11] Soil health management can improve the resilience of agricultural systems to climate change and support sustainability goals (Figure 11.4).[12] Conservation-based agroecological approaches that improve soil health are increasingly recognized as necessary to maintain productivity while achieving a healthier environment.[13,14,15] While agroecology encompasses ecological, economic, and social dimensions,[16,17,18] the fundamental scientific concept underlying agroecology is the use of ecological principles to sustainably design and manage agricultural systems.[19] Applying agroecological concepts spans a wide range of practices,[18,20] which may overlap with nature-based solutions, precision technologies, and climate-smart agriculture aimed at climate change adaptation and mitigation (Box 11.1; Figure 11.5).[21,22,23,24,25,26] Agroecological practices can also include matching species to the environment, organic matter–driven nutrient cycling, integrated management, and natural pest controls whenever possible,[27,28,29,30] all of which are expected to reduce reliance on synthetic agrochemical inputs. Further, a spatially diverse landscape of croplands, grasslands, forests, and wetlands is expected to support more robust ecosystem functioning (Box 11.1; Figure 11.5).

Soil as a Foundation



Healthy soil plays a foundational role in agriculture, ecosystems, society, and culture.

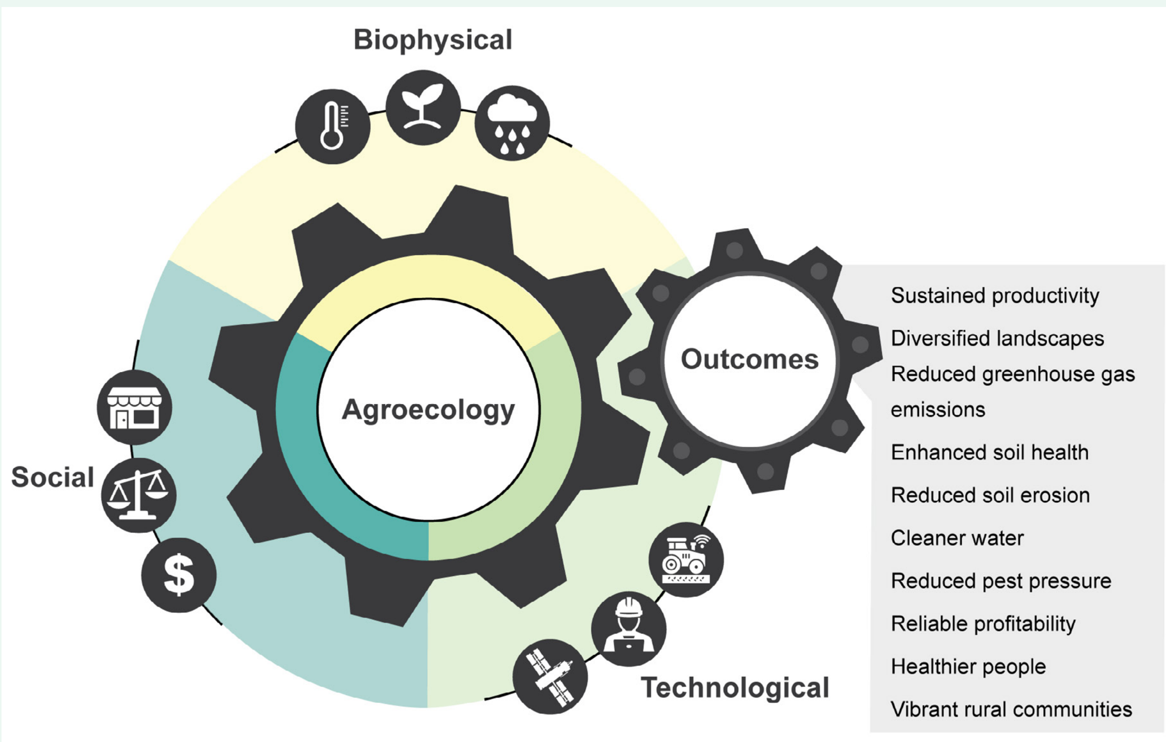
Figure 11.4. Healthy soil provides the foundation for many agricultural, ecological, microbiological, societal, and cultural activities. Climate change can negatively affect soil health, thus weakening its foundational role. Adapted from Baveye et al. 2016[31] [CC BY 4.0].

Box 11.1. Agroecological Approaches to Land Management

Multiple definitions of agroecology exist. As a result, what constitutes an acceptable practice under one definition may be excluded using a different definition. Here, agroecological approaches are defined as land management practices that integrate biophysical, technological, and social concepts and principles to guide the design and management of food and agricultural systems. Agroecological practices include, but are not limited to, 1) improved genetics and breeding, 2) soil health management, 3) integration and diversification of crops and livestock, and 4) precision technologies. Agroecology considers farming practices and management approaches that are developed through a systems science lens, taking into account local conditions and history. Agroecology might include subsistence and organic farming but may also include prudent use of resources through technological interventions. Regardless of scale and level of technological investment, agroecology is the application of science-based ecological concepts and principles to design and manage productive and sustainable agroecosystems. (For a more thorough discussion on agroecology, see Altieri et al. 2015.[32])

Agroecological approaches are used to achieve practical, climate-smart agricultural outcomes balanced with improved ecosystem services and rural livelihoods. Goals of climate-smart agriculture are increased productivity, adaptation to climate change, and reduced greenhouse gas (GHG) emissions.[33] Desired ecosystem services are to mitigate GHG emissions, increase soil carbon, enhance biodiversity, improve environmental quality, and increase agroecosystem adaptability and resilience. Specific practices for climate adaptation are not prescribed; this scientific framework allows practitioners to make decisions reflecting their unique environmental and socioeconomic conditions.

Agroecology Approaches and Outcomes



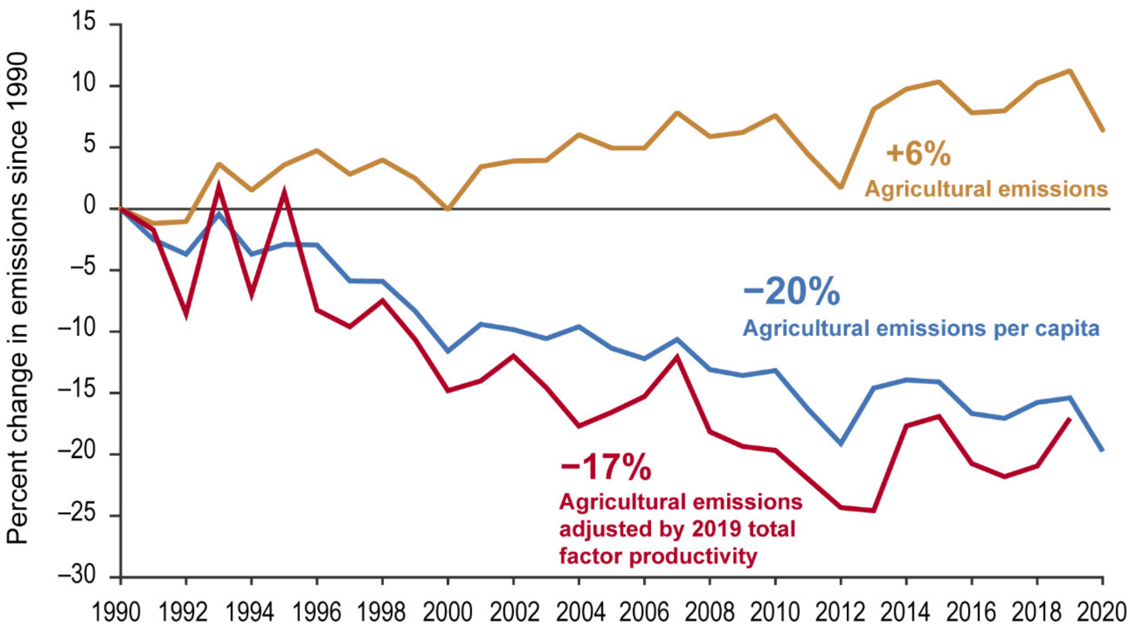
Agroecological approaches seek to achieve beneficial agricultural outcomes while promoting ecosystem services and rural livelihoods.

Figure 11.5. Science-based application of agroecological approaches results in outcomes that balance agricultural productivity and profitability with ecosystem services and societal well-being. Figure credit: USDA.

Agroecologically based systems promote the transfer of nutrients between living soil components (bacteria, fungi) and non-living soil components (organic matter, minerals) to make nutrients more available to crops and minimize reliance on synthetic fertilizers. Nitrogen fertilizer is a major contributor to emissions of nitrous oxide (N_2O), a potent greenhouse gas (GHG). Improving crop nutrient-use efficiency (i.e., increasing crop production per unit of fertilizer used) can reduce input costs for farmers, avoid contamination of water bodies from runoff and leaching, and reduce N_2O contributions to climate change while also making farms more resilient to climatic changes (Figure 11.5).[34,35]

Greenhouse gas emissions from US agriculture over the last three decades have been steadily rising (Figure 11.6). However, economies of scale, enhanced farm technologies, and improved genetics have also increased overall productivity, leading to lower GHG emissions per capita and per unit of total factor productivity (a ratio of agricultural outputs produced to inputs used).

US Agricultural Greenhouse Gas Emissions Indices, 1990 to 2020



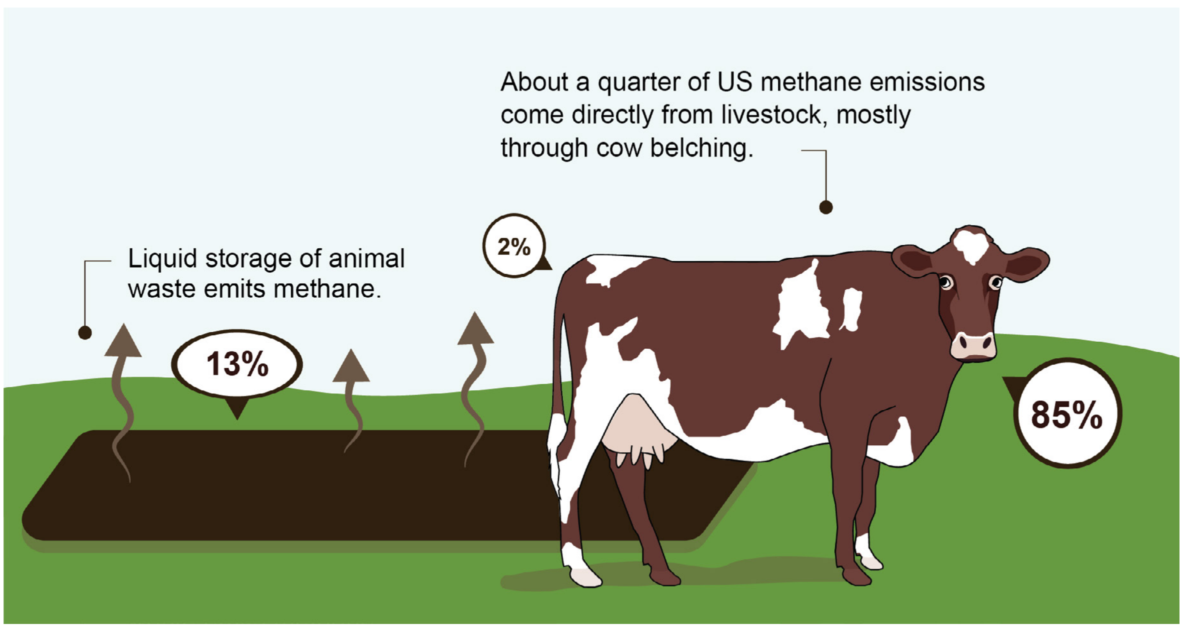
While total agricultural greenhouse gas emissions continue to increase, emissions per capita and per unit of total factor productivity (a ratio of agricultural outputs produced to inputs used) have declined over the last 30 years.

Figure 11.6. Over the last 30 years, declines in US agricultural emissions per capita (blue line) and per unit of agricultural productivity (red line) reflect an increasingly efficient US agriculture sector that produces more food, fiber, and renewable fuel with fewer resources. Despite per capita and per unit of productivity improvements, the long-term trajectory of total emissions from US agriculture (yellow line) continues to rise, and mitigation remains a critical priority. Adapted with permission from ©Myers 2022.[36]

Despite greater production efficiencies (KM 11.2), total GHG emissions to the atmosphere continue to increase, and mitigation remains a critical priority (Ch. 32). Agroecological practices often mitigate GHG emissions while providing key adaptation mechanisms to overcome water deficits, improve nutrient cycling, avoid pest pressures, and stabilize production over time.[37,38] Sequestering carbon in agricultural soils has emerged as one strategy to reduce GHG emissions. Land uses and agricultural practices that enhance year-round plant cover and growth convert atmospheric carbon dioxide (CO_2) into plant biomass, most of which decomposes and is re-released to the atmosphere as CO_2, but a small proportion is stored as soil organic matter. Because soil loses carbon much faster than it can gain carbon,[39] minimizing disturbance and/or maintaining more stable, persistent plant cover or residues is critical for soil carbon storage and its associated ecosystem services. For example, perennial systems—such as agroforestry that combines grassland with woodland—stimulate carbon storage in soil and in woody vegetation while also supporting greater biodiversity, alleviating heat stress for grazing livestock, and improving watershed management.[40,41,42,43]

Livestock production is impacted by and contributes to climate change by emitting multiple GHGs (CO_2, N_2O, and methane [CH_4]), which vary in amounts by production scale. Livestock producers also face increasingly challenging management decisions due to fluctuations in precipitation, rangeland forage conditions, feed costs, and livestock market prices.[44,45,46] Changing conditions have led to adaptive livestock management, which promotes flexible decision-making while documenting and learning from previous management actions.[47,48] Enteric emissions from livestock production contribute 25% to total US CH_4 emissions (Figure 11.7).[49] Some mitigation-reduction options, such as ruminant feed supplements and energy capture from liquid manure systems, have been identified (KM 32.3). Methane is a potent GHG but is generally shorter-lived in the atmosphere (approximately 10 years) than CO_2 (months to millennia) and N_2O (116 years; Table 2.1). More accurate accounting of global warming potential that differentiates between long-lived versus short-lived GHGs is expected to improve calculations of future global temperature as well as the non-climate benefits of GHG-specific abatement strategies, especially for CH_4 from agriculture.[50,51]

Cattle-Based Methane Emissions



Ruminant livestock systems contribute to US methane emissions primarily through belching.

Figure 11.7. Ruminant enteric fermentation via eructation (i.e., belching) contributes most of the methane emissions from US animal production systems (85%), with smaller contributions from manure lagoons (13%) and livestock flatulence (2%). Enteric fermentation contributes approximately 25% of total domestic methane production, making agriculture the largest source of US methane emissions. Figure credit: USDA, NOAA NCEI, and CISESS NC.

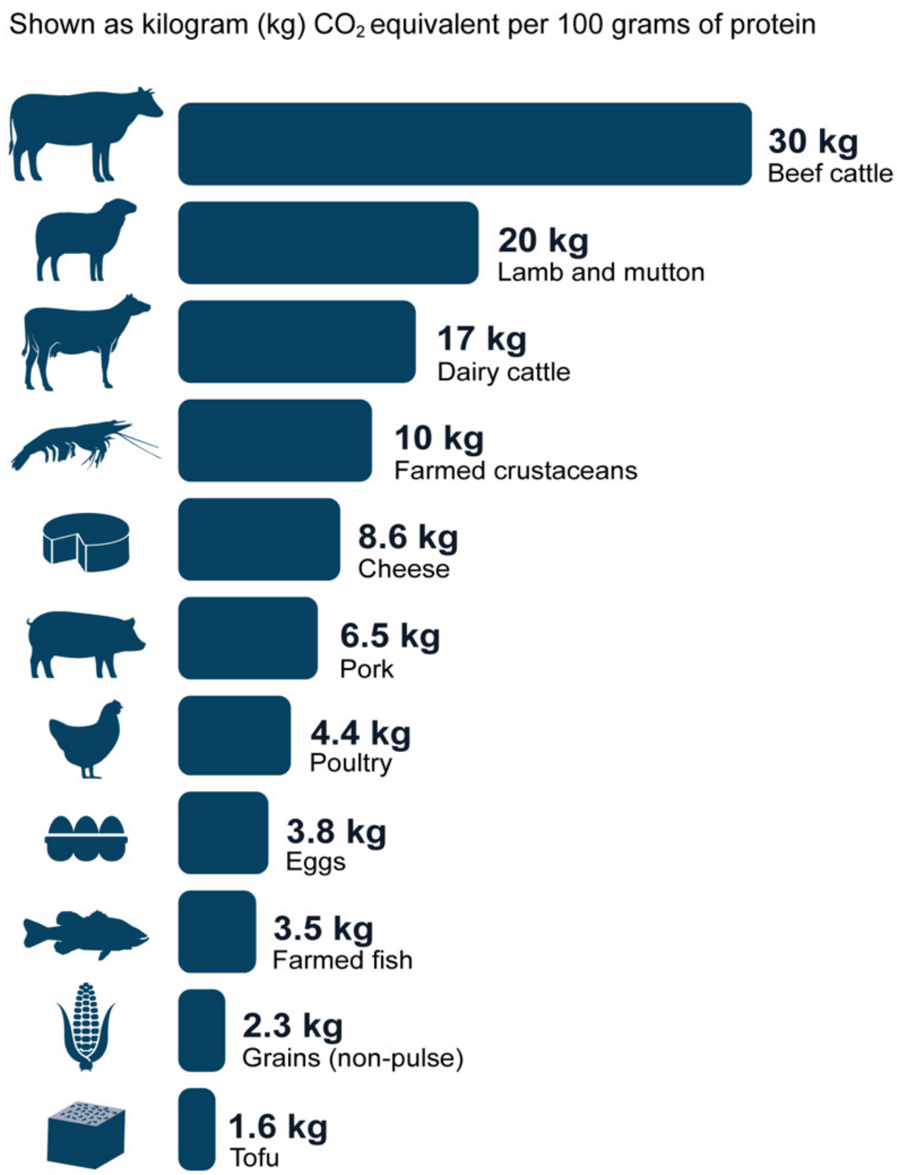
The complexity of climate-related threats and the diversity of agricultural environments in the United States require an array of management approaches. Matching unique regional combinations of plant and animal genetics with regionally relevant management practices can optimize soil carbon sequestration, reduce GHG emissions, and enhance adaptability to a changing climate. Finer-scale precision management aided by digital support tools and artificial intelligence can better account for soil and microclimate variability at farm, field, and subfield levels to maximize results with existing natural resources.

At all spatial and temporal scales, accurate, reliable, and accessible data are critical for effective agricultural management decisions and to improve resilience to climate change. Instrumentation and technology have rapidly evolved but must be harmonized with historical information to guide adaptive management approaches.[52,53] Data collected over longer time periods are necessary to interpret, for example, water availability across periods of drought. Coupling field measurements with computer models can aggregate estimates of productivity, soil carbon changes, biodiversity, and water quality over farms, counties, and regions. Developing these technologies for local, regional, and national scales will help decision-making to address increasing competition among food, water, and energy sectors. To be effective, however, agricultural data on climate-smart practices need to be widely accessible and large in scale.[54]

Rising concerns over food sustainability have driven public interest in alternative production of plant and protein sources, revealing consumer preferences for products that claim reduced GHG emissions. Examples include urban agriculture (e.g., community gardens, food forests, rooftop farms), controlled-environment agriculture (e.g., greenhouses, grow houses, growth chambers), substitution of seafood (“Blue-diet”) for livestock-based foods,[55] plant-based meats, and cell-cultivated food production (e.g., cultured meats). These options offer the potential to reduce GHG emissions.[56,57,58,59] However, some approaches can involve more infrastructure or energy inputs per unit of food production, increasing their GHG emissions compared to conventional farming practices.[60] The development, affordability, and sustainability of alternative agricultural systems will depend on social, economic, and environmental factors, as well as institutional constraints (e.g., laws and incentives for creating sustainable systems).[61]

As with terrestrial production practices, innovations in aquaculture have also led to climate-adaptive approaches to protein production. Aquaculture’s high feed-conversion efficiency (i.e., unit of protein produced per unit of feed)[62] and lower overall GHG emissions compared to other animal proteins (Figure 11.8)[63] highlight its climate-smart potential to increase protein production, human nutrition, and food availability.[64] Within aquaculture, however, GHG emissions vary by species, with seaweeds and bivalves among the lowest emitters.[65] In addition, location of marine aquaculture and selective breeding can further reduce climate-related impacts.[66] While planned production through aquaculture can buffer climate change disruptions in output from wild-caught fisheries (Ch. 10), rising temperatures, ocean acidification, and sea level rise due to climate change will also limit increases in aquaculture production.[67] Furthermore, complex social and ecological concerns about aquaculture have been raised by some coastal and Indigenous communities. Social concerns include conflict with traditional and commercial livelihoods and consolidation of business activities. Ecological concerns include introducing disease and parasites to wild species, competition between wild and farm-raised species, pollution, and damage to shellfish beds from fish farming, among others (KM 11.3).[68,69]

Greenhouse Gas Emissions from Protein Production



Greenhouse gas emissions from protein production vary greatly according to food type.

Figure 11.8. Estimated greenhouse gas (GHG) emissions from protein production vary widely depending on food type. Global median emissions (in kg of carbon dioxide [CO_2] equivalents for every 100 g of protein produced) are shown here for 11 major protein sources. Although cereal grains have lower protein content, they are included here because they contribute 41% to global protein intake. While US emissions values may differ slightly from global values, the relative differences in GHG emissions by protein type are expected to be consistent. Figure credit: USDA, NOAA NCEI, and CISESS NC.

Creating resilient agricultural production systems in the face of climate change is possible. Agroecological approaches supported by conservation programs (such as those offered by the USDA through the Natural Resources Conservation Services, Farm Service Agency, and Risk Management Agency)[70] can create rural opportunities (Box 25.3) while optimizing production goals with ecosystem services to store soil carbon, reduce GHG emissions, protect biodiversity, maintain water and air quality, and improve soil and human health by reducing exposure to pollutants. Producers may focus on adaptation to adjust management to climate change and/or on mitigation to store soil organic carbon and reduce GHG emissions.

Key Message 11.2

Climate Change Disrupts Our Food Systems in Uneven Ways

Climate change is projected to disrupt food systems in ways that reduce the availability and affordability of nutritious food, with uneven economic impacts across society (*likely*, *medium confidence*). Impacts of climate change on other measures of human well-being are also distributed unevenly, such as worsening heat stress among farmworkers (*high confidence*) and disruptions to the ability of subsistence-based peoples to access food through hunting, fishing, and foraging (*high confidence*).

Climate Change Impacts on Food System Security

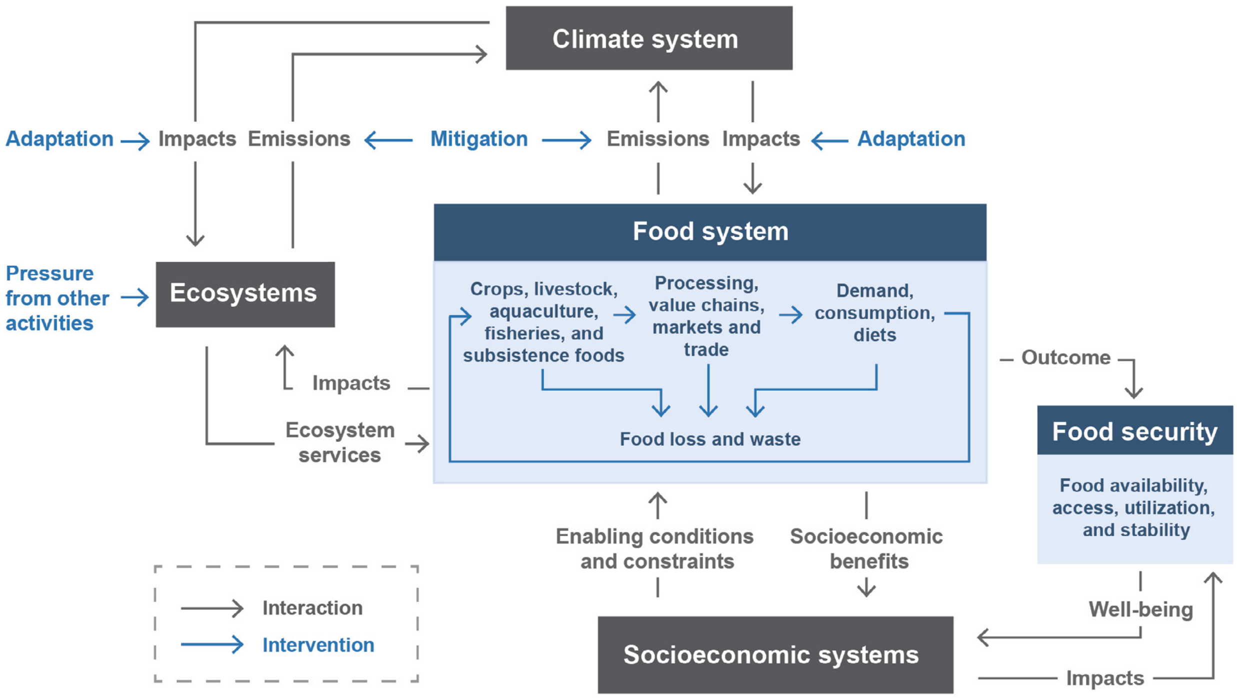
All dimensions of food security—availability, accessibility, utilization (or usability), and stability[71]—are expected to be affected by climate change through long-term changes in average climatic conditions (e.g., annual precipitation and temperature), as well as increases in climate variability and the frequency, magnitude, and duration of climate extremes (Ch. 2). These climatic changes are affecting all aspects of the food supply chain (Figures 11.9, 11.10), including production, storage, processing, distribution, retail, and consumption (Figure F4.1).[72,73] Disruptions to the food supply chain have both local and global impacts on food systems, including food security (Figures 11.11, 23.9).

At local or regional levels, extreme weather events and compound extremes (for example, a heatwave during a drought) are affecting local food security by damaging food production and destroying associated infrastructure (see Focus on Compound Events; KMs 22.4, 28.3).[74,75] These impacts sometimes ripple out to global food systems, impacting prices and availability in other regions of the world.[76,77] At national or international levels, co-occurring extremes and non-climate disruptions (e.g., recessions, pandemics, conflicts) sometimes cascade down to limit food access and availability at local scales throughout the world by reducing supplies, limiting trade, and increasing prices (KM 30.1).[72,78]

Vulnerabilities of food systems to climate change are a function of their complex structures, such as how dependent the systems are on locally grown versus imported foods[79] and how systems respond to changes in climate, ecosystems, and socioeconomic factors (Figures 11.9, 23.9). When widespread shocks occur, local elements of the food system can help insulate communities against some large-scale impacts (KM 30.1). For example, local farmers, mobile meat processors, and food assistance organizations helped insulate their communities against some of the effects of COVID-19-related worker shortages in the commercial food processing and transportation sectors.[78]

Conversely, when a localized shock occurs, interstate, national, and international trade can help fill gaps in food availability (KM 19.2).[79] Each of these local and non-local elements of the food system has unique strengths and weaknesses,[78,80,81] including different impacts on GHG emissions, socioeconomics, and ecosystem goods and services (e.g., carbon storage, biodiversity, water quality; Figure 11.9; Box 11.2).

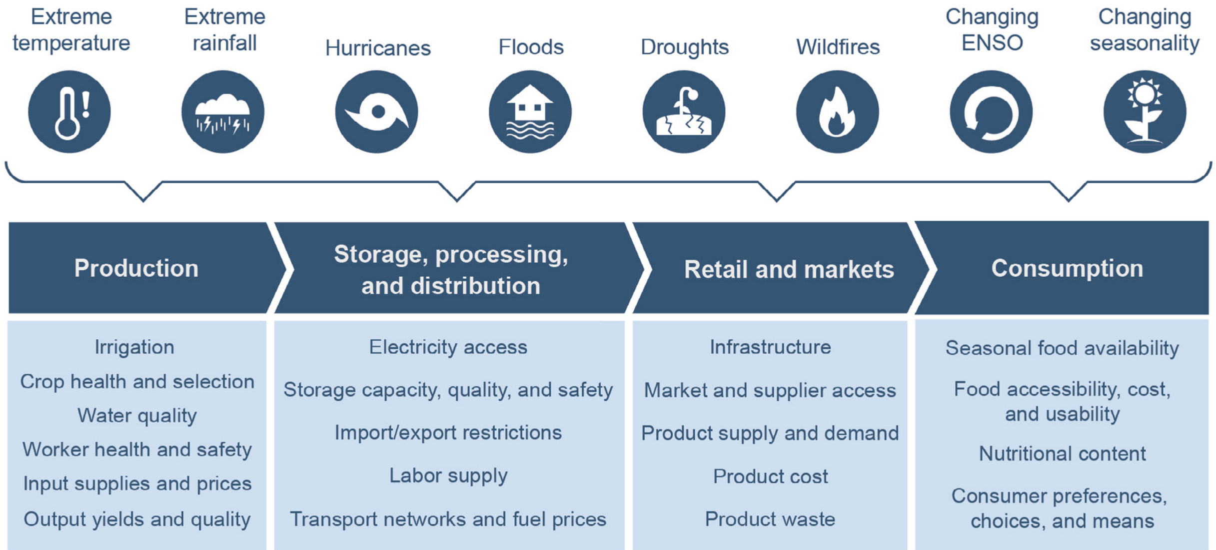
Connections Between Climate, Food, Ecosystem, and Socioeconomic Systems



Food security is an outcome of the food system, which influences and is influenced by the climate system, ecosystems, and socioeconomic systems.

Figure 11.9. A food system is a complex network that encompasses all inputs and outputs involved in food production, foraging, harvesting, transport, processing, retailing, consumption, and food loss and waste. There can be different types of food systems, each having impacts on and being impacted by climate, ecosystems, and socioeconomic systems. Interactions between these systems influence human well-being through food security outcomes, such as food availability, access, utilization, and stability. Interventions, such as mitigation and adaptation, can reduce risks to food systems, which improves food security and well-being within socioeconomic systems. Adapted with permission from Figure 5.1 in Mbow et al. 2019.[82]

Example Effects of Climate Change on the Food Supply Chain



Climate change has cascading and compounding effects on all stages of the food supply chain.

Figure 11.10. Extreme events fueled by climate change (first row, icons) can affect each stage of the food supply chain (second row, dark blue), resulting in compounding and cascading effects on the food system (third row, light blue). Adapted with permission from Davis et al. 2021.[72]

Socioeconomic Costs of Climate Change in Food Systems

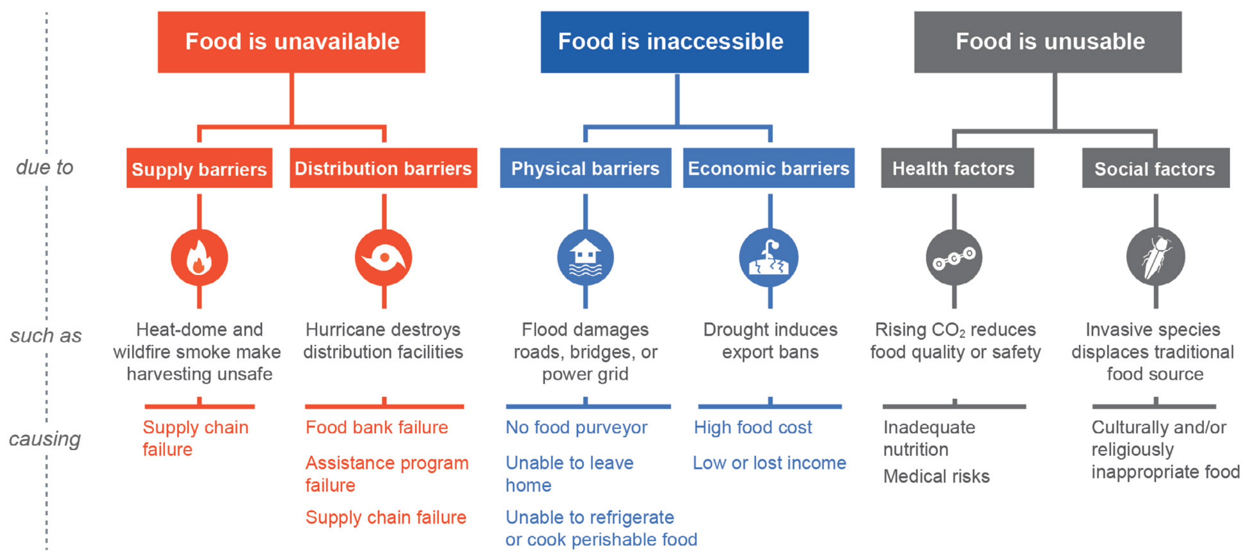
Food security risks from climate change impose socioeconomic costs that workers, producers, and consumers may feel but can be challenging to measure (Ch.15; KM 19.1). Climate change impacts on food production have been measured more comprehensively than impacts on food processing, distribution, marketing, and consumption.[83] For example, climate change is affecting crop insurance costs and losses.[84,85] Between 1991 and 2017, increasing temperature with climate change was responsible for 19% of crop indemnities in the US.[86]

Total factor productivity (TFP) is the focus of several economic studies about the effects of climate change on agriculture.[87] The United States has seen steady growth in agricultural TFP, 1.4% per year since 1948, due largely to technology improvements.[88] While TFP varies annually with extreme weather events, climate change has dampened TFP growth in the United States by 12% over a 54-year period (1961–2015).[89] Agricultural TFP is projected to decline back to pre-1980s levels by 2050 unless the positive effects of innovation and adaptation in US agriculture (after accounting for any negative effects) can be doubled relative to recent historical rates.[88] In the Midwest, greater specialization in crop production has instead caused TFP to become more sensitive to high summer temperatures and soil moisture deficits.[87,90]

Higher temperature and humidity are also affecting farmworker productivity, earnings, and safety, for example, in labor-intensive fruit and vegetable systems (Focus on COVID-19 and Climate Change).[91,92] Heat-related stress and death are significantly greater for farmworkers than for all US civilian workers, and the number of unsafe working days is projected to double by midcentury (Ch. 15; Figure 28.7).[93,94] These effects on farmworker safety and productivity influence the broader economy through reduced agricultural output and higher food prices.[95] Farmworkers also disproportionately experience food insecurity,[2,96] which can be worsened by extreme events fueled by climate change. For example, drought reduces demand for farm labor, thus lowering workers' income and ability to buy food (Ch. 28).[97]

By 2050, climate change is projected to increase some crop prices (see Table 2 of Baker et al. 2018[98]). For example, a 26% price increase is expected for corn due to a 5.5% reduction in production, while a 30% price increase is expected for soybean due to a 19% reduction in production (relative to a no-climate-change baseline and averaged across nine climate change scenarios ranging from a low scenario [RCP2.6] to a scenario slightly higher than a very high scenario [RCP8.5]). A 26% price increase is expected for wheat due to a 36% reduction in production, and a 3.1% price increase is expected for rice due to a 61% reduction in production. Price increases depend on complex interactions between climate change, international trade, and domestic institutions and policies,[80] but they generally benefit producers and hurt consumers (KMs 19.2, 22.3),[99] especially if consumer income cannot keep pace with rising food prices. In such cases, higher food prices can reduce food accessibility (Figures 11.10, 11.11).

Examples of Food System Failure Due to Climate Change



Climate change is expected to increase risks to food security in multiple ways.

Figure 11.11. This fault-tree shows some of the many ways that food system failures can occur due to climate change, ultimately making food less accessible, available, or usable. In some cases, food may still be available yet inaccessible or unusable. For example, power outages during extreme heat events or after a hurricane may prevent some consumers from safely refrigerating or cooking perishable foods they have already purchased. Adapted from Chodur et al. (2018)[100] [CC BY 4.0].

Climate Change Impacts on Food Security Are Distributed Unevenly

Climate change interacts with food security and human health (KM 15.1; Figures 11.9, 11.10, 23.4). Approximately 38 million people in the United States live in food-insecure households.[1] Food insecurity is associated with lower income and affects both dietary quality, quantity, and stability.[1] Food system disruptions during increasingly frequent and severe extreme events due to climate change will disproportionately affect food accessibility, nutrition, and health of some groups, including women, children, older adults, and low-wealth communities (KMs 15.2, 22.4, 28.4).[101,102]

For example, if climate change reduces the affordability of some nutritious foods,[98] then households might rely more on calorically dense but nutrient-poor diets, which increase health risks and healthcare costs.[103,104,105] Some older adults who have limited transportation or financial resources face complex challenges and trade-offs when trying to safely access, store, and cook adequate amounts of nutritious food, particularly during and following extreme events (e.g., floods that close roads or stores; KM 11.3).[106,107]

Climate change is also affecting the ability of individuals and communities to obtain food through hunting, fishing, foraging, and subsistence farming (KMs 16.1, 22.1, 25.3, 27.1, 30.1).[108] People from a variety of socioeconomic and cultural backgrounds, including some from Indigenous communities and rural areas, engage in these activities for various reasons, such as cultural or spiritual traditions, medicinal practices, and recreational enjoyment or to diversify food types or nutritional value or reduce purchased foods.[109,110]

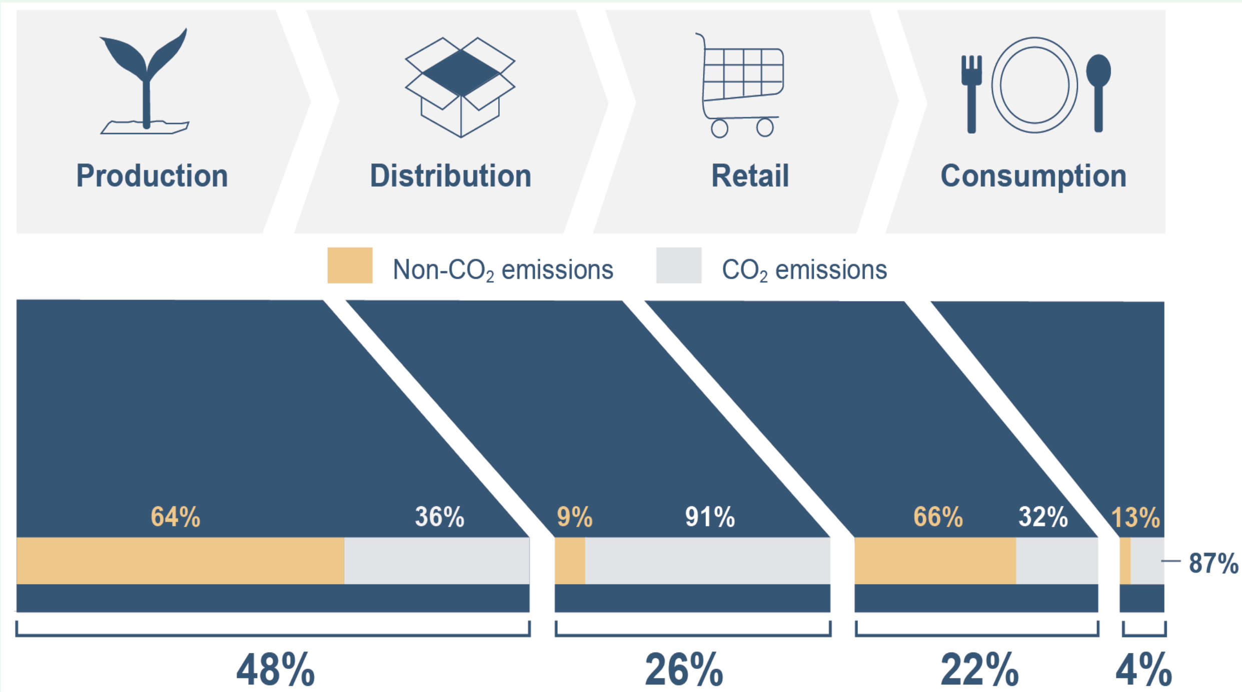
Subsistence-based people who forage for food (such as wild rice, beans, and mushrooms) may face unique challenges from climate change (KMs 16.1, 24.2).[111] Drought can reduce the availability of forest-based foods such as berries, nuts, and seeds. In Alaska, where subsistence hunting and fishing are prevalent among Indigenous Peoples, thinning sea ice makes travel to traditional hunting and fishing/shellfishing grounds longer and more dangerous (Ch. 29). Ecosystem changes reduce the abundance of important species and alter ranges, making it more difficult for people to anticipate those species' locations (KM 29.3).[111]

Subsistence food producers may also be more vulnerable to the effects of climate change due to smaller farm size, insecure land tenure, lower capitalization, and other non-climate stressors (e.g., reduced market access).[112,113] Some communities, however, are proactively leading food security projects to help adapt to and mitigate against climate change (Box 30.4). One example is the Osage Nation's community orchard—informed by Tribal Ecological Knowledge, designed with community health in mind, and providing nutritious fruits, nuts, and berries for community members.[114] Other examples of Tribal adaptation to climate change are described in Key Message 25.5 and Box 29.6.

Box 11.2. Greenhouse Gas Emissions in the Food System

Most food consumed in the United States is domestically grown, primarily in the Midwest (KM 24.1) and California (KM 28.3).[115,116,117] Production of food is the largest contributor of GHG emissions from the food system, followed by distribution, retail, and consumption (Figure 11.12). Of the total food supply chain (Focus on Risks to Supply Chains), an estimated 30%–40% of food spoils or is wasted, largely at the consumption stage (e.g., households and restaurants).[118,119,120] The further along a supply chain that food waste occurs, the more energy and GHG emissions have been invested. Reducing food loss and waste would reduce food system GHG emissions and provide opportunities to increase food security (KMs 6.3, 32.2; Table 31.1).[120]

Greenhouse Gas Emissions by Food Supply Chain Stage



Greenhouse gas emissions differ by stage of the food supply chain.

Figure 11.12. Greenhouse gas (GHG) emissions occur at all stages of the food supply chain. Production (i.e., the growth and harvesting of crops and the rearing and slaughter of livestock) represents 48% of the overall GHG emissions from the food supply chain. Non-carbon dioxide (non-CO_2) emissions are largely from nitrous oxide emissions from nitrogen fertilizer and manure management and methane emissions from livestock production in the production stage, along with chlorofluorocarbon emissions at the retail stage. Carbon dioxide emissions in the primary food production stage are from soil and land-use management, fertilizer production, and farm energy use. Energy use is the primary CO_2 emissions contributor to supply chain stages downstream from food production. Adapted from EPA (2021).[119]

Key Message 11.3

Rural Communities Face Unique Challenges and Opportunities

Rural communities steward much of the Nation's land and natural resources, which provide food, bioproducts, and ecosystem services (*high confidence*). These crucial roles are at risk as climate change compounds existing stressors such as poverty, unemployment, and depopulation (*likely*, *medium confidence*). Opportunities exist for rural communities to increase their resilience to climate change and protect rural livelihoods (*high confidence*).

Rural (nonmetro) areas comprise over two-thirds of the Nation's total land area[121] and are home to approximately 46.1 million people, or 14% of the total US population, including the majority of Indigenous census respondents. Rural communities represent a way of life with unique environmental assets, cultural heritages, and local identities. Rural populations are stewards of forests, watersheds, rangelands, farmlands, and fisheries and contribute significantly to natural resource conservation and society's benefit and enjoyment of some ecosystem services. Rural communities across these diverse contexts support national economic sustainability and food security.

Climate Change Risk in Rural America

Climate threats compound risks posed by structural trends such as dependence on goods produced outside the local area, digitization of economic and social life, and demographic change that may reduce resilience and rural quality of life.[122] Budgetary pressures during and after climate-related disasters can reduce local governments' ability to provide critical infrastructure, goods, and services (KM 19.2), especially in under-resourced (Ch. 19; KM 22.1), Indigenous (Ch. 16; KM 25.4), and other historically overburdened (Ch. 20) communities.[123,124,125] The increasing rate and severity of climatic disasters and the compounding and cascading effects of climate change place large economic hardship on local governments and rural communities (KM 2.2),[126,127] although metrics that reflect the complexity of these challenges and their spatial disparities have been historically lacking.

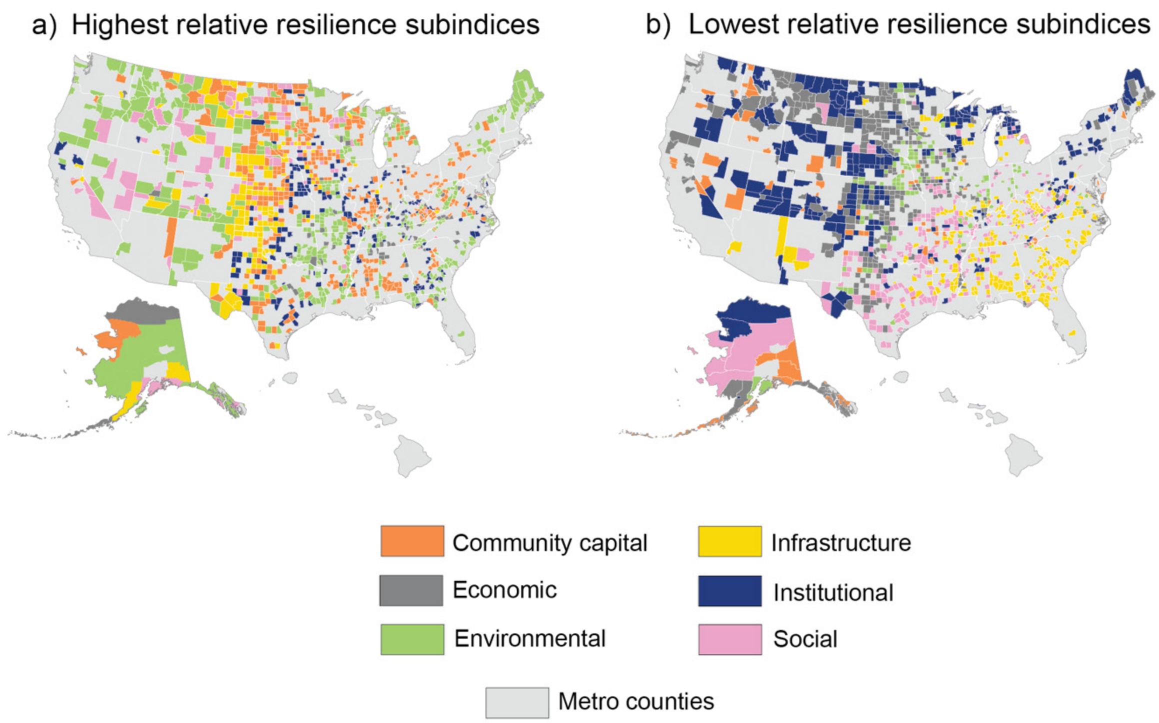
In recent years, there have been significant advances in analytic capabilities for identifying risk variation as influenced by a wide range of social (Ch. 20), economic (KM 22.3), and ecological factors (KM 24.5; Ch. 31). Measures that capture the ability of a community to prepare, adapt, and recover from disruption or disaster indicate greater risk to rural communities than what can be quantified in terms of expected annual loss due to natural hazards alone.[128] This suggests that a broad perspective of rural risk needs to be considered in prioritizing and supporting resilience efforts.

Rural Community Resilience

There is considerable spatial variability in social, infrastructural, institutional, economic, environmental, and community sources of resilience in rural areas (Figure 11.14). However, most rural communities rank lowest in economic resilience and highest in environmental resilience (Figure 11.13). Resilience encompasses the ability to anticipate, prepare for, adapt to, withstand, and recover from disruptions like climate change. Rural communities have unique sources of and barriers to resilience (Figure 11.14).[123] Resilience is hindered in communities with strained economic and social institutions.[129] Many rural areas struggle to maintain effective government services, economic sustainability, and a strong social base. Demographic and socioeconomic trends, such as population loss and persistent poverty, limit social and economic resilience in some rural areas. These communities lack the capacity or resources needed for recovery in the face of natural hazard events (KM 22.1; Box 25.1). Lack of access to technology and a lack of institutional capacity, for example due to limited financial and human resources, can compound the effects of natural disasters.[130]

Historical environmental justice inequities (Figure 20.1) often underlie and add further complexity to the resilience of rural communities to climate change (Ch. 20; KMs 15.2, 16.2, 26.4, 27.1, 31.2). Rural communities that are characterized by a sense of community, self-reliance, and tacit knowledge of the natural environment have enhanced capacity for resilience (e.g., Box 30.6).

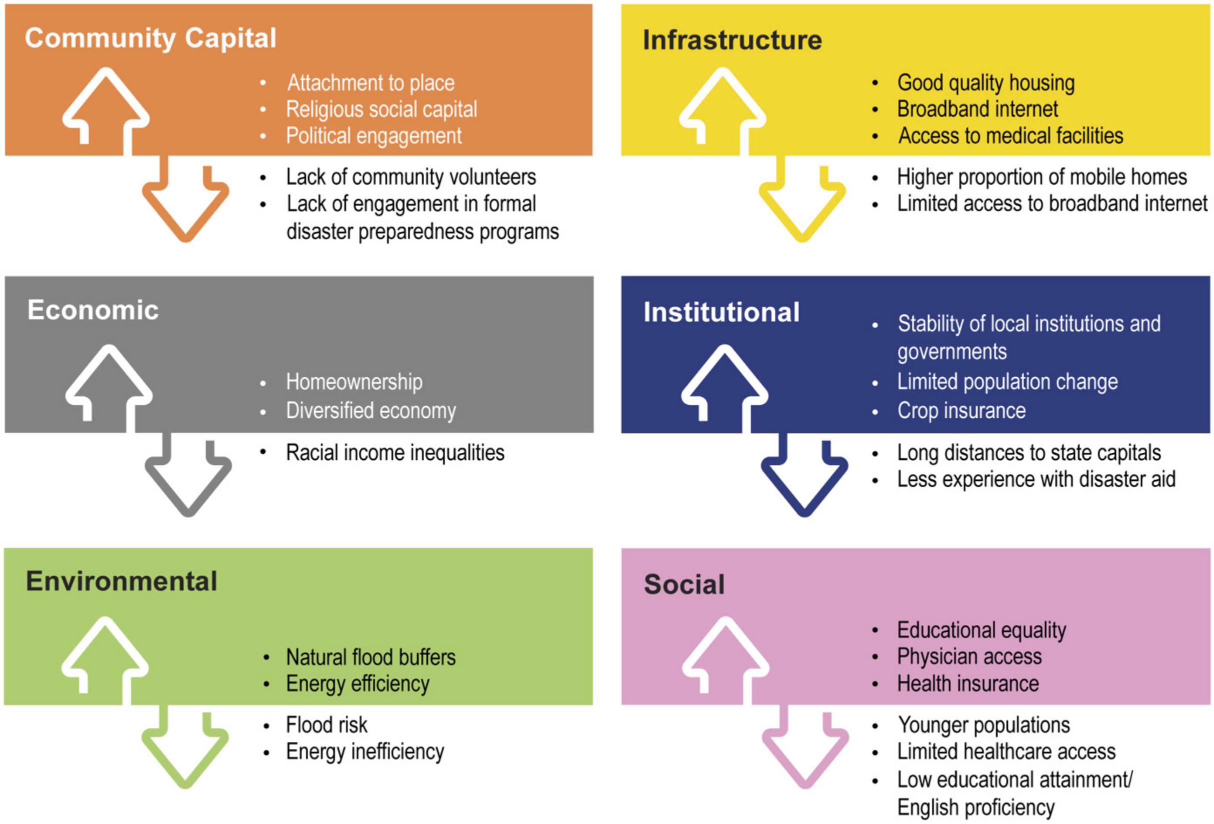
Community Resilience Index



Rural communities differ in the categories of the Baseline Resilience Indicators that contribute most substantially to their resilience.

Figure 11.13. Six broad categories (social, economic, community capital, institutional, infrastructure, and environmental) constitute the Baseline Resilience Indicators for Communities (BRIC; see Figure 11.14).[131] The highest (**a**) and lowest (**b**) relative category of resilience for communities within nonmetropolitan counties is shown at the county level. There is considerable spatial variability in each category of community resilience. The US Caribbean and US-Affiliated Pacific Islands are not represented on the map because of a lack of data. Discussion of resilience vulnerabilities for these areas can be found in Chapters 23 and 30. Figure credit: USDA, NOAA NCEI, and CISESS NC.

Baseline Resilience Indicators for Communities



Rural community resilience to natural hazards is measured by several broad categories of indicators that affect aspects of resilience (both positively and negatively).

Figure 11.14. The Baseline Resilience Indicators for Communities (BRIC) index is a composite measure of community resilience to natural hazards. It considers 49 indicators of existing attributes of resilience arranged in six broad categories: social, infrastructure, institutional, environmental, economic, and community capital. It can be used to compare community resilience within one county to that of another (see, for example, Figure 11.13). Positive and negative drivers of resilience for rural counties are provided for each category. Figure credit: USDA.

Economic dependence on single-sector or resource-based economies, as often found in rural areas, further constrains resilience (KMs 22.3, 25.3).[122] Many rural jobs are based on resource extraction and dependent on natural resources that are at an increased risk of disruption from climate hazards (e.g., the effects of rising ocean temperature on fisheries and the effects of drought on agriculture). Rural Alaska fishing communities provide a poignant example of how climate impacts compound persistent poverty, geographic isolation, lack of economic diversity, and resource dependence (KM 29.3). A marine heatwave, unprecedented in intensity and duration, hit the Gulf of Alaska from 2014 to 2016, leading to 18 fisheries disaster declarations in the region (Ch. 29).[132,133,134] Climate change is greatly altering the conditions of fishing access and distribution, with increasing collapses that are leaving fishers scrambling for the few alternative income opportunities or taking greater risks to harvest fewer and smaller fish (KM 10.2).[135,136]

While rural communities face challenges, they are also making positive contributions in enhancing climate resilience and mitigating climate change through renewable energy production (KM 5.3). Participatory approaches are needed to ensure that these efforts are equitable and meet community needs. After a natural disaster destroyed the town of Greensburg, Kansas, the community utilized a participatory approach involving multiple rounds of public meetings to engage citizens in planning a sustainable, climate-smart rebuilding process. Emphasis on green materials and Leadership in Energy and Environmental Design

Platinum–certified public buildings allowed the community to rebuild and procure 100% of the energy needed to supply the community through wind energy. Rural communities can contribute to an emerging clean energy economy, including through advanced biofuels[137] and agrivoltaic systems that simultaneously use land for both agriculture and photovoltaic energy production (Chs. 5, 6). Alternative energy sources have the potential to provide a significant portion of US energy needs while also reducing emissions and creating additional jobs and economic opportunity in rural areas.[138]

Traceable Accounts

Process Description

The chapter lead, with input from the coordinating lead author and agency chapter lead author, recruited the author team exclusively from federal agencies, in accordance with the decision of the National Climate Assessment (NCA) Federal Steering Committee (FSC). The author team was selected to provide expertise on the impacts of climate change on agriculture, food security, and rural communities, with an emphasis on diversity in research expertise, professional experience, and gender. The author team included agricultural, physical, and social scientists. Some were involved with previous Assessments. The author team met weekly to develop and revise drafts throughout the writing process. When disagreements over content, wording, or figures occurred, discussions among the author team occurred until a consensus was reached by the entire author team.

Because this chapter covered a wide range of issues, the author team considered and discussed a broad array of important issues and topics. The Key Messages and topics within each theme were selected after weekly discussions among the authors; a review of the pertinent literature by the author team; review of the Fourth National Climate Assessment and other government reports dealing with climate change and agriculture, food systems, and rural communities; listening sessions organized by the US Global Change Research Program; comments on the Zero Order Draft by the FSC and the public; and comments provided by reviewers on later drafts. A stakeholder public engagement workshop on January 28, 2022, also gave the public an opportunity to provide feedback on proposed Key Messages and topics. Based on these deliberations and feedback from the public, the author team decided to 1) make justice, equity, diversity, and inclusion issues a priority, reflecting the stated goals of the Fifth National Climate Assessment (NCA5); 2) focus on the entire food system rather than just at or behind the farm gate; and 3) reflect growing societal interest in an expanded set of agricultural outcomes beyond agricultural productivity.

The decision to include food systems as a key theme was driven, in part, by the FSC's decision to add "Food Systems" to the NCA5 chapter title. Chapter authors recognized that the US food system is shaped by many factors in addition to on-farm agricultural production. Climate and weather events impact food transportation, processing locations, and waste streams and intensities. Agricultural production is also affected by upstream value chains that influence on-farm production. Therefore, a more holistic approach was taken to understand climate and its changes.

Throughout chapter development, chapter leadership regularly engaged with leads from other relevant chapters to discuss cross-cutting issues and how best to incorporate them among the chapters.

Key Message 11.1

Agricultural Adaptation Increases Resilience in an Evolving Landscape

Description of Evidence Base

Agricultural Production at Risk

Extensive peer-reviewed literature has shown that climate change is slowing agricultural productivity and increasing agricultural vulnerability.[84,89,139] Multiple assessments have quantified that increasing air temperatures have lengthened the growing season in the contiguous US by about two weeks.[7] Higher temperatures are projected to lead to greater weather volatility, increased frequency and/or severity of extreme events (drought, frost damage, floods), and greater pest/disease incidence, all of which disrupt crop and livestock growth as well as the timing and effectiveness of agricultural management operations.

Adoption of Agroecological Practices

A growing number of agricultural studies report that agroecological practices can maintain agricultural productivity while also promoting a broader range of ecosystem services.[13,32,140,141] A recent survey of US farmers showed greater voluntary adoption rates of agroecologically based conservation practices in the last 10 years.[142] While the chapter does not discuss why US producers adopt, retain, or reverse practices, research consistently shows positive correlations between producer adoption of agroecological practices and environmental attitudes, formal education level, and awareness of a program/practice.[143,144,145,146]

Greenhouse Gas Emissions

The assessment of agricultural contributions to national greenhouse gas (GHG) emissions relied on inventories and estimates from the EPA[49] and were supplemented by data from other federal sources as well as numerous academic studies. Calculations of overall estimated GHG emissions from the agricultural sector among these various sources were comprehensive and in good agreement.

Mitigation via Agroecological Management

A growing body of evidence shows that adoption of agroecological management practices and technological advances can mitigate agricultural GHG emissions. Soil carbon storage can be increased with no-till cropping and diversification of production systems (e.g., greater crop rotation complexity, perennialization through more grazing lands and/or agroforestry).[147,148] Nitrous oxide and methane emissions can be reduced with improved management (e.g., efficiencies in fertilizer use, water use, and animal grazing and feed).[39,149,150] In addition to increasing the likelihood of GHG mitigation, implementation of such key strategies is projected to reduce dependency on exogenous inputs, protect the environment, and enhance agroecosystem resilience to climate changes.[151,152,153,154]

Major Uncertainties and Research Gaps

Although climate change impacts on agricultural crop and livestock production are known,[88,155] future effects at the farm, regional, and national scales are uncertain given the variety of adaptation strategies that can be deployed. Further, how these adaptation strategies will interact within highly spatially and temporally variable landscapes (i.e., soils, weather, topography) increase the uncertainty of strategy effectiveness.

Curbing GHG emissions from soil (carbon dioxide [CO_2] and nitrous oxide) remains a challenge, because greater production demands are expected to require tillage in some production environments and greater fertilizer inputs to stimulate growth. One major research gap is determining whether and how rapidly practices can be widely deployed to reduce emissions. There is also considerable uncertainty in the capacity of soils to increase carbon storage, given the many interacting factors between management, weather, and landscape properties. Improved livestock diet formulations and integrating livestock into cropping systems could significantly reduce GHG emissions, but scaling issues remain unresolved.

Crop production could be more resilient to climate changes if soils were healthier than at present, but the speed with which such a transformation is possible using an agroecological approach remains unknown.[156,157] Future water availability has a major impact on soil health, and forecasting this will be a challenge.

Description of Confidence and Likelihood

Confidence is *very high* and it is *very likely* that growing zones and growing days are changing. Historical evidence from a nationally distributed weather network and independent measurement and modeling studies consistently document increasing annual average air temperatures, increasing nighttime temperatures, and greater variability in frost-free periods. The body of evidence indicates an overall migration of growing zones and growing days toward northern latitudes and higher altitudes.

Confidence is *very high* for greater adoption of agroecological practices by producers. Statements on increasing adoption of agroecologically based conservation practices are supported by evidence that agricultural productivity can be maintained and/or increased while improving environmental outcomes.

Confidence is *medium* and it is *likely* that agricultural mitigation strategies will significantly reduce total GHG emissions because there is significant spatial and temporal variability in soils, weather, and type/timing of practices. Measured and modeled literature supports statements that agroecological approaches can increase soil carbon and improve efficiencies will mitigate GHG emissions.

Confidence is *high* that agricultural resilience can be improved in response to climate change. An increasing body of evidence shows that greater stewardship and new economic opportunities (i.e., carbon markets, conservation program cost-shares) can confer greater resilience through improved soil health and resource-use efficiency of external inputs.

Key Message 11.2

Climate Change Disrupts Our Food Systems in Uneven Ways

Description of Evidence Base

Food System Resilience

Much of the research on climate change impacts to US food systems, including economics research, focuses more on agricultural production and less on food processing, distribution, marketing, and consumption.[72,83,158] The literature provides some qualitative examples of impacts to these other sectors (e.g., Chodur et al. 2018;[100] Reardon and Zilberman 2018[83]), but the extent is limited and quantitative estimates are rare.

Socioeconomic Costs of Climate Change in Food Production

A larger set of literature exists on economic impacts of climate change to agricultural production. Economists have focused particularly on impacts to total factor productivity (TFP) of agriculture, which is the ratio of agricultural outputs produced to the quantity of inputs used.[87,88,89] This literature is mostly consistent in describing the negative impact and general magnitude of climate change effects on US agricultural TFP. Methods are well established, based on broader economic analyses of climate change impacts on productivity of entire economies (not just agriculture; e.g., Letta and Tol 2019[159]).

Also abundant is economics research on climate change and international trade of agricultural products.[80,160] This topic is not covered in depth here but can be summarized as 1) how climate-driven changes in agriculture production around the globe affect US agriculture through international trade[98] and 2) how interstate trade helps dampen economic impacts of climate change on US agriculture.[79]

Implications of Climate Change for Food Prices

Basic economic theory on supply, demand, and prices indicates that a reduction in agricultural yields due to climate change, and subsequent reductions in supply of an associated food product (holding all else constant), should increase that food product's price. In reality, complexities arise because not all else is held constant. For example, when wheat yields in the US Central Plains are negatively affected by drought, trade among states and nations dampens the impact on wheat prices. At the same time, consumer incomes and tastes for wheat versus substitute and complementary goods might also change, for entirely separate reasons, making it challenging to quantitatively isolate the effects of climate change on wheat prices.

Due to complexities in markets for agricultural and food products, relatively few economic studies have estimated the effects of climate change on prices of multiple agricultural commodities and food products at a national or international scale. The few studies that have (e.g., Baker et al. 2018;[98] Beach et al. 2015[99]) reached similar conclusions about the direction of impacts and are generally consistent with economic theory (i.e., when supply decreases, holding demand constant, price should rise). It is more difficult to assess the accuracy of the magnitude of their price change estimates.

Climate Change Impacts on Food Security Are Distributed Unevenly

Impacts of rising air temperature on outdoor workers' safety and productivity are well understood (Chs. 3, 15).[92] Consistent across multiple studies is that outdoor workers, including farmworkers, will be exposed to more heat stress in the future due to climate change. Disproportionate food insecurity among farmworkers in the US is also well documented in the literature, with consistent findings.[2,96]

The impacts of climate change on home food procurement activities, such as hunting, fishing, foraging, and subsistence farming are well documented in the literature.[110] Regarding impacts to Indigenous Peoples, Norton-Smith et al. (2016)[111] reviewed the literature on this topic and found abundant examples and agreement among studies; more recently, STACCWG (2021)[161] provides numerous examples directly from Tribes and Tribal Peoples.

Major Uncertainties and Research Gaps

Socioeconomic Costs of Climate Change in Food Production

The role of interstate trade in dampening the impacts of climate change has been studied less extensively than the role of international trade, but Dall'Erba et al. (2021)[79] provided a peer-reviewed example of this emerging body of literature.

Implications of Climate Change for Food Prices

Major sources of uncertainty in economic modeling of climate change impacts on crop yields and prices result from assumptions about 1) choice of climate models, 2) breadth of impacts from CO_2 fertilization, 3) land-use change and yield aggregation, 4) GHG mitigation efforts, and 5) future socioeconomic conditions.[162]

Climate Change Impacts on Food Security Are Distributed Unevenly

In studies of food-system workers' exposure to climate change impacts, sources of uncertainty include underreporting of heat-related stress among undocumented workers; variability in individual, workplace, and community risk factors; and future changes in the location of crops and labor needed.[94] There are also relatively few studies documenting or projecting how climate change affects food insecurity among farmworkers or other disproportionately affected groups, such as women, children, and older adults.

Description of Confidence and Likelihood

The statement about climate change impacts on the affordability of nutritious food is based on a relatively small number of studies about US agricultural TFP, but those reached consistent conclusions about impact direction and magnitude. Conclusions are also consistent with broader research about the separate effects of climate change on yields (or output) and input use. Therefore, confidence is *medium* with a likelihood level of *likely*.

The statement about the magnitude of quantitative impacts on food prices is based on a small number of contemporary studies with many sources of modeling uncertainty about complex national and international markets for agricultural and food products. However, statements about the direction or sign of estimated impacts on food prices, assuming climate change decreases the supply of some agricultural or food products, are consistent with economic theory. Additionally, numerous studies have consistently found that food price increases have uneven economic impacts across society, with reasonable levels of uncertainty.[163] Therefore, overall confidence about the direction or sign of change in food affordability, with subsequent uneven impacts across society, is *medium*.

The statement about worsening farmworker exposure to heat stress is based on numerous studies with consistent findings and reasonable levels of uncertainty. Confidence is *high*.

The statement about worsening ability to obtain food through hunting, fishing, and foraging is based on numerous studies with consistent findings and reasonable levels of uncertainty. Confidence is *high*.

Key Message 11.3

Rural Communities Face Unique Challenges and Opportunities

Description of Evidence Base

Extensive evidence supports the importance of agriculture as a driver of rural economics and social systems.[164,165] Efforts to conserve the natural resources on which rural communities depend, not only for agriculture but also for other natural amenities–based industries (e.g., recreation and retirement destination), are well documented.[166,167] Ample research documents challenges for rural communities in sustaining their way of life. Challenges include decreasing and aging populations, limited resources available for education and workforce development, limited capital access, infrastructure needs, limited access to healthcare services, and land-use preservation.[168,169,170,171,172,173] Further, many rural communities have high concentrations of socially vulnerable and historically underserved populations. A growing body of research illustrates that these populations are disproportionately at high risk of climate change impacts, which can further exacerbate existing problems.[83,101,123,174,175,176,177]

Community resilience indices (e.g., Baseline Resilience Indicators for Communities) and related metrics (CDC's Social Vulnerability Index, FEMA's National Risk Index for Natural Hazards, and the Census Bureau's Community Resilience Estimates) are increasingly being used to inform community disaster preparedness and climate change adaptation research.[177,178,179,180,181,182] Data to further support this work contribute to an emerging area of study of climate resilience measurement. Recent advances include improvements in small-area estimate methodology (https://www.census.gov/programs-surveys/community-resilience-estimates.html) and emerging public–private partnerships that leverage artificial intelligence and machine learning (e.g., First Street Foundation's Risk Factor and Headwaters Economics' Rural Capacity Map).[183,184,185]

Major Uncertainties and Research Gaps

Numerous federal, state, and local programs focus on capacity building and specifically provide support and services to rural and underserved communities.[165,186,187] However, there is uncertainty about rural community sustainability and resilience to climate change. Many of the challenges and stressors faced by rural communities are long term, including but not limited to persistent poverty, population loss, an aging population, natural resource depletion, loss of farmland, and limited on- and off-farm economic opportunities.[121,188,189,190,191,192] Further, while many rural communities share similar challenges, they are not socially, culturally, economically, or environmentally homogenous.[193] Greater confidence in the ways communities could successfully adapt to perturbations would require additional research and training from a variety of potential strategies across the diversity of rural communities.

Description of Confidence and Likelihood

Extensive data show that rural communities support agricultural systems, which provide essential sources of food, fuel, feed, and fiber. Rural communities and their residents manage more than two-thirds of US land[194] and thus bear responsibility for protecting the natural resources and ecosystem services and disservices they provide. Confidence is *high.*

Extensive evidence indicates that climate change and its compounding effects exacerbate existing stressors such as poverty, limited revenue, unemployment, and depopulation on rural communities. However, studies on the impact and extent of these detrimental impacts on the ability of these communities to continue to provide food, fuel, feed, and fiber resources to the Nation are less numerous. Evidence indicating that these communities will lose the ability to manage natural resources and maintain current levels of ecosystem services is limited. Confidence is *medium* with a likelihood level of *likely*.

Evidence from numerous communities documents the existence of opportunities for rural communities to increase climate change resilience. However, future climate change impacts on rural livelihoods and the long-term efficacy of rural resilience efforts are uncertain. Significant variability exists in the challenges and needs of individual rural communities.[195] Confidence is *high*.

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