Fifth National Climate Assessment: Chapter 31

Adaptation

Chapter 31. Adaptation

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Introduction

Changes in the climate have been observed and experienced across every region of the United States (Ch. 3). Chronic changes such as increasing temperatures, sea level rise, and changing precipitation patterns are affecting the frequency and intensity of diverse extreme weather events. These changes directly impact many millions of people and ecosystems (Ch. 2)[1] and are projected to increase in the future. Adaptation is essential for human and ecological survival in this rapidly changing, complex, and interconnected world.

Adaptation refers to actions taken to reduce risks from today's changed climate conditions and to prepare for further impacts in the future. It includes diverse activities designed to reduce climate-related risks and increase capacity to prepare for climate impacts (Table 31.1). Actions taken to adapt to climate change often provide major opportunities to create a healthier and more resilient future for generations to come. Through these actions, billions of dollars can be saved by investing now and avoiding future losses, new jobs can be created, innovative solutions can be realized, and productivity and efficiencies can be increased across all sectors. Done well, adaptation can protect human lives, improve quality of life, enhance social equity, reduce healthcare costs, and safeguard and restore the natural ecosystems on which society depends for its very survival.

The various risks driven by climate change are extensive, diverse, and intensifying, and they interact with complex social, geographic, economic, and political contexts to exacerbate underlying stresses in overburdened and frontline communities. These communities already experience disproportionate impacts of climate change, and these impacts will only increase over time if equitable adaptation actions are not taken now (KM 31.2). The loss of biodiversity and ecosystem services, the displacement of people due to rising sea levels and more frequent extreme weather events, the loss of natural resources, the increased demand on the aging energy grid and critical infrastructure, and many other challenges will only get worse if society does not transform the way it tackles climate change in the US today.

The urgency for climate adaptation is clear and very well documented.[1,2,3,4,5] The benefits of climate adaptation can be immense and felt by everyone if advanced and scaled sufficiently in relation to the pace of climate change (KM 31.1), if equity is centered from the start (KM 31.2), and if both transformative and incremental adaptation actions are taken now (KM 31.3). Transformative adaptation aims to reduce risks through fundamental shifts in systems, values, and practices. Equitable adaptation intentionally incorporates recognitional, procedural, contextual, and distributional principles of equity in design, planning, and execution. Equitable adaptation addresses the disproportionate effects of climate change for overburdened and frontline communities. It dismantles barriers, considers underlying stresses, creates opportunities, and enables learning through iterative evaluation and sustained engagement.[6]

Effective adaptation governance needs to empower all voices to navigate (e.g., discuss, weigh, and prioritize) competing goals in a collaborative manner (KM 31.4), and adaptation-related services need to go beyond the traditional offerings of science, data, and information to be more accessible and to meet the needs of overburdened and frontline communities (KM 31.5). Adaptation finance and investments will be needed to scale, support, and implement adaptation, and systems will need to be developed to adequately track and evaluate the effectiveness of these investments (KM 31.6). In brief, widespread and dedicated adaptation efforts will be essential for securing a sustainable and prosperous future for all.

Table 31.1. Example Climate-Related Adaptation Actions

This table provides examples of incremental and transformative actions being implemented at various scales across US regions and sectors and by various actors to adapt to a range of different climate hazards. See cross-references to other chapters for more detail on certain adaptation actions. The "action" categories in this table have been adapted from Biagini et al. 2014, Hicke et al. 2022, and GCC 2022.[1,7,8]

Action	Description
Capacity Building	Community building (KM 23.5); interdisciplinary public education, literacy, and outreach at all age levels; trainings (KM 21.4) and workshops; knowledge and skill development; technical assistance; dissemination of decision-useful information; equitable partnerships (KM 24.5); sharing best and leading practices; local groups and coalitions to assist communities (KM 25.5)
Early Warning and Observing Systems	Developing, testing, and deploying monitoring and observing systems; early warning systems (e.g., for heat, famine, drought, wildfire); strategic foresight; upgrading weather or hydrometeorological services
Financing	Insurance (KM 21.5); microfinance; funding; investments; grants; contingency funds; environmental impact bonds (KM 21.4); land trusts (KM 21.5); equitable availability and accessibility of capital before and after disasters (KM 31.6); community-based public–private partnership (KM 24.4)
Physical Infrastructure	Coastal accommodation; ecosystem-based adaptation; minimizing ecosystem stressors; restoration or creation of natural areas (KMs 23.5, 31.4); revegetation; afforestation woodland management; increased landscape cover; natural coastal embankments; floodable parks and parking structures; flood mitigation (Box 22.1; KM 24.4); urban flood management (KM 31.4); stormwater management (KM 21.4); retention and detention ponds; "living" roofs; rain gardens; green space (KM 21.3); building or retrofitting infrastructure to withstand future climate change (KM 31.5); water capture and storage; water supply and distribution; infrastructure for health services; improvements to water and sanitation infrastructure; adaptive buildings; reservoirs for water storage; irrigation systems (KM 31.3); canal infrastructure; seawalls; solar infrastructure for electrification; restoration of native species diversity; increase in structural diversity (e.g., variation in age structure; KM 24.2); air conditioners (KM 21.1); cooling centers (KM 31.2); sustainable development (KM 23.5)
Information	Decision support tools (KM 21.1); data analytics; public reporting and disclosures; visualization tools; data acquisition efforts; digital databases; remote communication technologies; climate hazard, vulnerability, and probabilistic mapping tools (KM 21.1); collaboration and coproduction of data and information (KM 24.2); toolkits (KMs 21.1, 31.5)
Management and Planning	Scenario-based planning (KM 25.5); spatial planning; incorporating climate change and adaptation into planning (e.g., hazard mitigation plans), design standards, management, and decisions (KM 21.1); collaborative adaptation planning at multiple scales (e.g., federal, regional, state, territorial, Tribal, local, organizational [public and private]); assessing underlying conditions and needs (KM 21.4), risks (KM 23.5), adaptive capacity, and options; adaptive management; cooperative governance (KM 31.4); cultural adaptation; regional collaboratives (KM 31.4)
Policy	Law and governance (KMs 21.3, 23.5); local climate policy (KMs 21.3, 23.5, 27.1); revised design parameters, adaptive building codes, and integration of future climate projections into codes and standards (KMs 12.3, 31.5); creation of new policies or revisions of policies or regulations to allow flexibility to adapt; mainstreaming adaptation into development policies; improvement of water resource governance
Practice and Behavior	Institutional change; changes to diets and food waste; diversification of livelihoods and income sources; adaptive farm, fishery, or livestock practices (Box 29.5); improved crop varieties; food storage, distribution, and security; disaster risk reduction; permanent migration, planned retreat, or relocation (KMs 21.3, 24.4); seasonal or temporary mobility; social safety nets and cohesion; adaptive social protection; water use and demand; soil or land management techniques; post-harvest storage; rainwater collection; expanding integrated pest management; strategic coastal retreat (KM 9.3); land protection; changes in transportation habits; improved public health (KM 23.5)
Technology	Developing new or expanding existing technologies to enable and advance adaptation; water use or water access improvement technologies; solar energy capacity; wind power; energy storage; biogas; water purification; solar salt production; microgrids; artificial intelligence and machine learning

Key Message 31.1

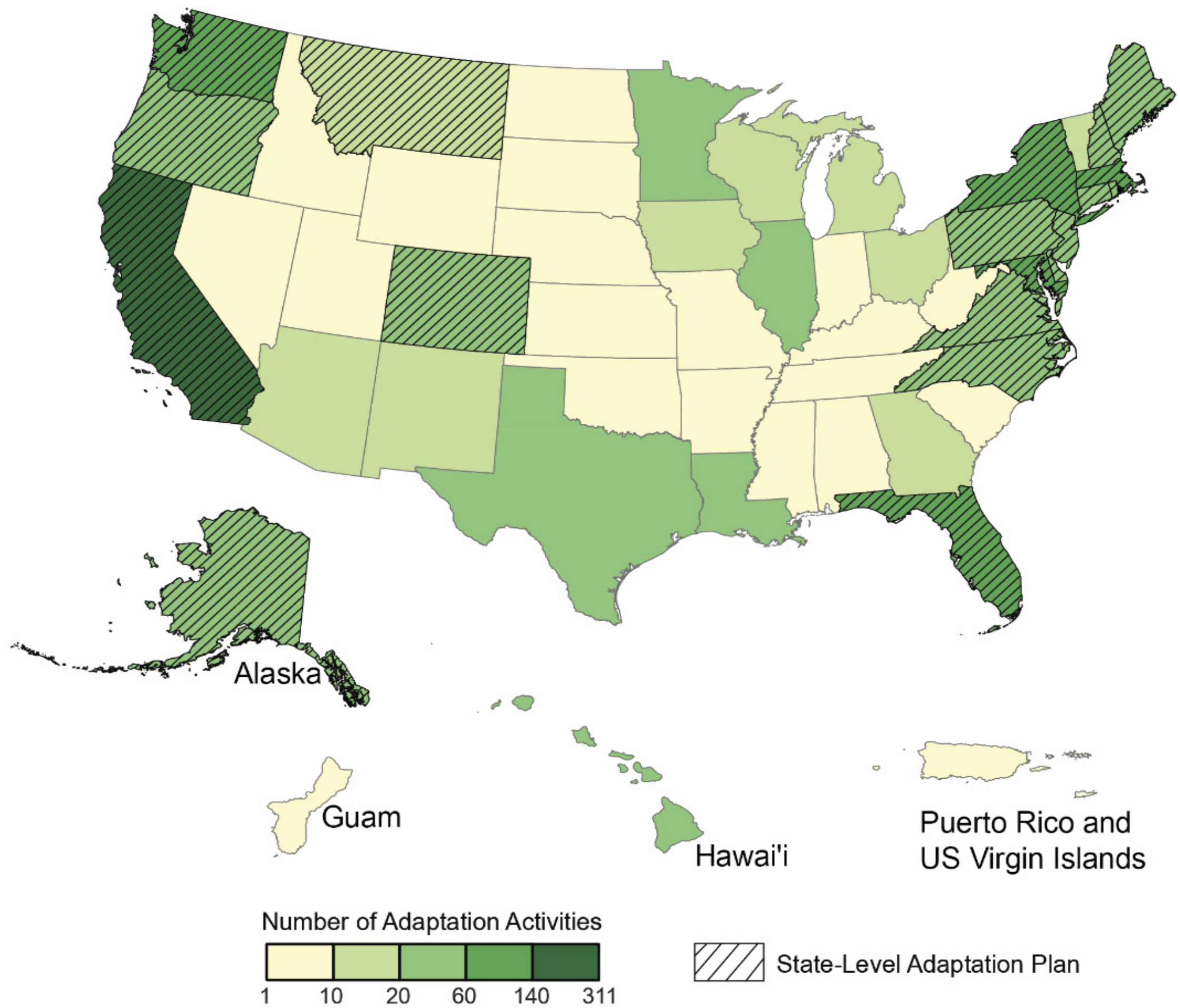
Adaptation Is Occurring but Is Insufficient in Relation to the Pace of Climate Change

Diverse adaptation activities are occurring across the US (*very high confidence*). Adaptation activities are increasingly moving from awareness and assessment toward planning and implementation (*medium confidence*), with limited advancement toward monitoring and evaluation (*high confidence*). Numerous social, economic, physical, and psychological barriers are preventing more widespread adoption and implementation of adaptation (*high confidence*). Current adaptation efforts and investments are insufficient to reduce today's climate-related risks (*high confidence*) and are unlikely to keep pace with future changes in the climate (*medium confidence*).

Actors, stakeholders, and rights-holders (hereafter actors)—from individuals and organizations to companies, communities, and government entities across all levels, regions, and sectors—are already investing in adaptation measures (Figure 31.1) to reduce the harms caused by climate change and leverage new opportunities to enhance their ability (or capacity) to adapt.[9,10,11,12,13,14] The extent, type, and stage (Box 31.1) of these activities vary regionally and across sectors (Figure 31.1; Chs. 4–16, 21–30). Adaptation has increasingly progressed from the awareness and assessment stages toward planning and implementation (Box 31.1). However, few adaptation activities advance monitoring or evaluation.

To date, adaptation across the US has been incremental in nature, and given the expected future pace of climate change, more action is needed at greater rates and larger scales, across more sectors, and in context-specific ways.[1,15,16,17,18] Historically, actions to adapt often have not centered equity (KM 31.2) and were not designed using a systems-oriented, regional, or collaborative approach for transformation (KM 31.3). Adaptation lacks the attention, investment, financing, and monitoring needed to prepare for both acute and chronic climate impacts (KM 31.6).

Number of Publicly Documented Adaptation Activities (2018–2022)



The level of documented public- and private-sector adaptation activity varies widely across US states and territories.

Figure 31.1. This figure illustrates the number of public- and private-sector adaptation activities—see examples offered in Table 31.1—publicly documented and/or updated since 2018. There are several states that have publicly documented numerous adaptation activities, while others have very few or have not documented the activities. Figure credit: WSP, University of Delaware, and University of California, Irvine. See figure metadata for additional contributors.

Box 31.1. Evidence of Adaptation Occurring Across the Five Adaptation Stages

Adaptation actions are generally categorized into five stages, from raising awareness to implementation and evaluation.[4,19] Evidence of action exists along the five adaptation stages at varying scales and levels.

Stage 1: Awareness and Engagement

American adults understand that climate change is happening (72%).[20] However, they have low risk awareness (e.g., they underappreciate how severely climate change might affect themselves and society) and lack a clear understanding of adaptation and its importance (KM 31.2).

Stage 2: Assessment

Approximately 40% of US states have assessed their climate change risks.[8] Of US-based companies disclosing through CDP (formerly the Carbon Disclosure Project), 88% have assessed their climate-related financial risks in alignment with the Task Force on Climate-related Financial Disclosures (KM 31.6)[21] and, if material, disclosed such risks in their financial statements. Assessments of adaptive capacity (the potential of a system to adjust to climate change) and climate resilience have progressed but lag assessments of climate risks, raising concerns that some actors, including local governments, may be ill-equipped to prepare for climate change. There is an increase in the number of publicly available datasets and tools to inform assessments, as well as use of Traditional Knowledge and climate storytelling.

Stage 3: Policy and Planning

Many governments and organizations have individual sustainability, resilience, or adaptation plans (Figure 31.1). Eighteen states have climate adaptation plans, and another six states have plans underway. Thirty-two states lack a public adaptation plan, a select few US-based companies have disclosed adaptation-related actions they are taking, and very few jurisdictions have adaptation plans co-designed between the private- and public-sectors. Across jurisdictions, plans are developed for different reasons (e.g., climate impacts, investor requests, regulatory requirements) and rarely in a coordinated, collaborative, or regional manner.[22,23] As required in Executive Orders 14008 and 14057, more than 20 federal agencies have prepared and updated climate adaptation plans.[24] Funding and implementation of adaptation plans remains moderate or low (KM 31.6).[1,25] Climate adaptation–related congressional legislation is becoming more prevalent, but it is often embedded within other topics (e.g., infrastructure, disaster relief, water). Federally funded opportunities remain untapped and inaccessible to overburdened and frontline communities.[26]

Stage 4: Implementation

Implementation of adaptation actions has made some progress. However, most actions have been incremental in nature; have focused on acute extreme weather events rather than systemic, chronic climate change; and/or involve small infrastructure changes to business-as-usual activity, such as changing irrigation systems or expanding stormwater pipes to withstand increased flooding.[1,15] Current levels and types of adaptation being implemented are insufficient to deal with future climate change.[1,15,27,28]

Stage 5: Monitoring and Evaluation

Adaptation researchers and practitioners are starting to track the number of actions, assess the adaptation effectiveness of those that have occurred, and evaluate the long-term sufficiency of adaptation projects. However, frameworks, monitoring, indicators, and evaluations that assess adaptation practices, co-benefits, equality, and implementation at appropriate levels of granularity are still under development.[1,29,30,31,32,33,34,35] Research is focused on evaluating adaptation-enabling governance structures and barriers to adaptation.[36,37]

Evidence of Adaptation Barriers

Although adaptation is occurring across the US, barriers remain. These barriers can mostly be overcome with financial, cultural, technological, legislative, or institutional changes.[38,39]

There is growing divergence in the ways government, private industry, and civil society are planning for climate adaptation, with each focusing on a subset of climate vulnerability—disaster resilience, risk and liability, and equity and justice, respectively[40]—and individual climate hazards (e.g., sea level rise, flooding, heat), instead of compounding and complex events (Focus on Compound Events). This incoherence increases the potential for investments that may unintentionally exacerbate climate-related risks or overlook the need to target adaptations for frontline communities that experience a plethora of compounding issues (both chronic and acute), creating greater societal vulnerability to climate impacts (KM 31.3).[41] It is also important to distinguish between *planning* for adaptation and *actually* adapting; there is still more of the former than the latter. The ability to adapt is uneven and inequitable: communities or businesses with means, wealth, or access to resources are more able to adapt, while those with fewer means or opportunities are less able to adapt. The gap between planning and action could also be due to the ease of tracking adaptation plans compared to tracking evidence of systems, people, or environments that are adapting, which can take years to show progress.[1] With the lack of consistent tracking and evaluation of adaptive capacity and how effectively society and ecosystems are adapting to climate change, it is challenging to measure progress, continually improve, and understand the overall impact of adaptation actions and investments.[42]

Adaptation is routinely limited by a range of political, structural, psychological, and normative barriers.[1] Few regulatory requirements focus directly on adaptation.[26] Existing environmental and disaster policies, frameworks, and governance systems are ill-suited to handle the long-term, widespread, transformative changes needed to adapt to climate change; tend to be reactive rather than proactive; and assume fixed rather than dynamic environments.[43,44,45]

Methodologies and tools to assess climate risks, adaptive capacity, and adaptation options are lacking in transparency or are nascent (KM 31.5). While there are many datasets and tools to inform adaptation, their usefulness for decision-making remains uncertain.[46] Resources remain constrained and dispersed when it comes to assessing climate change and adaptation.[43,44,47,48] There is a lack of clear pathways for sharing datasets and tools among multiple actors and jurisdictions (KM 31.4) and a lack of streamlined and transparent processes for integrating local and Traditional Knowledge. The inherent time lag in the scientific peer-review process of science and assessments does not allow for progress to be made swiftly.

Competing values and goals held by diverse public entities and organizations and differentiated responsibilities across levels of government or types of organizations create challenges in developing shared goals (KM 31.4).[44,45,48] The lack of coordination across government agencies at all scales and with diverse actors creates a fragmented and ineffective adaptation governance system.[47,48,49,50,51] The continued reliance on fossil fuel economies discourages transition and economic diversification,[52,53,54] limiting collaborative planning with these high-emitting industries.

Justice and equity are rarely centered in adaptation activities by all sectors and actors (public and private; KM 31.2).[55] In many settings, there is not a widely accessible forum for local participation, particularly of Indigenous communities living in remote and vulnerable locations. Social hierarchies and structures can prevent overburdened groups from sharing their opinions, preventing achieving equitable adaptation. Frontline communities are hit first and worst by climate change, and oftentimes adapting to climate change may not be their immediate concern. Intentionally centering equity in adaptation solutions in partnership with frontline communities has the potential to improve some systemic issues such as inequality, discrimination, and limited access to essential resources and opportunities (KM 31.2).[56]

Finally, there remains a minimal degree of investment and funding for adaptation. As for the funding that is available, communities with the highest climate vulnerability do not have adequate and equitable access to these funds (KM 31.6).[43] Organizations often do not understand potential returns on investment in adaptation, so there is less appetite for expensive measures (KM 31.6).[57]

Key Message 31.2

Effective Adaptation Requires Centering Equity

People and communities are affected by climate change in different ways (*very high confidence*). How people and institutions adapt depends on social factors, including individual and community preferences, capacity, and access to resources (*very high confidence*). Adaptation processes, decisions (about whether, where, and how adaptation occurs), and actions that do not explicitly address the uneven distribution of climate harms, and the social processes and injustices underlying these disparities, can exacerbate social inequities and increase exposure to climate harms (*high confidence*).

Climate adaptation that responds to people's values, concerns, and priorities requires not only identifying disparities in how people are affected by climate change but also understanding the underlying causes and conditions of climate vulnerability. Vulnerability (predisposition to adverse impacts) is shaped by interactions across physical, social, and ecological processes (Chs. 3, 20).[58] The places most vulnerable to climate change share traits of high *exposure* to climate change and climate hazards (e.g., long-term water scarcity and extreme drought), high *susceptibility* to adverse impacts, and constraints on *capacity* to adapt.[1] The specific mechanisms that produce vulnerability vary from place to place and over time; are shaped by historical racial, ethnic, gender, and socioeconomic inequalities (Chs. 16, 20);[59] and are sensitive to climatic and demographic change in the future.[60]

Inequalities in social, economic, and political power and resources[61] mean that populations marginalized by society and underserved by government or private-sector systems often face disproportionately worse effects of hazards. For example, higher proportions of Native American, Hispanic, Asian and Pacific Islander, and African American populations live in places prone to extreme wildfire, heat, floods, and permafrost thaw.[62,63,64,65,66,67] Such differential exposure often results from historical injustices such as housing discrimination, forced displacement, social exclusion, lack of investment in hazard mitigation, and lack of provision of other social services by government or the private sector (e.g., insurance, mortgage lending).

Uneven patterns of climate hazard exposure are well documented. Recent work is helping to untangle context-specific processes through which the geographic distribution of climate hazards and social inequality interact to shape local experiences of vulnerability (Ch. 20). Examples include illuminating how disaster damage exacerbates long-term wealth inequality,[68] how disaster assistance distribution policies and differential access constrain recovery outcomes,[69,70] and the influence of racial and economic privilege in flood buyout programs.[71,72,73] Greater understanding of the complex human drivers of climate vulnerability can illustrate how and why transformative adaptations may be required (see KM 31.3) to address interlocking social processes and to remedy vulnerability at its roots (Ch. 20).[40] This improved understanding reinforces why effective adaptation extends beyond cost efficiency and technocratic concerns to intentionally incorporate equity and environmental justice principles.[18,74] Effective adaptation that centers equity is needed to address disparities in the causes and effects of climate risks, dismantle barriers, and create opportunities for all people to thrive.

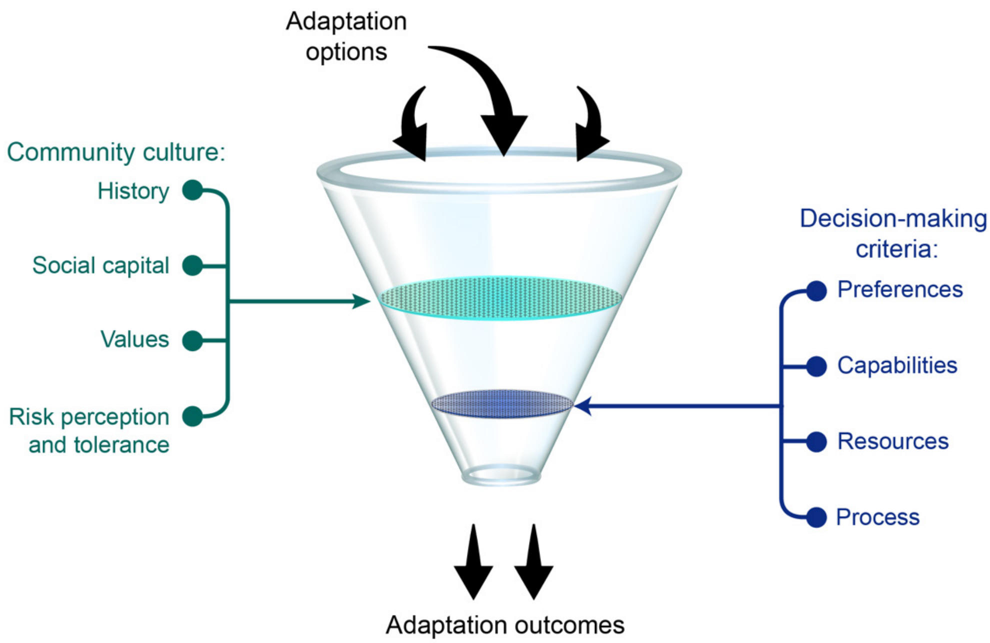
Whether, when, and how people adapt to climate change depends on complex geographic, political, economic, social, and cultural contexts (Chs. 18, 20; Figure 31.2). The ability of individuals and institutions to engage in adaptation is affected by their access to resources, which is unevenly distributed and mediated by factors such as income, race, ethnicity, and gender.[72,75,76,77,78] Factors such as citizenship status and land ownership can create administrative hurdles.[79,80] Federal or state resources for adaptation are often available to individuals, communities, and Tribes only if they navigate bureaucratic systems or succeed in competitions. Equity concerns arise when the system privileges those who already have resources—time, English-language skills, personnel, power, and/or funds to acquire adaptation resources.[68,81,82] Rural or less populous towns, for example, may have fewer professionals to dedicate time to grant applications, fewer resources to meet federal cost-share requirements, or difficulty in proving that adaptation would be cost effective (Ch. 11; KMs 11.3, 31.6). Private-sector adaptation resources are similarly more available to some people than others, as when insurance companies cease to offer wildfire insurance in some risk-prone areas.[83]

Social factors—including place attachment, identity, social capital, and perceptions of what is fair and effective—influence the adaptation actions people are willing and able to pursue.[84,85,86,87] Risk perceptions and risk tolerances are influenced by social factors such as experience, culture, and demographics, and increased risk awareness alone does not predict increased adaptation.[88,89] For example, a survey of Puerto Rican farmers found that half did not engage in adaptation even though they perceived themselves to be at risk and to be capable of taking action.[89] A survey of homeowners in North Carolina found that knowledge of climate change and its risks had no effect on the adaptation actions taken.[88]

Geographic, political, economic, social, and cultural contexts also influence how people adapt (Figure 31.2). Different types of adaptation actions reduce risk to different degrees and in different ways, cost different amounts, have different downsides, and benefit and harm different groups.[90,91,92] Individual and community values, circumstances, and priorities shape which benefits are considered most important, which trade-offs people are willing to endure, and what opportunities they are willing to forego. For example, building seawalls can disconnect communities from the water, which may affect their place attachment, recreational and economic amenities, sense of identity, local ecosystems, and long-term risk profile, while providing short-term gains in safety and property values.[93,94] Culture, heritage, and traditional ties to the land influence adaptation preferences[95,96] and can be important sources of motivation and guidance, especially for locally led adaptation efforts.[97] People may disagree about the goals of adaptation and their preferences for trade-offs, values, or risk tolerance levels, and how these disagreements are handled within a community or institution further shapes adaptation practices.

Participatory processes create space for people to discuss goals, values, social factors, and resources and are a necessary element of participatory justice, which holds that those affected by decisions should be involved in the decision-making process. Such processes benefit from practices that facilitate participation, such as convenient meeting times, language translation, and provision of transportation, food, and childcare. To more deeply embed equity, participatory processes designed to stunt power imbalances—such as those featuring transparency, information access, and opportunities for substantive influence—are most likely to represent the full range of people affected by a decision.

Adaptation Actions Defined by Multiple Factors



Adaptation outcomes are the result of individual and group values and decision-making processes and constraints.

Figure 31.2. The path from potential adaptation options to adaptation outcomes is filtered through culture and decision-making criteria, processes, and resources. Individual traits, circumstances, and preferences mean that adaptation outcomes are not identical for all members of a community. These social factors may create, perpetuate, or exacerbate existing social inequities in a systemic fashion, such that even passive actions can produce inequitable outcomes. Intentionally integrating equity into adaptation, which requires accounting for differences in access, capacity, and resources, can lead to more inclusive and sustainable outcomes. Figure credit: ICF, University of Delaware, and University of Iowa.

Failure to intentionally center equity—as in the distribution of resources, participatory processes, and recognition of local contexts—may unintentionally increase the vulnerability of people and places.[98] This is a type of maladaptation, in which efforts to address a climate vulnerability unintentionally increases vulnerability.[99,100] Maladaptation can occur, for example, if engineered infrastructure (e.g., levees) or disaster response programs create a false sense of security that incentivizes continued development in hazardous areas, which in turn produces higher losses in the event of system failure—a situation known as the safe development paradox.[101,102,103] Adaptation tailored to a specific context can become maladaptive if subjected to a different hazard type or context, as when crowded spaces in community shelters or cooling centers contribute to the spread of a pandemic.[104,105] Interventions advanced in the name of engineering adaptation may undermine ecological adaptation, and adaptation for some people (e.g., wealthy communities, homeowners) may lead to maladaptive outcomes for others (e.g., low- to moderate-income communities, renters). Given the potential for maladaptation to substantially redistribute or amplify risk, the topic would benefit from significant attention from practitioners and policymakers.[106,107,108]

Intentionally centering equity in the design, planning, and implementation stages of adaptation would require a paradigm shift. This shift would include asking a number of questions: For whom, with whom, and by whom would proposed adaptation actions be undertaken? Who would benefit and who would be burdened by these actions? Are steps being taken to lessen the burdens borne by underserved populations (Ch. 20; Figure 20.1)?[109,110] This type of proactive engagement from disadvantaged and frontline communities would be especially important in transformative adaptations that may cause substantial social upheaval (KM 31.3). Accounting for intersecting identities and structural inequalities as organizing principles of adaptation planning could help produce adaptation actions that simultaneously mitigate the effects of climate change and address compounding social inequities.[111,112] Other strategies for equity-centric adaptation include prioritizing adaptation actions and assessing adaptation effectiveness based on satisfying the needs and preferences of the most vulnerable.[113] Adaptation equity and environmental justice involve multiple concepts, including recognition of how past injustices have contributed to current patterns of exposure and capacity, consideration of cultural values and norms, fair decision-making processes and distribution of resources, and efforts to redress past and current injustices.[95,108,114,115,116] Adaptation efforts that center equity and justice are best positioned to avoid perpetuating social injustices.[40,113,117]

The Justice40 Initiative[118] is an example of public policy that centers the redress of social inequity in adaptation. Justice40 defines investment focus areas of climate change, energy, health, transit, affordable housing, pollution reduction, water infrastructure, and workforce development. It calls for 40% of benefits from federal investments in these areas to occur in communities disadvantaged by historical marginalization, pollution hazards, and long-standing underinvestment. To identify disadvantaged communities, the White House Council on Environmental Quality developed an online geospatial application called the Climate and Economic Justice Screening Tool (CEJST). CEJST is primarily designed to be used by federal agencies[119] and could significantly shape the distribution of adaptation resources by the Department of Energy, Department of Housing and Urban Affairs (HUD), Federal Emergency Management Agency (FEMA), and other agencies. CEJST can also inform adaptation investment decisions by business and philanthropic organizations and raise public awareness of the social factors that shape climate vulnerability and adaptation.

Key Message 31.3

Transformative Adaptation Will Be Needed to Adequately Address Climate-Related Risks

Climate adaptation actions undertaken in the United States to date have generally been small in scale and incremental in approach, involving minor changes to business as usual (*very high confidence*). Transformative adaptation, which involves more fundamental shifts in systems, values, and practices, will be necessary in many cases to adequately address the risks of current and future climate change (*high confidence*). New monitoring and evaluation methods will also be needed to assess the effectiveness and sufficiency of adaptation and to address equity (*high confidence*).

Most adaptation efforts across a wide range of sectors across the United States have involved incremental adaptation: minor shifts in usual practices that affect small geographic areas and that have been limited in their ability to affect multiple sectors or hazards by technical, social, and economic barriers.[1,15,27,120] Although the performance of adaptation actions is difficult to assess, the available evidence suggests that many US adaptation practices are not sufficient to deal with either current or future climate change.[27,121] Future adaptation may require not only more adaptation efforts (more actions, scaled up, across a wider range of actors, sectors, and systems) but also more transformative adaptation: actions that involve persistent, novel, in-depth changes that shift the fundamental traits of institutions, behaviors, values, or technologies across multiple scales and sectors.[90,122,123] Transformative adaptation can involve changes to the built environment, or it may involve fundamental changes in economic and governance paradigms to redress historical injustices and center equity and justice.[40]

Adaptation actions in the US more often involve using air-conditioning during heatwaves, increasing irrigation or temporarily reducing water consumption to address frequent droughts, using sandbags to resist coastal erosion, redefining fisheries boundaries in response to shifting habitats, or elevating homes above flood waters—rather than more transformative actions such as redesigning cities and buildings to address heat, shifting water-intensive industry to match new rainfall patterns, or directing new housing development to less flood-prone areas.[1,15,27,120,124] A range of cognitive biases sometimes make people favor incremental change, such as status quo bias (an inclination to preserve the current state even if changes would bring greater benefits).[73,125] However, preserving the status quo can perpetuate existing systems of inequality (KM 31.2).[116,126] Incremental adaptation has also been favored in part due to the framing of adaptation as a type of disaster risk reduction rather than long-term planning (e.g., response to hurricanes rather than permanent inundation due to sea level rise).[15,127,128,129] For instance, a national survey of metropolitan transit organizations found that most agencies rely on traditional emergency management approaches to address extreme weather during or after the event, rather than advance planning for such events and making changes to preemptively avoid harms.[130] Disaster risk reduction provides an important set of tools and frameworks, but responding to and preparing for permanent changes in climatic conditions requires a different set of approaches than reactively responding to extreme events or sudden hazards. In the long term, an overemphasis on incremental adaptation can lead to maladaptation, where efforts to address climate risk unintentionally increase risk.[99,100] A classic example is that using more air-conditioning to deal with rising temperatures and extreme heat events may increase fossil fuel consumption (if the electricity is generated from fossil fuels), contributing to more climate change and even higher temperatures.

Other incremental adaptation actions may displace risk,[131,132] such as when one home is elevated on a filled mound that pushes rain and floodwaters onto neighboring homes, or have unintended consequences, such as reducing motivation to engage in adaptation (KM 12.4). An emphasis on financially conservative "no regret" decision-making, which limits current costs and prioritizes adaptation options that would be justified under all plausible future climate scenarios, may lead to less expensive but less effective actions.[15,90] Local governments, individuals, communities, or businesses may have insufficient capital to cover the up-front costs of transformation even if those actions would produce long-term gains (KMs 31.5, 31.6). For example, in the short term, reducing agricultural water use through improved irrigation (an incremental change) is cheaper and easier than fundamentally reimagining how and where crops are produced, stored, and transported across the US (transformative change). However, improved irrigation may be insufficient to adapt to long-term effects of climate change and may be less cost-effective in the medium and long term than more transformative options.[27,121]

Climate change will cause both chronic shifts in baseline conditions—such as rising temperatures, sea levels, and water insecurity—and acute risks through extreme events and increased variability (Chs. 2, 3), and these effects will interact with and compound multiple complex (Ch. 18) non-climate stressors such as public health concerns (e.g., pandemics, epidemics; Ch. 15), economic events (e.g., recession, depression), and social injustices (e.g., systemic racism; Ch. 18). Complex social, economic, ecological, and technological systems can be challenging to adapt because elements within the systems reinforce and constrain one another.[1,133,134,135] Transformative adaptation—spanning both social and physical systems—may be needed to address the increasingly intense and nonlinear effects of climate change and their complex interactions with multiple non-climate stressors (Ch. 18).[28,40,136,137] Adaptation actions that consider co-benefits where possible (including contributing to climate mitigation but also biodiversity, pollution reduction, social justice, and others) are expected to provide the greatest social gains and long-term sustainability.

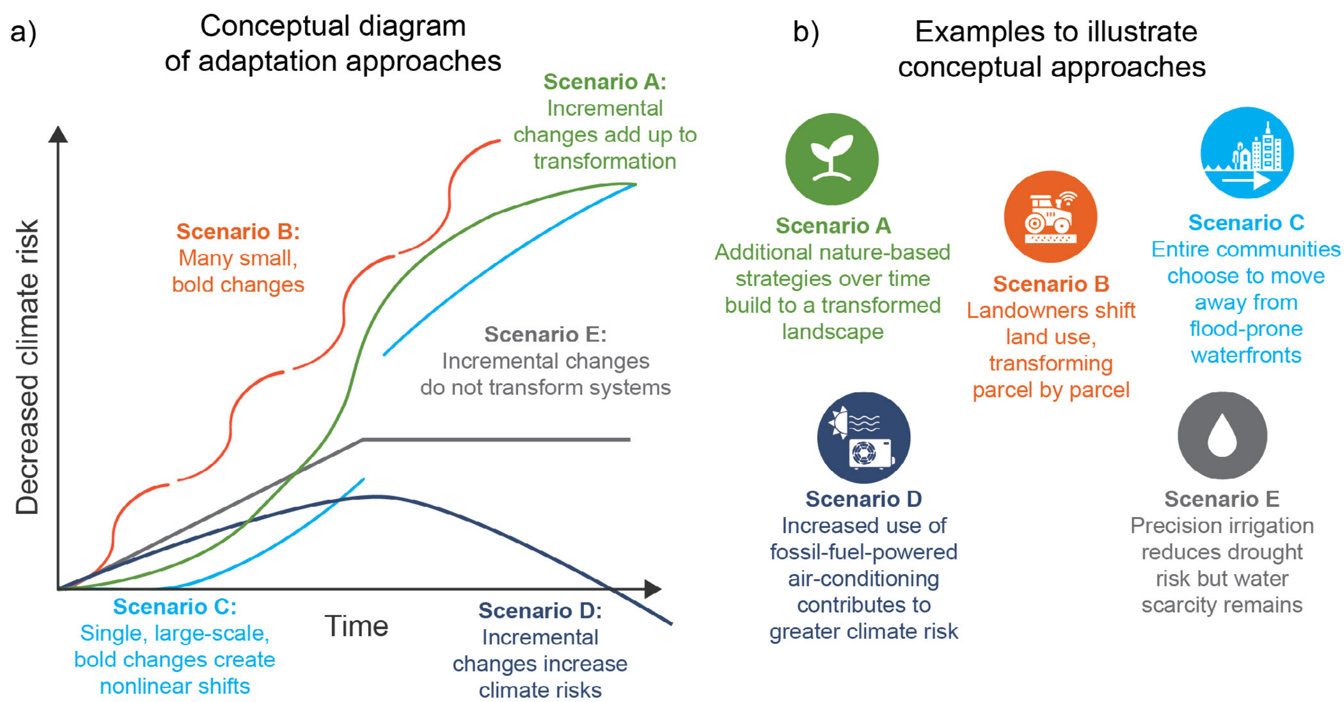
Adaptation may increasingly require a systems approach to focus on how multiple systems (e.g., social, political, cultural, ecological, physical infrastructure, energy, water, food) interact with and shape one another and to identify adaptation actions that cut across or leverage multiple systems.[6,138] Compared with transformative adaptation, most incremental adaptation requires less coordination across interested parties, making it appealing to actors working within a single sector of a larger system and where coordination is difficult to achieve. A systems approach, for example, would consider vulnerabilities across different modes within a system (e.g., highways and public transit) or across systems such as transportation, water, the electric grid, telecommunications, supply chains, stormwater management, and land-use or development patterns. A systems approach to adaptation might argue for adaptation efforts to occur in different government offices (e.g., in transportation planning and housing as well as in emergency management and environmental agencies), for coordination of public and private efforts, or for greater cooperation across silos to support transformative adaptations (KM 31.4). Adaptation actions that take a systems approach to assessing vulnerabilities and adaptation opportunities are expected to be more transformative insofar as they affect multiple systems at multiple scales.[90]

Transformative adaptation may also involve changes to systems and paradigms in ways that redress historical injustices and center equity.[40] Transformative adaptation has the potential to perpetuate or exacerbate social injustices, but inequities are not inevitable.[137,139,140] Addressing them requires express consideration of equity and justice along with direct engagement with disadvantaged and underserved communities (KM 31.2), and lessons can be learned from the "just transitions" literature and movements (Ch. 20; KM 20.6).[108,141,142,143] For example, transforming car-centric transportation systems to emphasize public transportation and walkability could increase accessibility for underserved communities and people with limited mobility if the transformation intentionally includes user input to address accessibility and equity from the start. Transformations may also advance equity by reforming systems and institutions that perpetuate inequities. For example, the reliance of local governments on property tax revenue as a major source of funding has contributed to disaster risk reduction and adaptation governance systems that sometimes prioritize protection of property values rather than people or ecosystems.[144,145] Transformations to these and similar underlying systems may be needed to address climate adaptation equitably.[40] Congressional efforts to reform to the National Flood Insurance Program, for example, have struggled to balance, on the one hand, the need to increase premiums and enrollment to accurately reflect risk and, on the other, the need to keep premiums affordable. Solutions to this problem may require broader transformations in the way insurance and risk information are provided.[146,147,148] Transformative actions are also expected to be necessary to address numerous systemic inequities such as colonialism, systemic racism, wealth inequality and distribution, and economies based on extractive industries.

Adaptation actions are not divided distinctly between incremental or transformative actions (Figure 31.3). In some cases, incremental adaptation actions add up to transformative change if they are widespread enough; however, the place-based nature of adaptation can make this particularly difficult to achieve. In others, incremental adaptation can lead to a limited degree of change that may be insufficient in the face of future climate conditions. Similarly, transformative adaptation can take different forms (Figure 31.3). The exact blend of incremental and transformative actions that will be needed across the United States is not clear, but given the current predominance of incremental action, it is expected that future adaptation will need to include more transformation. The more and faster the climate continues to change (e.g., if global greenhouse gas emissions are not aggressively cut in the near term; Ch. 32), the more severe and spatially uneven climate change impacts will be and the more transformative adaptation will be needed at greater rates, scales, and extents. Transformation and even creative incremental adaptation may be able to overcome soft limits—challenges such as affordability that may be surmounted with additional research or investment—but if global emissions continue unabated, systems and communities will eventually encounter hard limits, points beyond which adaptation cannot avoid intolerable risks and impacts.[149,150]

The pros and cons of different types of adaptation are difficult to compare because adaptation, in general, is difficult to evaluate since it involves measuring harms that do not occur (e.g., avoided losses). Assessments of the effectiveness of adaptation actions have generally been limited to project-specific performance against a limited set of extreme events or climate conditions.[32,151,152,153,154] Adaptation researchers and practitioners have begun to track the number of actions that have occurred across the US and to evaluate adaptation projects in a limited manner (KM 31.1; Figure 31.1). However, efforts to assess trade-offs, effectiveness, sufficiency, and long-term consequences of incremental and transformative adaptation actions are still largely theoretical and will need more work to implement and consistently track over time. Metrics will need to be granular enough to observe disparities among communities to reduce potential inequities.[32,33]

Incremental and Transformative Adaptation Approaches



Incremental and transformative adaptation may take many forms, but incremental adaptation involves small changes while transformative adaptation involves profound shifts.

Figure 31.3. (**a**) Adaptation actions can involve small changes to business as usual (incremental) or bold measures that break from past practices and create new systems (transformative). In some cases, incremental changes may add up to a transformation of the overall system (Scenario A). In other cases, they may not (Scenario E), or they may even cause maladaptation (Scenario D). Transformative adaptation can also take different forms, including a series of small-scale transformations (Scenario B) or larger one-time shifts (Scenario C). Neither incremental nor transformative adaptation is always preferable, and both approaches may exacerbate injustices if equity is not centered (KM 31.2). The examples in panel (**b**) illustrate these conceptual approaches to incremental and transformative change; each could be equitable if it follows the principles of equitable adaptation. Current adaptation practices in the US are predominantly incremental and do not clearly add up to system-wide transformation. Adaptation in the future, therefore, is expected to require a greater degree of transformative adaptation in the overall portfolio. Figure credits: (a) adapted with permission from Fisher and Williams 2020;[155] (b) University of Delaware and National Institute of Standards and Technology .

Key Message 31.4

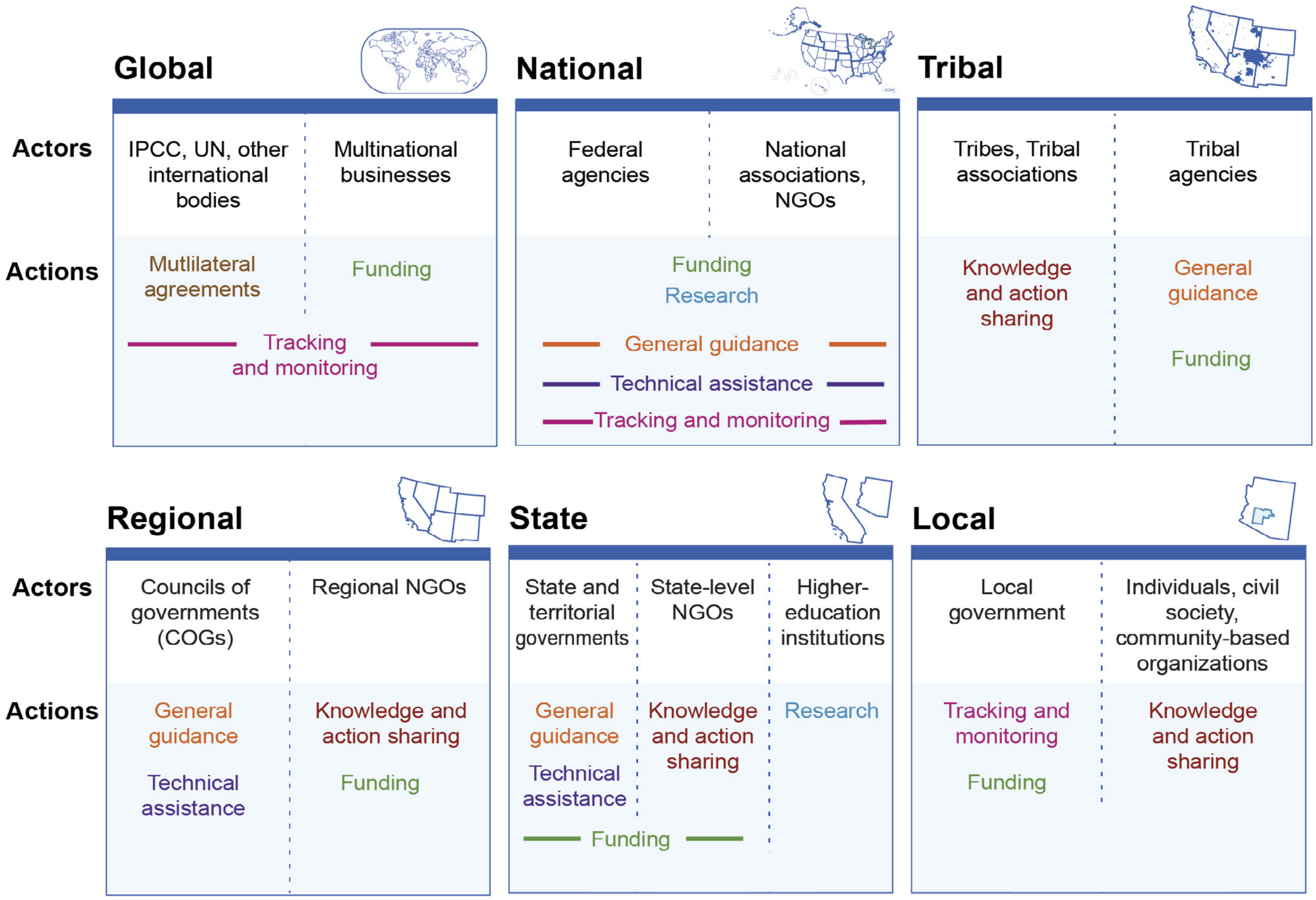
Effective Adaptation Governance Empowers Multiple Voices to Navigate Competing Goals

Adaptation involves actors from government, private-sector, nongovernmental (e.g., nonprofit and for-profit institutions), and civil society organizations, which often have different priorities and approaches (*high confidence*). Adaptation decision-makers must balance competing goals while also addressing uncertainties regarding future climate change and the ways that political, social, and technological systems will be transformed (*high confidence*). To minimize the potential for adaptation actions to benefit some at the expense of others, adaptation processes must emphasize collaboration, center equity and justice, and incorporate a wide range of values and knowledge sources (*medium confidence*).

Governance refers to the structures and processes used by governments and other decision-makers to develop and implement policies, programs, and institutions.[156] Compared to many policy fields, formal governance of adaptation is relatively underdeveloped, with weakly defined ambitions, responsibilities, routines, and evaluation methods and no overarching federal policy framework for adaptation.[157,158] Nonetheless, numerous organizations are engaging in adaptation governance in a more bottom-up fashion.[15,40] For example, urban flood management may be directed by local actors coordinating activities without a higher-level directive.

Many different types of organizations make decisions about adaptation, including federal, state, territorial, Tribal, and local governments; businesses; nonprofits; households; and individuals—all with variably overlapping jurisdictions (Figure 31.4). While some adaptation decisions are made unilaterally, such decisions often involve multiple organizations; adaptation networks have become more complex in the last decade, involving more actors from more diverse organizational backgrounds.[159] The actors involved often have distinct (and at times conflicting) views of the problem, risk tolerance levels, priorities, preferred solutions, and ideal futures.[160,161,162,163,164]

Organizations and Actors in Adaptation Governance



Climate adaptation involves numerous actions by different actors at multiple jurisdictional scales.

Figure 31.4. Climate adaptation governance occurs at multiple scales, with numerous government, private, and civil-society organizations supporting adaptation through funding, guidance, and other activities. While all actors can directly implement adaptation activities, activities implemented in a coordinated fashion and with technical assistance, funding, and monitoring provided by actors across sectors and scales have the potential to be more effective and transformative. Figure credit: University of California, Irvine, and National Institute of Standards and Technology.

When organizations have an explicit focus on adaptation, they tend to organize their governance activities in diverse ways. For instance, some cities, states, and utilities have created centralized offices focused on overall resilience and/or sustainability, while others have distributed climate adaptation tasks across critical functions, each focusing to varying degrees on hazards, social resilience, and/or environmental protection.[165] At the federal level, legal frameworks for climate adaptation cover a broad range of agencies, and these agencies may differ from those mandated to conduct research on the efficacy of adaptation governance (e.g., Executive Order 14008, Section 203[118]).

Given this complexity, adaptation governance is often fragmented and uncoordinated, with the diverse actors operating independently and ignoring potential side effects or spillovers.[48,49,50,51] This problem exists even in settings where actors recognize the need for more coordinated governance.[166] Finally, while there is increasing recognition of cross-jurisdictional impacts, fragmented governance systems are not structured to handle impacts that cross geographic borders.

Leading practices in adaptation governance are based on credible science and involve ongoing open processes to support multiple voices across government, civil society, and expert advisors (Ch. 2).[156,167,168] Linking adaptation policy and governance involves timely and salient communication across actors, involving media, lobbyists, and boundary organizations that help translate scientific information and co-develop technical support relevant to local communities.[169,170,171]

Effective and equitable adaptation governance also benefits from intentional engagement and coordination among all involved actor groups over a sustained period.[1,51,165,172,173] For example, following multiple wildfires and postfire floods, Santa Clara Pueblo collaborated with multiple federal agencies, the state of New Mexico, and several other Tribes to restore their watershed and build resilience against future floods.[174] Such collaboration is particularly effective when a single government agency leads coordination of an interorganizational group to oversee adaptation activities.[175,176,177] Alternatively, coordinating hubs can help bridge activities of disparate actors;[178] having well-defined roles and responsibilities can avoid duplicated efforts.[165] However, federal agencies can face administrative barriers when engaging with community and nongovernmental actors, such as the Paperwork Reduction Act's requirement of extensive documentation when collecting information from the public.

Well-functioning, multilevel governance helps in adaptation strategy development.[179,180] For example, California, Florida, and other states have used informal regional collaborations (e.g., Southeast Florida Regional Climate Compact, Alliance of Regional Collaboratives for Climate Adaptation) to share resources and develop adaptation strategies that serve regional needs. The Coastal Zone Management Act,[181] which requires federal, state, territorial, Tribal, and local coordination in a single review of newly developed laws beyond borders to protect and develop coasts, is a potential model for encouraging greater cross-scale actions. Vertical linkages between governance levels can help bridge the gap between community-based and national-level adaptation efforts[179] and enhance horizontal linkages across public and private actors and institutions. Horizontal network linkages enable diffusion of information and resources across similar organizations; for example, horizontal connections between community groups facilitate selective adoption of context-specific adaptations and the scaling out of successful adaptation actions.[182]

In instances when adaptation governance brings together groups that traditionally have not worked together, guidance from conflict resolution and collaborative governance can help.[183,184] Ensuring that decision-making processes regarding adaptation planning and implementation are inclusive is necessary to enable a just and equitable distribution of burdens and benefits (KM 31.2). Additionally, adaptation decision-making structures are most effective when they allow for innovation, learning, feedback, and continual improvement.[165,173]

At the federal level, much adaptation has been governed through disaster policies (e.g., through FEMA hazard mitigation planning and grants and HUD disaster recovery grants).[185,186] These policies may not be adequate or appropriate for long-term and systemic adaptation because they are often framed in ways that may not address local adaptation needs and focus mostly on critical infrastructure and disaster response rather than institutional change.[187] Either those systems will need to be transformed or new systems will need to be developed for the US to adequately adapt to future climate hazards.

Another key issue in adaptation governance tends to be unfunded mandates or responsibilities assigned to regions or communities without dedicated increases in funding and capacity.[1,188,189] Government-led adaptation planning would benefit from a greater focus on understanding community-driven adaptation before making significant resource-allocation decisions, given the inherently local nature of adaptation.[190] Development of enabling conditions and frameworks to support adaptation is best guided by recognizing local values, competence, interest, awareness, and analytical capacity.[171,191]

Most governance institutions were created when climate change was not recognized and the climate system was relatively stationary.[123,192] New and revamped governance arrangements face tensions with structures of pre-existing institutions that are strongly embedded and may be protected by long-standing power dynamics.[123,193] Creating adaptive systems will require fundamental changes across multiple systems and sectors, such as infrastructure, agriculture, public health, and natural resource management (KM 31.3; Chs. 6, 11, 12, 15, 18). Additionally, transformative adaptation benefits from aspirational vision and leadership, as transformative adaptation can upend existing norms and practices.[194]

Systemic change can be facilitated through changes in laws, codes, and standards; data collection (e.g., disaggregated demographic data); and regulations that shape decision-making for intentional and equitable adaptation. For example, laws requiring cost–benefit analyses prioritize infrastructure investments in neighborhoods with high-value properties unless explicit practices to target specific beneficiaries are included and the disaggregated data to identify desired beneficiaries exist.[195,196] Likewise, laws that prescribe the types of science used in decision-making may exclude local or Indigenous Knowledge, limiting both participation in decision-making and incorporation of multiple actors' views and priorities (KM 16.2).

The body of research to inform effective and equitable adaptation governance is growing, but knowledge gaps and a need for translating research findings into on-the-ground implementation action remain. Adaptation researchers can inadvertently create gaps, make translation more difficult, or duplicate efforts if they do not fully reference previous works or if the field becomes too fragmented across disciplinary or topical silos.[197] Local governments can prioritize adaptation activities and avoid maladaptation and unintended side effects by effectively identifying and assessing synergies and trade-offs that are context specific.[198,199] Building local capacity can also support more equitable adaptation governance.[197] Research on adaptation governance may increasingly address a rise in climate litigation, with thousands of US cases identified in climate litigation databases.[200] A key driver for litigation is compensation for the costs of adaptation. The dynamic sociopolitical and scientific context in which climate litigation takes place makes it challenging to assess its impact.[201] Finally, identifying institutional and systemic shifts that may support more coordinated and transformative governance would require more research.

Key Message 31.5

Adaptation Requires More Than Scientific Information and Understanding

Effective adaptation to a changing climate requires both decision-relevant climate information and evidence-based decision-making approaches (*high confidence*). Adaptation requires that researchers intentionally collaborate with communities to identify goals, assess vulnerability, improve capacity, and address contextual factors, such as values, culture, risk perception, and historic injustices (*medium confidence*). Climate services can be improved by ensuring access for historically disinvested communities and by attention to procedural and recognitional equity when scientists work with communities and decision-makers (*medium confidence*).

Climate data and information remain a limiting factor for adaptation. However, many people and organizations, especially those in historically disinvested communities, require more than scientific data and information to adapt.

Cities and states use climate data, information, and decision-support tools in adaptation decisions (Table 31.2) to, among other things, identify, assess, plan, and reduce risks. For example, the city of New York recently legislated Climate Resiliency Design Guidelines,[202] which, among other things, determine the height of flood protection measures using climate projections from the New York City Panel on Climate Change.

Tools like the US Climate Resilience Toolkit,[203] Climate Mapping for Resilience and Adaptation,[204] the Sea Level Projection Tool,[205] and even the web-based format of the National Climate Assessment (NCA)[206] provide broad access to climate information across the US. Several states have developed climate data portals to provide communities with location- and sector-specific climate hazard data (e.g., Cal-Adapt in California,[207] the New York Climate Change Science Clearinghouse,[208] and the New Mexico Climate Risk Map[209]). These tools are particularly useful for organizations with the technical and technological expertise to interpret and customize the data (e.g., insurance companies, larger cities and states, and other entities). However, many adaptation decisions are made without customized adaptation decision support,[162,210] which may be due to the overwhelming number and complexity of tools that exist.

A growing number of efforts provide science- and evidence-based support that extends beyond climate data and information. These efforts are referred to by many names, including climate services,[47,211,212,213,214] technical assistance,[215,216] decision support,[217] sustained assessment,[218] and boundary spanning.[219,220] These terms are not synonymous in that they have distinct approaches related specifically to adaptation that go beyond technical support. These various efforts might

- consider context and need in early stages of development to increase scientific adequacy and to respect processes of knowledge creation involving people with diverse values and lived experiences;[211,221,222,223,224,225]
- honor Traditional Knowledge systems[226] and Indigenous self-determination (KM 16.2);
- address contextual factors such as risk perception, decision-making authority, and organizational agility;[227,228,229]
- customize data and information to fit the time frame and spatial scale of interest;[222,229,230]
- manage uncertainty about the extent and timing of climate change and its effects, as well as about potential social–economic–environmental futures;[161,231,232,233,234]
- plan for and anticipate multiple possible futures to respond to changing conditions and unforeseen consequences;[235,236,237,238]
- strengthen public participation and democracy by engaging multiple actors in negotiating goals, evaluating trade-offs, and making adaptation decisions (KM 31.3);[10,84,227,239,240,241,242,243,244] and
- develop evidence-based strategies for changing behaviors and systems and evaluating outcomes.[151,245,246,247,248]

There are several Federal programs that provide broader forms of climate decision support. For example, NOAA's Climate Adaptation Partnerships Program, USDA's Climate Hubs, USGS's National and Regional Climate Adaptation Science Centers, National Park Service's Climate Change Response Program, EPA's Environmental Justice Thriving Communities Technical Assistance Centers, and Department of Energy's national labs[47,249] all provide climate services for a range of sectors and regions. Similarly, the Tribal Climate Adaptation Menu (Dibaginjigaadeg Anishinaabe Ezhitwaad),[250] developed by numerous stakeholders in Minnesota, provides a framework to integrate Indigenous and Traditional Knowledge into the climate adaptation planning process. Despite these existing efforts, there are still limitations on awareness of and access to services, especially for historically disinvested communities.

Access to broader forms of technical support varies, with underserved communities facing critical gaps (KMs 16.2, 29.4). Not all regions are covered. Some sectors are further along in climate adaptation planning than others. While there has been some research on gaps by region and sector,[249] no comprehensive nationwide evaluation exists that assesses the availability of climate services, and most existing evaluations are largely based on geographic and sectoral coverage, not differential exposure and factors related to social vulnerability. Moreover, many emerging forms of support are not explicitly focused on climate services.

Instead, they are providing climate-related technical assistance, which is unfamiliar to some environmental justice communities and Tribal Nations.[215,216,251] Additionally, environmental justice communities and Tribal Nations face barriers to obtain federal funding for technical assistance because there is a high level of technical skill required to apply and/or strict eligibility criteria.[252] When, how, where, why, and for whom climate services and climate-related technical assistance are distributed can be tied to transformative and equitable adaptation (Table 31.2).

Table 31.2 Climate Services Can Be Designed to Support Transformative and Equitable Adaptation

Climate services can be aligned to the level of community engagement and the impact of adaptation efforts. Climate services are not about supporting decisions in a vacuum. They can be designed to avoid engagement fatigue and advance transformative adaptation. Climate services can assess vulnerability and adaptive capacity to support actions to reduce unjust, maladaptive choices. Engaging communities in the development of climate services related to adaptation can empower environmental justice communities and Tribal Nations. Data and information tools can help reduce engagement fatigue if the goals, outcomes, and values have been established. If community engagement is needed to codevelop goals and values necessary to evaluate the consequences of transformative adaptation options, institutional partnerships can build and sustain the inclusive participation of diverse community voices.

Level of Community Engagement in Climate Services	Incremental Approach to Adaptation	Transformative Approach to Adaptation
Low	**Are services enabling maladaptation?** Consider services that assess vulnerability and adaptive capacity to account for injustices.	**Are services supporting equity?** Consider services that remove barriers to participation in climate adaptation, including knowledge generation.
High	**Are services operationalized?** Consider services that provide decision tools to reduce engagement fatigue.	**Are services sustained and mainstreamed?** Consider institutional arrangements that maintain trust, credibility, and saliency and embed services into decision processes.

Adaptation decisions range from smaller-scale, incremental decisions with clearer and limited participants to far-reaching, transformative changes with multiple decision points and decision-makers. Climate services can support adaptation and equity by encouraging discussion between historically disinvested communities and decision-makers regarding relevant climate risks and trade-offs between adaptation options.[56,253,254,255] In some cases, the trust and relationships built through an inclusive decision-support process lead to collective learning and adaptation over time, sometimes referred to as coproduction.

Coproduction encompasses a range of collaboration modes—from consultative to collegial—that structure science and decision support to advance societal goals.[151,227,247,248,256,257,258] Coproduction involves iterative, multiway processes that can strengthen procedural equity through power sharing and collaborative knowledge creation. For example, Looking Forward, Looking Back: Building Resilience Today, a partnership between the Alaska Climate Adaptation Science Center and the Aleutian Pribilof Islands Association, involved five community teams with leaders from each spanning multiple governing bodies, including the Tribal Council, the city governments, and the village corporations.[259] Training and workshops in each community were designed to support the development of climate adaptation plans.

Coproduction needs to be structured in ways consistent with the need and potential adaptation impact (Table 31.2). Coproduction is time- and resource-intensive, which can be another burden on disinvested communities,[260] especially given that language differences, remote locations, and other logistical challenges (e.g., lack of childcare) present barriers to participation and engagement. Additionally, there is a risk of unintentionally creating competing and unaligned goals across community members, technical experts, and government officials.[227] There are also often mismatches between the urgency for climate action, the long-term development of scientific evidence, and governmental decision processes.

To improve adaptation practice, adaptation-needs assessments—not solely focused on science gaps but also on adaptation barriers—can identify how practitioners and communities are or are not supported by the scientific community in their adaptation efforts and in what contexts different forms of support are preferred over others.[261,262,263]

In particular, decision-makers can benefit from access to or the development of methods, metrics, and indicators (App. 4.7) that support trade-off analysis when making adaptation decisions.[264] Additionally, to evaluate adaptation choices, decision-makers can

- use these tools to track progress on adaptation efforts and outcomes;[33,153]
- assess short-, medium-, and long-term adaptation effectiveness;[151,152,265] and
- evaluate the advantages and disadvantages, including cost-effectiveness, of incremental and transformative adaptation.[152,154]

Although vulnerability indicators have been developed and thoughtfully used in planning efforts,[266,267,268] and resilience indicators have gained traction recently to assess community impacts or resilience factors,[269,270,271] adaptation indicator development has lagged, because assessments of effectiveness and comparisons against baselines have been limited to evaluation of specific projects.[32] Indicators need to consider context, audience, and use to be effective, including the multiple ways that adaptation affects communities and ecosystems. For example, building a seawall may reduce the likelihood of floodwaters reaching the homes behind the wall (risk outcome), but the wall may also increase erosion of neighboring properties (risk outcome to people outside the wall), narrow the beach and affect coastal species (environmental outcomes), and cut off access to the shore, changing the way people in the community interact with the coast (social outcomes).[93,272]

Key Message 31.6

Adaptation Investments and Financing Are Difficult to Track and May Be Inadequate

Investments in adaptation are being made at the federal, state, territorial, Tribal, and local levels, as well as within the private sector, but they are not always evenly distributed, coordinated, tracked, or reported (*high confidence*) and may be inadequate (*medium confidence*). Future adaptation investment needs are expected to be significant, although projected amounts vary due to uncertainty in future emissions trajectories, associated impacts, and the timing of implementation (*high confidence*). Proactive adaptation can reduce some of the most severe costs of future climate change, particularly under very high emissions scenarios in the late 21st century (*medium confidence*), although adaptation is still needed in the present for communities and infrastructure that may not be well adapted to face current climate conditions (*high confidence*).

Estimates of the damages and associated costs of climate change without adaptation can reach into the hundreds of billions of dollars by the end of the century (Table 19.1).[273,274] Although there are national-level estimates of the economic cost (total damage) of climate change (Ch. 19),[273] there are no comprehensive national-level estimates of adaptation costs for the US. Across adaptation economics assessments, there is little consistency regarding which future emissions scenarios are considered in projecting impacts, the sectors evaluated, the types of damages considered (e.g., direct and/or indirect), the time horizon for cost estimates, and the costs of implementation.[1,275] Despite these differences, studies in the US consistently project adaptation costs on the order of hundreds of millions to billions of dollars.[273,274,276,277,278,279]

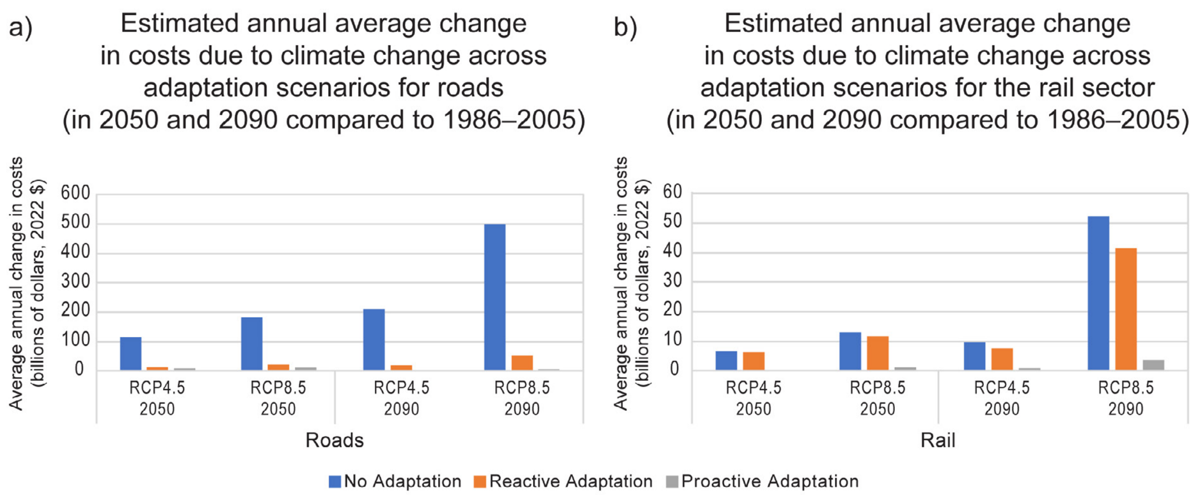
Determining how much and where to invest in adaptation involves decision-making under uncertainty, evaluation of trade-offs, and assessment of the risks associated with delaying action. Generally, this involves quantifying the projected economic impacts of climate change (KM 19.1), the projected costs of adaptation actions, and the expected benefits and/or avoided harms from those actions, all of which can be deeply uncertain. Other essential considerations include efforts to determine ideal levels of adaptation given resource constraints and how to efficiently and equitably allocate costs and benefits among stakeholders. Considerations that are implicit or explicit in adaptation-related economic analyses include questions of who pays for or benefits from adaptation, how to account for the nonmonetary or difficult-to-quantify costs of climate change (e.g., the emotional and physical toll of experiencing extreme weather events, displacement of community after an event, loss of traditional ways of living, and loss of sites of cultural significance; KM 19.1), and what stakeholder interests are reflected in the valuation (both cross-sectionally, in terms of different stakeholder groups, and temporally, as in the choice of discount rate). Some organizations have generated benefit–cost ratios to reduce the impacts of climate hazards through adaptation planning. For example, the National Institute of Building Sciences suggests a 4:1 benefit–cost ratio for hazard mitigation work, with federal grants spent on resilience achieving a 6:1 benefit–cost ratio.[280] However, even when adaptation implementation is favored, other factors such as finances, risk perceptions, inadequate incentives, community capacity, competing priorities, or social and political influences may lead individuals and communities to underinvest.[279,281]

Improvements have been made in the ability to quantify and monetize the physical impacts of climate change (KM 19.1), which are used to estimate both the costs and value of various adaptation actions,[273] although uncertainty and limitations in these estimates remain.[150,282,283] Estimating the aggregated and disaggregated (e.g., sectoral or regional) costs of adaptation, risks of inaction, and value of adaptation actions involves several methodological challenges:[284] developing damage functions that represent impacts of climate change and account for adaptation;[282] understanding the limits of adaptation options and capacity (e.g., effective options may not be presently known or adaptation limits may have been reached); analyzing the behavior of different cost estimation methodologies across climate scenarios and time horizons; incorporating the context specificity of adaptation choices and outcomes into analysis, especially at larger scales (KMs 31.2, 31.4);[285] and evaluating the effectiveness and sufficiency of the actions taken to adapt to climate change.

Both the Fifth and Sixth Assessment Reports of the Intergovernmental Panel on Climate Change state that the benefits of adaptation are expected to be larger than the costs.[284,286] However, both reports note important limitations in estimating aggregate climate damages, costs of adaptation options, and avoided damages from adaptation implementation that create uncertainty and can make it difficult to compare across studies (Cross-Working Group Box Economic in O'Neill et al 2022[150]). Proactive adaptation (e.g., actions, which can be transformative or incremental, taken with the goal of preventing repair costs associated with future climate change) has been shown to reduce climate change damage–related costs for some sectors compared to reactive adaptation (e.g., repairs to damaged infrastructure that do not generally include consideration of future climate change but do consider current climate conditions; Figure 31.5)[128,274,277,281] or no adaptation. In the context of electricity distribution infrastructure, for example, proactive adaptation might entail updating wooden pole designs to account for expected temperature and precipitation conditions over the full future life span of the asset.[128] Reactive adaptation would entail replacing the poles with designs that are only reflective of current climate; no adaptation would entail using designs that do not account for any climate change that already may have occurred.[128]

Despite the estimated value of proactive adaptation, real-world impediments to proactive adaptation, such as ill-timed revision of infrastructure codes and inadequate incentives, can inhibit feasibility of implementation,[128,274] and findings may not be applicable in all sectors.[273] In many studies, proactive adaptation becomes increasingly valuable with greater levels of warming (e.g., under higher emissions scenarios), with benefits accruing over time, particularly in the later decades of the 21st century.[274,277] Where there is considerable current risk to infrastructure and assets from climate conditions (e.g., flood-related risk), it can be cost effective to implement adaptation now even if future benefits from proactive adaptation are small when discounted to the present.[279]

Estimated Annual Change in Costs Due to Climate Change



Future costs associated with climate change will depend on adaptation efforts and scenarios.

Figure 31.5. In some sectors, proactive adaptation can help reduce projected damages from climate change. Estimates are shown for a 5-model ensemble for two sectors (roads [**a**] and rail [**b**]), two time periods (2050 and 2090), and two scenarios—an intermediate scenario (RCP4.5) and a very high scenario (RCP8.5). The three adaptation scenarios reflect the nature in which adaptation has been implemented. Estimates include only costs incurred above historical climate conditions (e.g., climate conditions associated with historical climatology) and assume that adaptation can be readily implemented. Findings should be interpreted only for the sectors shown. Adapted from Neumann et al. 2021[274] [CC BY 4.0].

The scale of the adaptation challenge requires multiple streams of investment (personal, private, and public) and multiple financing options for individuals and communities that may struggle to finance it on their own (KM 21.5). Investments in adaptation[287] are being made at the federal, state, territorial, Tribal, and local levels, as well as within the private sector, but they are not always evenly distributed, coordinated,[288] tracked, or reported.

Adaptation finance relates to monetary investments that reduce the vulnerability or increase the resilience of human and ecological systems to negative climate change impacts.[289] Funding for adaptation, which to date has traditionally originated within the public sector, lags financing for mitigation-related projects (e.g., renewable energy development, energy efficiencies).[275,290,291,292] In addition, adaptation funding is tracked and reported more transparently at the international level than in the US, both in terms of total volume of investment and flows between countries.[284,291] In 2019 and 2020, the annual average of global adaptation finance investments was approximately $55 billion, compared to $659 billion for mitigation projects (in 2022 dollars).[291] Funding is largely funneled through public lending institutions such as multilateral and national development finance institutions but can also originate from other sources, including commercial finance institutions, governments, and corporations. Tracking of domestic public-sector and overall private-sector adaptation-related investment and financing is a known gap.[284] However, given their cross-cutting nature and co-benefits, investments in adaptation are not always clearly demarcated or obviously identified, making it difficult to explicitly track them and ultimately evaluate their effectiveness. Funding for infrastructure hardening, home weatherization, or cooling centers, all of which can be considered adaptation-related investments (and more incremental), may come from diverse organizations, be dispersed across programs, or not be clearly tagged as adaptation-related expenditures.

Federal and state budget and expenditure tracking does not always distinguish between mitigation- and adaptation-related activities (Box 12.1).[25] Assessing the landscape and uptake of available financing instruments can illuminate where adaptation finance presently originates and is concentrated. Several toolkits, such as the Equitable Adaptation Legal and Policy Toolkit[287] and Ready-to-Fund Resilience Toolkit,[293] provide an overview of different funding (e.g., government grants) and financing (e.g., debt or equity financing) options that are available and help communities design and finance adaptation projects. Services from network organizations such as the American Society of Adaptation Professionals facilitate exchange of leading practices and collaborative spaces for trusted partnerships to form and co-investments to occur for climate adaptation. Understanding how to utilize funding sources would also require understanding levels of vulnerability, hazard exposure, and adaptation and resilience requirements in a future climate context.

At the federal level, government entities such as the Department of Treasury and FEMA provide grants and manage national tax credit and similar financing programs. Other Federal Government entities such as the Department of Transportation, NOAA, and the Department of Energy fund projects to advance adaptation at various levels of government and sectors (KMs 5.3, 9.3, 13.1).

Private-sector investments in adaptation can include funding or financing options (e.g., grants from private and philanthropic organizations, impact investing from private and development finance institutions, incentives for adaptation measures from insurance companies [KM 21.5], and/or loans from green banks), as well as direct investments from private companies to implement adaptation measures to reduce physical climate risk. There has been increased activity in the private sector exploring adaptation to physical and transition risks. This activity has been driven partially by investors requesting increased transparency in climate-related and environmental, social, and governance impacts (e.g., the Task Force on Climate-related Financial Disclosures) and ranges from climate risk disclosure to organizational resilience and from capital stress testing to adaptive asset management. Private-sector organizations have also made independent and regulatory-required adaptation-related investments after natural disaster events (e.g., asset hardening after a severe storm). With limited information on corporate and other private-sector adaptation, it is hard to know the scale and sufficiency of actions implemented to date, but overall, adaptation planning and investments appear to lag significantly behind low-carbon transition planning.

Data on corporate and other private-sector investments in adaptation are very limited, in part due to confidentiality restrictions, uncertain causality, and lack of agreed-upon impact metrics.[275,294] Lack of data makes it difficult to determine where private-sector investment is occurring and any gaps in sectoral, geographic, or community access to privately funded opportunities. Investments in adaptation by the private sector may face more hurdles due to greater challenges with quantifying return on investment compared to mitigation-related projects, uncertainty in policy and regulatory environments, mismatched investment time horizons, and challenges in mapping climate impacts to business-related activities.[57] Increasing transparency in climate-related disclosures that describe the actions corporations and other private-sector entities are taking to minimize the physical and transition risks to their organization, their value chain, and the communities where they reside and operate may advance the ability to track action and progress toward adaptation where climate risks are extensive. Concerns remain, however, about the comprehensiveness, alignment, and quality of information included in disclosures, as well as the ability to compare across responses.[295] Responses also overwhelmingly skew toward large corporations in specific sectors, in part due to the significant resources required to prepare disclosure responses.[295]

In practice, there are multiple examples of communities leveraging the diversity of investment instruments, risk finance mechanisms, and broader finance-relevant solutions to support adaptation. Examples include federal and state public funding (e.g., Louisiana's Strategic Adaptations for Future Environments program[296]), municipal public–private funding (e.g., DC Water's Environmental Impact Bond[297]), development institution investment (e.g., Coastal Enterprises Inc., a community development financial institution based in Maine[298]), and public–private risk transfer (e.g., a parametric insurance program for the Miami-Dade School District, developed by reinsurer Swiss Re). Financial instruments can serve multiple purposes—to finance activities that reduce direct exposure and vulnerability to physical climate change impacts and to transfer and/or reduce risk where physical climate impacts are difficult to eliminate through more direct measures (e.g., through insurance and other instruments). In late 2022, the 117th Congress passed the Community Disaster Resilience Zones (CDRZ) Act[299], requiring FEMA to continue to maintain a natural hazard assessment program, designate community disaster resilience zones based on census tract hazard-risk ratings, and provide an increased federal cost share to those communities. The CDRZ Act is an amendment to the 1988 Stafford Act,[300] requiring the identification and improvement of the climate and natural hazard resilience of vulnerable communities. FEMA will engage with state, territorial, Tribal, and local emergency management partners to identify how the designation of the zones can benefit these government entities.

Despite these and other actions, several gaps limit the efficacy and volume of adaptation finance in the US, including the following:

- **Challenges in tracking and assessing adaptation finance flows:** As previously stated, sparse data on public and private adaptation-related investments inhibit the ability to track finance flows and overall investment levels within the US. Work to establish a process for tracking these data would be an important first step in better understanding the sufficiency and efficacy of adaptation investments. Adaptation finance gaps are also generally assessed in terms of aggregated finance volume (e.g., a country or regional average of adaptation finance), which does not capture the efficacy of finance.[301] Impact metrics are crucial for a full accounting of adaptation finance.
- **Upfront or operational costs of adaptation are, or are perceived to be, high or are inhibited by other factors:** Many interventions that could strengthen adaptation have, or are perceived to have, high up-front costs or uncertainty in total costs (especially if the costs or benefits are difficult to quantify) and may not be viewed as viable within many institutions' or communities' financial capacity. Local adaptation plan cost estimates sometimes exceed local governments' entire municipal budgets,[302] leaving very little budget to implement the actions identified in the plan.
- **Private entities have historically lacked incentives to invest in adaptation, but this may be changing:** Investments in adaptation can be perceived as public goods, limiting private-sector involvement.[57,286] Many private financiers have faced difficulties incorporating the economic benefits from avoided losses into their investment decision-making.[303] Emerging evidence points to increased investor, insurer, and credit rating agency attention to climate risk and the associated financial impacts or cost of capital for borrowers vulnerable to climate risk.[304,305] More publicly traded companies are estimating and disclosing the financial impacts of climate change and the investments made to reduce climate-related risks and to maximize the opportunities.[306] These evolutions may cause a shift in perspective by private investors if investment returns are perceived to be at risk from climate change.

- **Unsupportive legal and regulatory environment:** Although there are examples of regulatory mandates for adaptation planning (e.g., California Public Utilities Commission Rulemaking R.18-04-019[307] and New York State Senate Bill 7802[308]), in many contexts, the legal and regulatory institutions and infrastructure that support adaptation investment are insufficient, either because they are themselves underfunded (KM 31.3) or because political support is lacking (or both). Insufficient, weak, or nonexistent regulatory and policy frameworks (e.g., lack of or delayed adoption of forward-looking infrastructure codes and standards; KM 12.3) create barriers to action and investment. Such policy decisions limit incentives to address physical climate risk and reduce the likelihood of mobilization of finance.

Traceable Accounts

Process Description

Adaptation to climate change has the potential to affect people from all walks of life, so the author team was selected to represent people from a diverse range of disciplines including social sciences and engineering, as well as professional practitioners focused on adaptation. Care was taken to ensure that the team included both early-career and senior professionals from across industry, academia, and government who come from varying geographic areas and personal backgrounds. The authors were selected from the list of individuals who responded to the Federal Register Notice or otherwise directly contacted the US Global Change Research Program to volunteer. Authors met virtually on a weekly or bi-weekly basis throughout the assessment to build consensus, incorporate feedback from stakeholders received during the public workshops and comment periods, and collaborate and cross-reference other Fifth National Climate Assessment chapters where relevant.

It is important to note that while the terms "adaptation" and "resilience" are complementary concepts, there are distinct and important differences between the meanings of these terms, and confusion arises since they are often used interchangeably in policy and academic discourse. "At its most basic, adaptation refers to a process or action that changes a living thing so that it is better able to survive in a new environment, whereas resilience describes the capacity or ability to anticipate and cope with shocks, and to recover from their impacts in a timely and efficient manner. However, in practice, the distinctions and relationships between resilience and adaptation are more complicated and less easily defined."[309]

Historically, resilience was referenced as "bouncing back" and involved a return to baselines—such as a community recovering to its pre-disaster state after an acute climate-related event, such as an earthquake or hurricane.[310] More recently, however, the disaster planning and adaptation communities have realized that "bouncing back" to the status quo can be harmful. Therefore, the term "resilience" has recently been discussed as "bouncing forward"—changing a system or community to be better prepared for future conditions, whether those are sudden shocks like hurricanes or long-term stressors like drought and sea level rise. Bouncing forward implies that there has been reflection, growth, and learning, which does not always occur and is not always captured and evaluated after shocks and stresses have occurred. There are also communities that are forced to be resilient and can either bounce forward or bounce back depending on their access to the resources and support that meet their specific needs in both the short and long term. This chapter focuses on actions that help communities "bounce forward" to prepare for and thrive under future conditions.

Key Message 31.1

Adaptation Is Occurring but Is Insufficient in Relation to the Pace of Climate Change

Description of Evidence Base

The state of climate adaptation in the US has been somewhat well-documented through literature and organizations capturing publicly available adaptation actions to date at multiple scales, such as the Georgetown Climate Center, the Intergovernmental Panel on Climate change,[150] the Global Adaptation Mapping Initiative,[15] and this National Climate Assessment. In addition, there are numerous studies documenting diverse barriers to adaptation, including psychological, regulatory, financial, and political barriers.[43,44,45,48] The chapter authors, as adaptation practitioners and researchers, understand in depth the current state of adaptation and progress—or lack thereof—being made across the US from the local to the national scale and wove that into the evidence base. The authors were able to capture evidence of progress and barriers along the various stages of the adaptation cycle from recent research and literature, public comments, and their professional experience. Although there is progress being made across the US, there are still significant barriers to overcome for Americans to adapt to climate change now and into the future. The chapter documents these barriers further in the Key Message narrative and highlights some on-the-ground examples to illustrate these barriers.

Major Uncertainties and Research Gaps

Given the lack of research on evaluating the effectiveness and sufficiency of adaptation actions across multiple sectors, scales, and regions, the authors focused on evaluating the current status of and barriers to adaptation across the five stages of the adaptation cycle. Authors felt as though the previous graphics[4,19] that illustrate progress along the adaptation cycle do not accurately reflect the varying levels of progress from the national to local scale. For example, a rural town in Kansas may be at the awareness stage, whereas the City of New York is in between the implementation and monitoring and evaluation stages of the cycle. Given this disparity in the level of progress along the cycle, authors included examples—captured from literature and author experience—of progress and barriers to each stage of the adaptation cycle.

Description of Confidence and Likelihood

Very high confidence in the diversity of adaptation actions occurring across the US stems from widespread and well-documented academic and policy reports about adaptation. While there are few documented examples of fully implemented adaptations, a lack of systematic studies of adaptation implementation that enable a comparison over time and the difficulty of comparing across regions and sectors yield *medium confidence* that adaptation is moving from the planning to implementation phase. Available research agrees that few implemented adaptations are being evaluated (*high confidence*) and that organizations face numerous barriers to developing and implementing adaptations (*high confidence*). Most available sources agree that current adaptation efforts and investments are incremental in nature and are insufficient to address future climate risks (*high confidence*). However, projecting and evaluating actual levels of risk reduction remains difficult, which leads to our statement of *medium confidence* related to current adaptation efforts and investments being unlikely to keep pace with future changes in the climate.

There is no consistent or regularly updated and tracked source for adaptation actions across the US at multiple scales, regions, or sectors, and many actions that may be considered adaptation may not be publicly known or captured through sources currently available that do track adaptation actions (e.g., the Intergovernmental Panel on Climate Change [IPCC] and the Georgetown Climate Center [GCC]). Therefore, the chapter's authors can provide confidence levels but not likelihood assessments.

Key Message 31.2

Effective Adaptation Requires Centering Equity

Description of Evidence Base

A substantial number of peer-reviewed papers, government data and reports, and accounts from extreme weather and climate events illustrate the uneven effects of climate change (Chs. 16, 18, 20).[62,63,64,65,66] Specifically, there is mounting evidence of the ways climate change disproportionately impacts low-income communities with higher percentages of Black, Indigenous, and Latin people, women, and younger or older adult populations, among others. Research and government reports document numerous ways in which government and private-sector systems contribute to differential effects through discrimination, displacement, or underinvestment in hazard mitigation, other public infrastructure, or disaster response (e.g., Frank 2020;[69] Wilson et al. 2021;[70] Howell and Elliott 2019[68]). Some disparities are better documented than others, but the finding that climate change affects populations differently and that some of these differences are driven by government (in)actions and social systems is not disputed in the literature.

There is a converging body of evidence that demonstrates that individual and social factors play a significant role in whether people have the resources to reduce or avoid climate impacts (e.g., adaptation), as is the case in other areas of society (e.g., access to education as a limiting factor to job security).[84,85,86,87] The specific reasons why individuals and communities adapt the way they do remains an area for research, but there is robust evidence and high consensus that psychological, cultural, historical, geographical, and social factors play a role and that individual or community values are important drivers in the adaptation process.[95,96,311,312]

Maladaptation is a well-established concept in the adaptation literature, and cases of maladaptation have been well documented in numerous cases by a range of author teams,[106,107] although the exact criteria used to determine when an action is maladaptive often differ according to context. A growing body of research documents the ways that centering equity in the design, planning, and implementation stages of adaptation leads to improved outcomes.[40,113,117]

Major Uncertainties and Research Gaps

A source of uncertainty is the lack of standardized methods to evaluate the social justice or equity implications of climate adaptation. Numerous studies have documented inequities and injustices in adaptation or hazard risk-reduction programs and actions (e.g., Frank 2020;[69] Wilson et al. 2021;[70] Howell and Elliott 2019[68]), but different author teams use different metrics and concepts, including participatory, distributive, or recognition justice. The different methods make comparative analyses challenging, although notably the many methods and teams reach similar conclusions about the desirability of centering equity and justice to both improve quality of life for affected communities and reduce climate-related risks.

Description of Confidence and Likelihood

There is strong evidence from a wide range of academic studies and government reports, with high levels of agreement across numerous research teams, that people are affected by climate change in different ways and to different degrees and that these differences are affected by historical and contemporary social systems. This statement therefore warranted *very high confidence*. Similarly, there is widespread, robust evidence with strong consensus that adaptation choices are influenced by preferences, capacity, and access to resources as well as personal and community values, so this statement was also considered to have *very high confidence*. The statement that adaptation actions that do not center equity and underlying causes of injustice can exacerbate inequity and increase climate risk is considered *high confidence* because there is widespread consensus about this claim, but the evidence is slightly less robust due to a lack of standardized methods to assess the social justice of adaptation outcomes. Studies documenting maladaptation when equity is not centered also bolster this conclusion.

Key Message 31.3

Transformative Adaptation Will Be Needed to Adequately Address Climate-Related Risks

Description of Evidence Base

There is a significant and robust literature documenting the occurrence and type of adaptation practices globally and in the United States.[15] Technical contributors to this chapter reviewed adaptation actions as documented in government reports and adaptation plans, as collected by the GCC Adaptation Clearinghouse and a systematic review. Researchers use several frameworks to assess transformative adaptation actions, but core principles relate to the depth or novelty of the change, the scale of the change (e.g., geographic or across multiple sectors), and the ability to address fundamental traits of systems or to challenge constraints of adaptation.[40,90,122,123] The IPCC Sixth Assessment Report, Working Group 2, for example, reviewed the relative frequency of incremental and transformative adaptation in over 1,800 studies using a modified version of the Termeer et al. (2017)[123] framework.[150]

Determining whether transformative adaptation is necessary in a particular case or whether incremental adaptation is sufficient for a given location or sector requires evaluation of not only individual adaptation actions but also suites of actions. Adaptation actions are difficult to evaluate, as the goals of adaptation are often contested, and the effectiveness or sufficiency of actions may not become apparent for a long time[16,313,314] (see discussion below in “Major Uncertainties and Research Gaps”). Nevertheless, a common finding within the literature is that most adaptation actions are incremental, small in scale, and limited by soft and hard constraints on adaptation.[1,15] Studies that assess the sufficiency of adaptation actions to address future climate change impacts routinely find that current incremental actions may be insufficient,[27,120] where sufficiency is determined based on projected climate change effects and limitations of adaptation actions (e.g., the ability of irrigation systems to handle future droughts). While the degree to which future actions will need to be transformative is uncertain (e.g., whether some, most, or all actions will need to be transformative), the literature supports *high confidence* that more actions will need to be transformative in the future than is current practice. That is, the US adaptation portfolio will need to include more transformative adaptation to adequately address future climate risks.

Major Uncertainties and Research Gaps

The major source of uncertainty is a lack of consistent, high-quality methods to evaluate the sufficiency of adaptation actions to address future climate-related risks. Methods are being developed (e.g., Parker et al. 2020[27]), but lack of consistency across the field makes comparative studies difficult and complicates efforts to pin down optimal adaptation portfolios. Methods for decision-making under uncertainty are growing for this reason, as are methods to identify actions and portfolios of actions that are robust under numerous climate futures. Efforts to evaluate both the effectiveness of adaptation actions and portfolios in addressing current climate-related risks and the sufficiency of actions and portfolios to address future climate risks are areas for continuing research.

Description of Confidence and Likelihood

There is *very high confidence* that climate adaptation actions in the United States to date have been incremental, because numerous information sources reporting adaptation actions in academic and government literature document these results and generally agree on the incremental nature of the adaptation actions. Although there is evidence of a few examples of transformative action, the overall statement that actions are generally small in scale and incremental remains robustly supported with strong evidence and high consensus. The necessity of transformative adaptation is assigned *high confidence* because numerous author teams and government reports reach this conclusion, but there is less robust evidence to support the extent of transformation that will be necessary. Similarly, numerous research teams conclude that monitoring and evaluation of adaptation will need to improve, both in terms of the methods used and the data collection and processes, to better understand what adaptation actions are effective to deal with current risks or sufficient to address future climate risks. However, not all teams agree on the nature of these monitoring and evaluation methods, so the need for improvement is assigned *high confidence*. The finding that adaptation actions in the United States (both the type and extent of actions) are generally insufficient to deal with future climate risks is not controversial in the literature. Likelihood statements were not provided because they represent probabilistic assessments of uncertainty that are inappropriate for this type of analysis.

Key Message 31.4

Effective Adaptation Governance Empowers Multiple Voices to Navigate Competing Goals

Description of Evidence Base

Research on adaptation governance and how adaptation decisions are made is a less developed topic relative to research on mitigation policy and governance,[156,158] especially for papers empirically focused on the US. Over the last five years, an increasing number of case studies have focused on adaptation governance in specific locations and sectors, such as sea level rise in San Francisco[159] or flood risk in the Upper Mississippi basin.[48] Existing case studies of adaptation governance display a high level of agreement with respect to its multi-actor, fragmented nature, wherein actors working in distinct organizations and sectors make independent decisions related to adaptation in an uncoordinated fashion.[48,49,50,159,165,166] This literature also highlights that these organizations have distinct goals, values, risk perceptions, and capabilities that lead to inconsistent and sometimes conflicting adaptation choices.[160,161,162,163,164] Both theoretical and empirical literature on adaptation governance also emphasize the benefits of increased coordination and collaboration across organizations, sectors, and levels of government.[1,51,165,172,173]

Major Uncertainties and Research Gaps

The major source of uncertainty is a lack of systematic, cross-case research comparing adaptation governance approaches across multiple sectors, types of adaptation, or geographies. The majority of evidence stems from single case studies or comparisons of two or three city or community cases. The lack of larger comparative studies creates uncertainty about the specific contexts in which governance approaches work and more universal challenges in implementation. Comparative research has assessed the use of specific policy tools to promote adaptation[315,316] but rarely focuses on broader governance arrangements, such as who is involved in decision-making and the roles they play (an exception is Fastiggi et al. 2021[165]). Likewise, there is minimal research evaluating the outcomes of governance approaches on adoption of adaptation actions, risk reduction, or equity.

Description of Confidence and Likelihood

High confidence about the diversity of actors involved in adaptation governance and the challenge of balancing competing goals signals that these statements rely on many high-quality papers that show the same general trends. *Medium confidence* about the need for collaboration and diversity of values and knowledge signals that there is a lower overall number of papers showing empirically the value of these approaches.

Key Message 31.5

Adaptation Requires More Than Scientific Information and Understanding

Description of Evidence Base

Many integrated, science-based approaches are used to help manage decisions under uncertainty and decisions spanning future social–economic–environmental futures.[162,163,210] Even though some future uncertainties cannot be reduced (Ch. 18) for particular strategies, many other strategies can take advantage of computing power and artificial intelligence to reduce future uncertainty, hedge against uncertainty by selecting actions that work across multiple possible futures, or approach adaptation decisions as a long-term process to be revisited over time.[195,235,317,318,319,320,321,322,323,324,325,326,327,328,329,330,331,332,333,334,335] Tools include modifications to traditional approaches like cost–benefit analysis, scenario planning, and multicriteria decision analysis; more participatory versions such as participatory mapping and serious gaming;[240,244] computational methods such as robust decision-making, probabilistic decisions, and real-options analysis; less computationally intense options such as heuristics, a growing area of research; and flexible options such as dynamic adaptation policy pathways[235] and adaptive management and governance systems.

A wealth of peer-reviewed literature over at least the past two decades provides formal and informal evaluation of specific climate service efforts and examines the use of climate information for a variety of decision-making contexts and applications. Recent research in this body of literature made strides by illustrating that equally important to whether climate information is used is how climate information is used. Specifically, it is important to acknowledge that any one specific climate service effort need not change a specific policy or real-world condition to benefit progress toward those or other outcomes.

Climate services can have numerous societal benefits and support diverse outcomes (see, for example, the Pacific Islands Regional Climate Assessment Evaluation[336]).[246,248] Over the past two decades, social science has improved the development of climate services by evaluating the usability of services,[337] prescriptively improving public data products,[338,339] and, more recently, expanding the degree to which various service efforts support adaptation and related societal benefits. Social science, including formal and informal evaluation of climate services, has improved our ability to generate usable and actionable climate information.[151,228,247,337,340] Additionally, social and behavioral science illustrate that actionable climate information can be complemented with new models of participatory, adaptive decision-making geared toward long-term behavior change.[162,231,232,234,337,341,342,343,344,345,346,347]

While the aforementioned literature evaluating climate services speaks to trust, legitimacy, and other important indications that dimensions of equity (e.g., procedural) may or may not have been achieved in different climate service efforts, the body of research only recently has started to examine equity as a critical component of climate services, as an intentional or deliberate part of both the evaluation and the climate service effort itself. Furthermore, equity in adaptation is a relatively new area of literature, and efforts to link the two bodies of work may also be limited by ambiguity over the definition of what constitutes a climate service. Additionally, attribution remains a thorny problem for evaluation research and investigations into the use of climate information, as well as for equity in adaptation. More work will be needed to determine the relative influence of a climate service effort alone versus the combination of a climate service effort and preexisting community organizing efforts to make a difference in catalyzing equitable adaptation. Nevertheless, of the climate service efforts proven to have a range of societal impacts leading to positive social and environmental outcomes and/or adaptive decisions, many have drawn on foundational work by Cash et al. (2003),[221] rooted in the concepts of legitimacy and saliency defined from a stakeholder perspective.

Major Uncertainties and Research Gaps

Additional research would be beneficial to evaluate how well different models of climate service 1) align with different decision contexts, 2) contribute to societal benefits/impacts and outcomes, and 3) support dimensions of equity, particularly around racial and economic disparity. Spanning all three issues related to climate services, more research would be needed to more fully investigate the efficacy of various forms of engagement and collaborative decision-making and how they factor into coproduced climate services. More institutional research would also be needed to determine ways that for-profit services can generate value (e.g., empowerment, revenue) for lower-income communities.

Description of Confidence and Likelihood

High confidence stems from a wealth of literature that climate services do provide a range of benefits and have met a range of needs. *Medium confidence* stems from less literature on equity in adaptation and climate services specifically, and, where that research exists, definitional ambiguity and problems with attribution of societal outcomes directly to climate services, as opposed to a combination of factors.

Key Message 31.6

Adaptation Investments and Financing Are Difficult to Track and May Be Inadequate

Description of Evidence Base

The author team reviewed the literature by searching databases, inviting technical contributions from subject-matter experts, and soliciting feedback during public meetings.

Economic analysis of the costs and benefits of adaptation is a significant research field with numerous studies covering a range of sectors and geographies. Relevant studies include Melvin et al. (2017);[277] Reguero et al. (2018);[278] Martinich and Crimmins (2019);[273] Fant et al (2020);[128] Lorie et al. (2020);[281] Neumann et al. (2021);[274] Wobus et al. (2021);[279] LeRoy et al. (2019);[348] and Clavet et al. (2021).[349]

The peer-reviewed literature abounds with studies estimating the costs of adaptation, although these examples tend to coalesce around a subset of climate hazards, mostly flooding and other hydroclimate-related hazards (e.g., Clavet et al. 2021;[349] Lorie et al. 2020;[281] Melvin et al. 2017;[277] Neumann et al. 2021;[274] Reguero et al. 2018;[278] Wobus et al. 2021[279]); around a subset of sectors, historically agriculture, energy, and water; and in specific geographies, although there are several recent studies that evaluate the economics of adaptation for the continental US.[273,274,276,279] Time horizons for implementation of adaptation options vary across studies (e.g., next decades versus midcentury versus end of century), which can make it difficult to compare cost and benefit estimates. Recent studies (e.g., Neumann et al. 2021[274]) have attempted to incorporate estimation of the indirect costs of climate change on different sectors (e.g., train delays resulting from effects of temperature on rail lines) and these estimates' effect on evaluation of adaptation options.

Since the publication of the Fourth National Climate Assessment, there has been increased research into the effects of different adaptation implementation scenarios (e.g., proactive, reactive, and no adaptation) on damages associated with climate change (e.g., Martinich and Crimmins 2019;[273] Fant et al 2020;[128] Neumann et al 2021[274]), with much of this work supported by the EPA's Climate Change Impacts and Risk Analysis project.

Many organizations have climate investment tracking initiatives and publish regular reports on investment levels and flows (e.g., Climate Policy Initiative, World Bank, United Nations Environment Programme). This tracking is most robust at the international level and at monitoring investment and finance flows between countries, specifically transfers from developed nations to developing nations or transfers to international adaptation funding mechanisms.[284] Specific statistics on investment levels within countries, including the US, are more challenging to find. This is due in part to the fact that adaptation-related investments are not always labeled as such, especially when compared to climate change mitigation–related investments. Finally, tracking of public sector climate investment flows (e.g., from governments or multilateral institutions such as development banks) is also more robust than tracking of private-sector climate flows.

Major Uncertainties and Research Gaps

Despite the multiple case studies of individual examples of adaptation, evidence is unclear about how coordinated or transformative these activities are. The lack of detailed information on adaptation-related investment does not indicate that it is not occurring but rather that it may be uneven, uncoordinated, or underreported. Thus, a major source of uncertainty in assessing the current state of adaptation is assessing the extent to which it is being adequately funded and financed in a coordinated way. Research gaps center on improved tracking of within-country and private-sector adaptation investments; identifying methods to track investment needs or levels when it is difficult to categorize adaptation-related investments; and developing improved metrics and methods for justifying adaptation-related investments.

More finance options have emerged to assist communities with covering the costs of adaptation. The chapter briefly cites four examples: the Louisiana's Strategic Adaptations for Future Environments, a fund administered by the State of Louisiana to provide community-driven adaptation support to residents, targeting the housing, transportation, and energy sectors; the DC Water's Environmental Impact Bond, an environmental impact bond to share with investors the financial performance risk associated with projects to respond to water stress facing the systems; investments from community development financial institutions, such as Coastal Enterprises Inc. in Maine; and a parametric insurance program for the Miami–Dade School District, developed by reinsurer Swiss Re. More research, specifically in the US, investigating the rates of uptake and share of different financing types utilized compared to others would be valuable.

Description of Confidence and Likelihood

Multiple sources[275,284,290,291,295] consistently call out the lack of data on private-sector investments in adaptation, especially when compared to data on public-sector investments and financing. New et al. (2022)[284] note that progress has been made in tracking climate finance internationally but identify tracking of domestic public-sector and overall private-sector investments as critical gaps. For these reasons, there is *high confidence* that more investment in adaptation and improved tracking of domestic adaptation-related investments would be significantly beneficial.

Where adaptation may be occurring, the literature does cite evidence of underinvestment. Lorie et al. 2020[281] cite studies that reported that observed adaptation is lower than what would be expected from traditional cost–benefit analyses. There are many factors that influence the decision to adapt, including finances, lack of incentives, and technological unavailability, suggesting barriers to the decision to invest. Without a full picture of where adaptation investments are occurring and the nature of adaptation investments across sectors and communities, it is difficult to determine the adequacy of these investments. For these reasons, the authors decided to assign *medium confidence* to the statement that investments may be inadequate.

Studies that evaluate differences in aggregate costs of climate change across different scenarios consistently project higher economic costs under very high scenarios (e.g., RCP8.5) compared to intermediate (e.g., RCP4.5) or lower scenarios. Estimates of adaptation costs, which can translate into future investment needs, are consistently in the hundreds of millions to billions of dollars.[273,274,276,277,278,279] As many of these estimates are for specific sectors (as opposed to a comprehensive national-level assessment) and do not evaluate all possible climate impact pathways (for example, Fant et al. 2020[128] does not account for the impact of floods, hurricanes, and ice storms on transmission and distribution infrastructure), they may underestimate the total costs of climate change–related damages and total benefits of adaptation. For these reasons, there is *high confidence* that future investments needs will be significant but still substantial uncertainty as to what those figures will actually be.

Proactive adaptation has been shown to reduce costs compared to reactive and no adaptation scenarios,[128,274] with most benefits accruing in the later decades of the 21st century as warming levels increase under high scenarios. The choice of discount rate influences the additional cost reductions of proactive adaptation relative to reactive adaptation. Because of this and the fact that analyses of the effects of different adaptation scenarios are limited to select sectors, there is *medium confidence* in this part of the Key Message.

Multiple examples of events in recent decades that have caused significant economic damages and loss of life suggest that communities are not well adapted to face current climate conditions, including ways in which current climate conditions have changed with global warming. Events such as the Texas winter storm in February 2021, where cold temperatures were extreme but not unprecedented in the historical record, demonstrate that many communities are unprepared for current climate conditions. Similarly, Wobus et al. (2021)[279] report that current flood-related risk is serious enough in many locations to justify adaptation-related investments now. For this reason, there is *high confidence* that adaptation is needed to address the risks posed by current climate conditions.

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