Fifth National Climate Assessment: Chapter 12

Built Environment, Urban Systems, and Cities

Chapter 12. Built Environment, Urban Systems, and Cities

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Introduction

The built environment includes human-made or modified landscapes, structures, and infrastructure systems that bring together people, services, and economic activities. This chapter focuses on the built environment found in and around cities and suburbs across the country, where most Americans live and work. Cities and urban areas are also a key part of the country's culture, nature, and historical heritage. The choices that we make today in cities, suburbs, and the built environment to address climate change will affect the livelihoods, well-being, and quality of life for all Americans in the future.

Climate change has multiple and compounding effects on cities and the built environment. Cities and urban areas are notable drivers of climate change through the creation of greenhouse gas (GHG) emissions from human consumption and land-use change (KM 12.1). Attributes of the built environment also influence local and regional climates, which are further impacted by climate change. Across the country, cities face rising temperatures and sea levels, as well as changes in extreme events such as droughts, wildfires, extreme precipitation, flooding, and heatwaves (KM 12.2). Climate change is projected to have cascading effects on critical energy, transportation, communication, and supply chain systems (Chs. 5, 13, 18; Focus on Risks to Supply Chains). Climate projections also show demographic and land-use changes and uneven distribution of climate change risk (Chs. 2, 3). Urban infrastructure will be further strained by climate change unless effective GHG mitigation and climate adaptation actions are undertaken.

Many city governments are planning for short- and medium-term climate risks to protect their economies and the well-being of communities and residents (KM 12.3). These plans involve forward-looking infrastructure designs, land use and zoning, building codes, decision support tools, and services to ensure residents' quality of life. However, implementation of these actions is uneven and limited in scale and often lacks long-term vision (Chs. 31, 32), and not all city governments recognize the inequities experienced by overburdened communities. Persistent gaps in the provision of health services, housing, food, transportation, employment opportunities, and green spaces put already-overburdened communities at a greater risk of adverse climate impacts.

The recent growth in the number of local and community-led approaches points toward the potential for more inclusive planning and implementation of climate actions (KM 12.4). Still, without evidence-based strategies to evaluate climate actions, cities risk investing in infrastructures and built environment systems that lock in future urban GHG emissions, underperform or have shortened life spans, and exacerbate adverse climate risks to overburdened communities.

Key Message 12.1

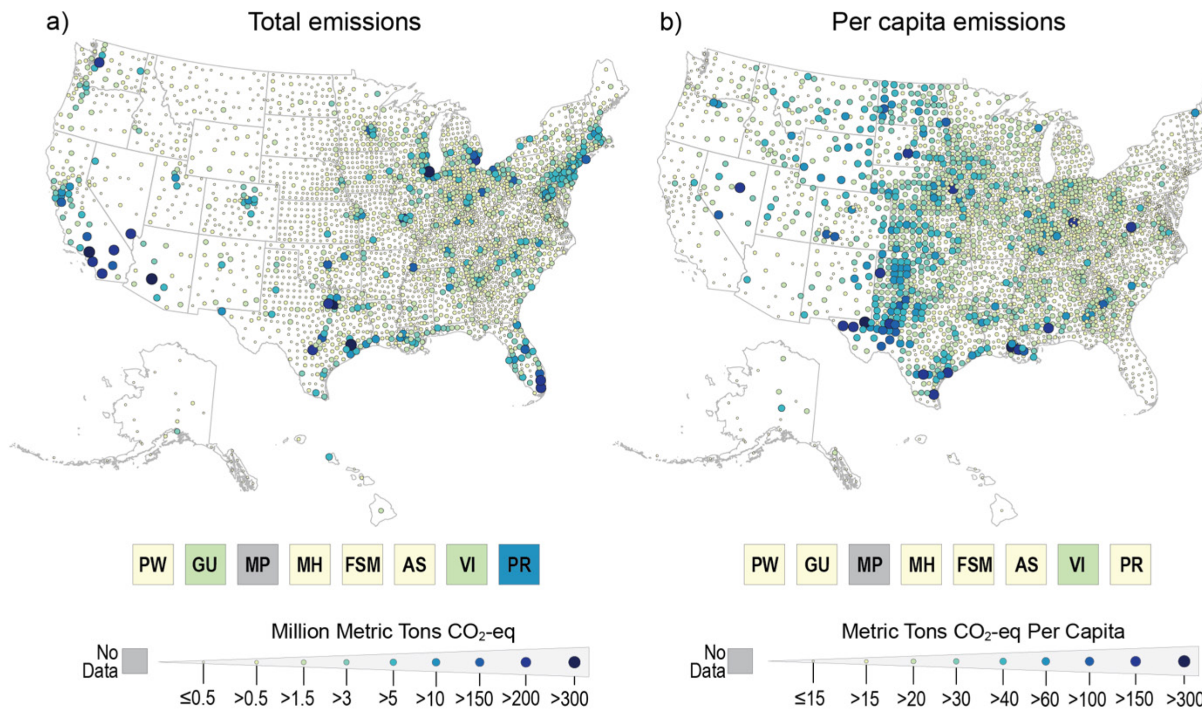
Urban Areas Are Major Drivers of Climate Change

Consumption of food, energy, water, and materials is a major driver of global climate change, and these consumption activities are disproportionately concentrated in urban and suburban areas (*virtually certain, very high confidence*).

Human consumption and economic activity in urban and suburban areas across the country contribute a significant portion of total US GHG emissions and other air pollutants.[1,2,3] The precise proportion of emissions from urban areas depends on their definition as well as the attribution of emissions from consumption (upstream), waste (downstream), and the import and export of goods and services (indirect emissions) to urban areas.[4,5] Emissions are also unevenly distributed among cities, with the largest 10 cities plus the top 5% of suburbs accounting for more than half of all emissions in the country.[6]

Cities have large GHG emissions in absolute terms (i.e., total emissions). Approximately 70% of urban GHG emissions come from building energy consumption, fuel for transport, industry, electricity supply, and construction (Figure 12.1).[5,7,8] While high population densities in urban areas may correspond to lower per capita emissions, this metric usually does not capture the full extent of indirect emissions and consumption by urban residents as well as spatial variation within urban areas.[3,9]

Greenhouse Gas Emissions by US County and Affiliated Territories

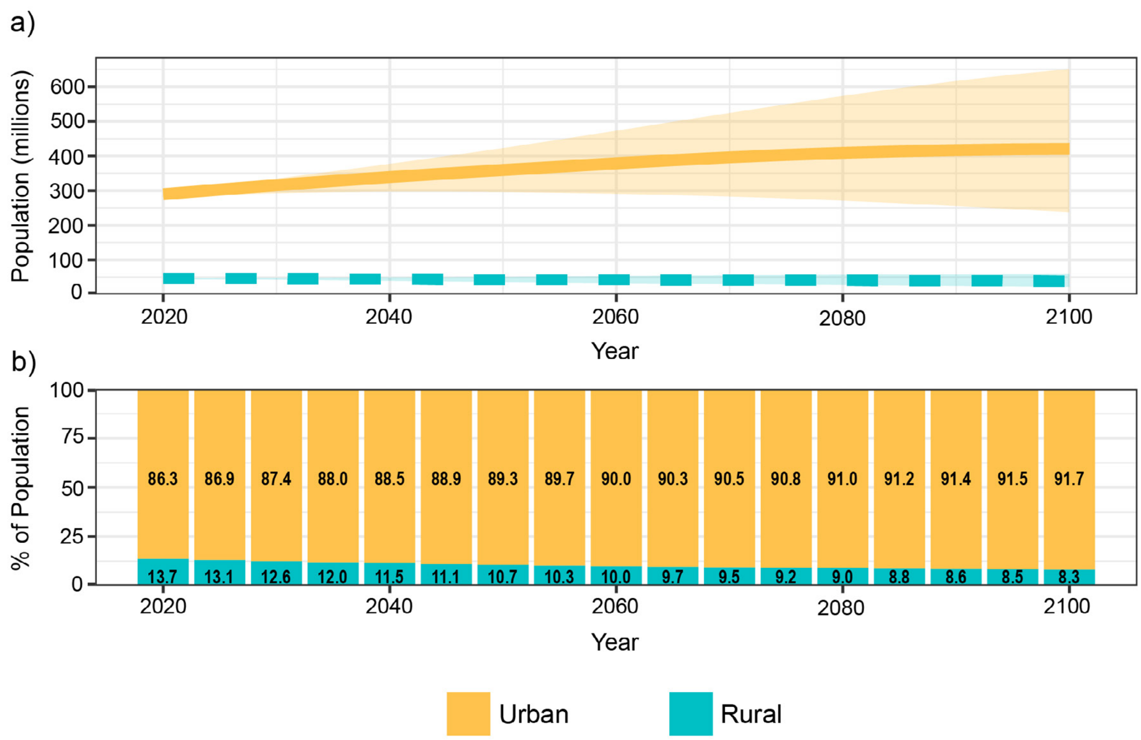


Urban and suburban areas contribute the majority of total greenhouse gas emissions through their consumption and populations.

Figure 12.1. The maps show the total (**a**) and per capita (**b**) emissions, measured in millions of metric tons of carbon dioxide equivalent (CO_2-eq) and metric tons of CO_2-eq per person, respectively. Total GHG emissions across the country are concentrated in cities and suburban areas. However, per capita emissions levels of urban and suburban residents are relatively lower compared to rural areas, although measurements usually omit indirect emissions by urban residents or the variations in their consumption levels. Emissions sources included are from electricity and natural gas used by residential, commercial, and industrial buildings, together with gasoline and diesel fuel used by on-road transportation, but do not include consumption of food, water, and materials. Data for the 50 states plus DC are by county or county equivalent for the year 2016. Data for Palau (PW), Guam (GU), Republic of the Marshall Islands (MH), Federated States of Micronesia (FSM), American Sāmoa (AS), US Virgin Islands (VI), and Puerto Rico (PR) are territory-wide—all for the year 2019 except FSM, whose data is from 2017. Commensurate data for the Northern Mariana Islands (MP) is not available. Figure credit: University of California, Davis; Northern Arizona University; NOAA NCEI; and CISESS NC.

Total emissions from urban areas may continue to grow with urban population. Figure 12.2 illustrates projected changes in US population to 2100 for urban and rural areas. Higher incomes and lower population densities relate to higher residential energy use, including transportation GHG emissions.[10,11] All of these observations indicate that if urban areas continue to grow in population, extent, and level of wealth as expected, their total emissions will also increase unless these linkages can be changed through mitigation.

Urban and Rural Population Trends



Urban areas constitute a significant majority of the total US population in all future scenarios.

Figure 12.2. Panel (**a**) shows projected changes in urban (including suburban) and rural population in the US from 2020 to 2100 based on Shared Socioeconomic Pathways (SSPs), along with modeled scenario uncertainties in shaded areas. SSPs describe potential futures of greenhouse gas emissions and economic development, so the range of uncertainty is bounded by the overall impact of climate interventions over time. Panel (**b**) shows the proportional split between urban and rural populations based on an average SSP scenario. It shows that the proportion of urban population is expected to increase over time. Such a trend highlights the importance of reducing emissions in urban areas and the built infrastructure systems that concentrate in and around cities. Demographic data are available only for the 50 states plus DC and not available for the US Caribbean or US-Affiliated Pacific Islands. More extensive discussions of regional data availability constraints can be found in Chapters 23 and 30. Figure credit: University of California, Davis; Florida State University; Massachusetts Institute of Technology; NOAA NCEI; and CISESS NC.

Key Message 12.2

Attributes of the Built Environment Exacerbate Climate Impacts, Risks, and Vulnerabilities

Urban development patterns can exacerbate climate change impacts such as increases in heat and flooding (*virtually certain*, *very high confidence*). Climate change is amplifying existing loads and stressors on the built environment, and this is expected to continue (*virtually certain*, *very high confidence*). Urban areas face elevated risk as both people and the built environment are exposed to climate hazards, and these risks are distributed unevenly across the population (*virtually certain*, *very high confidence*).

Urban development patterns—resulting from past decisions about urban land use—significantly influence local and regional environments (Ch. 6), and these patterns can exacerbate the local effects of climate change. Depending on the type of built environment, both urban growth and land-use change have impacted and will continue to impact surface and ambient air temperature,[12,13,14,15,16,17] local and regional humidity,[18,19] wind patterns,[20] precipitation,[21,22,23] flooding (KM 4.1),[24,25,26] dispersion of air pollutants,[22,27] intensity of storm surges, and amount of sea level rise.[28] Figure 12.3 shows several examples of common built environment types—also termed local climate zones (LCZs)—found in cities and suburbs across the country.

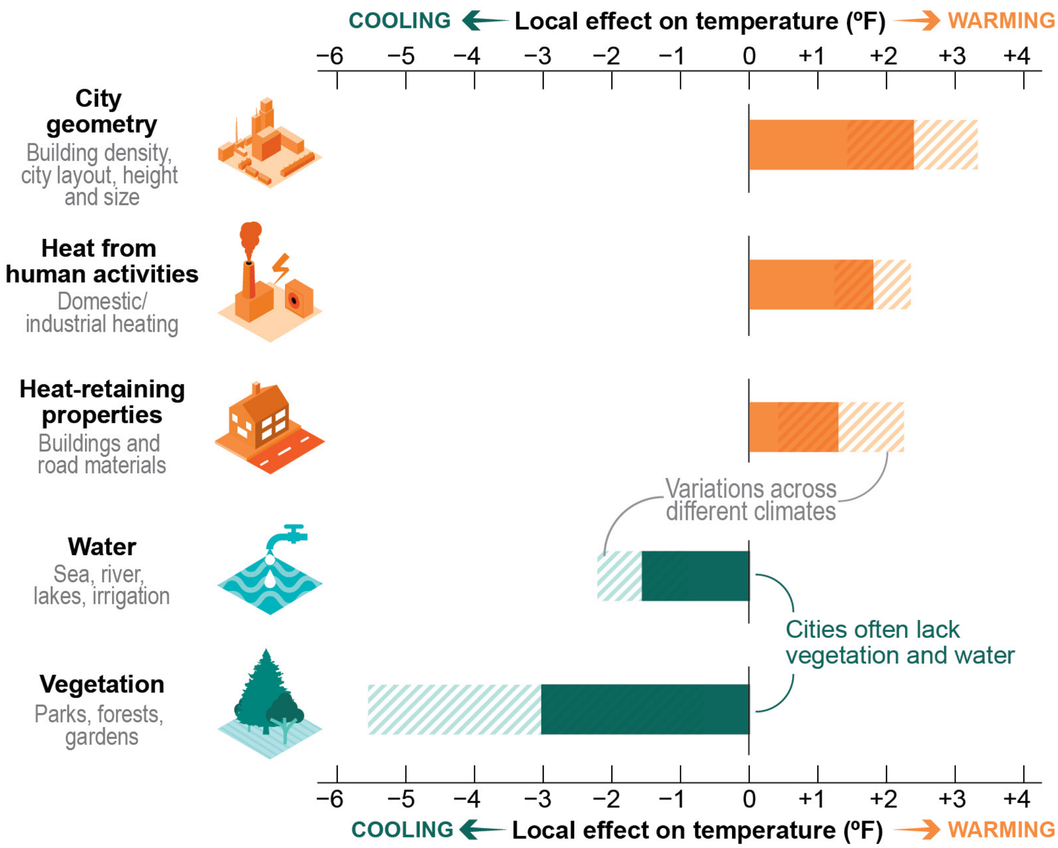
Examples of Built Environment Types Found in US Cities

Cities across the US include multiple types of built environments, ranging from dense urban cores to much less dense suburbs.

Figure 12.3. This figure illustrates five examples of a land-use and land-cover classification scheme called local climate zones (LCZs).[29] The scheme includes 10 classes and assumes that neighborhoods of the same LCZ are similar in their ability to modify urban climate and are different from neighborhoods of other LCZs. Residents living and working in more compact neighborhoods with a high density of mid- and high-rise buildings are more likely to experience urban heat islands, as buildings retain heat and prevent ventilation. Industrial areas also see higher temperatures because of the lack of shade from tree cover and the ways dark pavement or asphalt can trap heat. The examples shown in this figure are for illustrative purposes only. Adapted from Masson et al. 2020[30] [CC BY 4.0]. Photo credits: (Seattle) july7th/E+; (Chicago) Arial_Bold/iStock; (Washington, DC) Lingbeek/E+; (Charleston) Kruck20/iStock; (Jacksonville) Art Wager/E+; (Anchorage and Tucson) Jacob Boomsma/iStock; (Salt Lake City) olaser/iStock; (Long Beach) Jorge Villalba/iStock; (Texas City) Art Wager/iStock. All photos via Getty Images.

Changes in design, form, and mass of buildings and configurations of streets, open green spaces, and water features—as well as their interactions—have direct effects on urban temperature and energy demand (Figure 12.4).[5,31,32,33] For example, average daytime land surface temperatures in Las Vegas are approximately 3.6°F (2°C) higher in areas classified as heavy industry than those classified as high-rise. Nighttime air temperatures, in particular, are expected to be higher across many urban areas due to radiant heat and heat conductance from buildings (Figure 12.5).[34,35]

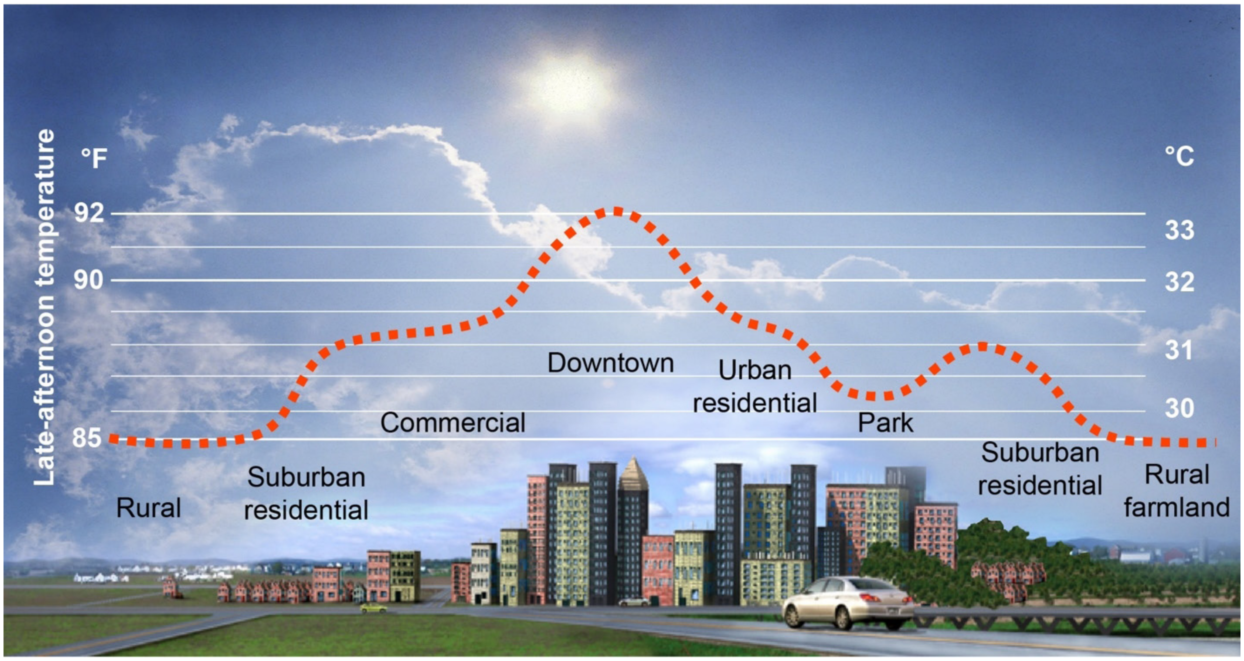
Effects of the Built Environment on Local Temperatures



Different aspects of the built environment affect temperatures in urban areas.

Figure 12.4. Cities are often warmer than their surroundings because of the urban heat island effect—the prevalence of higher air temperatures in urban areas because of the overall density of buildings, heat absorbed and emitted by buildings and asphalt, and heat from commercial, industrial, and household activities. The hatched portions of the bars show how the effects of warming or cooling of each factor vary depending on the local climate context. For example, vegetation has a stronger cooling effect in temperate and warm climates. Adapted with permission from FAQ 10.2, Figure 1 of Doblas-Reyes et al. 2021.[36]

The Urban Heat Island Effect



Urban heat islands are most prominent in dense downtown areas with little access to open space.

Figure 12.5. The figure illustrates temperature fluctuations across natural and built environments in a typical late afternoon in the summertime. Downtown areas with dense high-rise buildings experience the heat island effect because concrete and asphalt absorb and retain heat. Waste heat from cars, air-conditioning, and other human activities also contribute to the heat island effect. Cooler temperatures are found around urban parks, green spaces, open land, and in suburbs and rural areas. The temperature lines are shown for illustrative purposes and do not represent the climate in a particular city. Figure credit: ©Heat Island Group, Lawrence Berkeley National Laboratory. Adapted with permission.

Climate change creates negative and cascading effects on the built environment, with many infrastructure systems either projected or observed to be at risk of failing.[37,38,39,40] Temperature extremes also increase the energy demand of buildings as well as GHG emissions and air pollution.[41] Flooding overwhelms stormwater systems,[42] corrodes structures, scours foundations, and worsens indoor air quality through mold and bacteria.[43] Flooding can also inundate critical digital communication and internet infrastructure.[44,45,46] In addition, extreme heat and precipitation reduce the life expectancy of road pavements and tarmac surfaces (Ch. 13), and wildfire smoke reduces the life expectancy of heating, air-conditioning, ventilation, and filtration systems.[47]

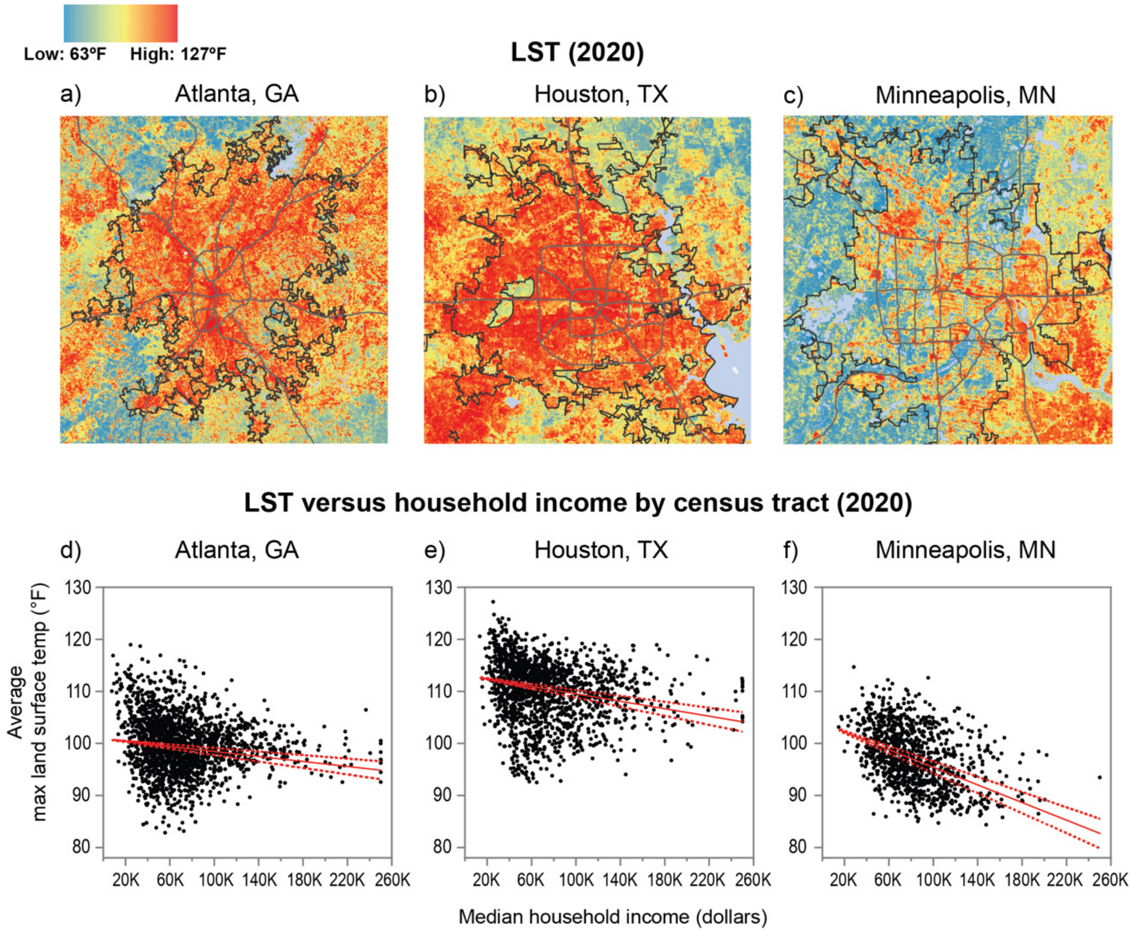
Many infrastructure systems across the country are deteriorating and at the end of their intended useful life, and many of these are not designed to cope with additional loading due to climate change.[48,49] Climate change has significant structural implications for buildings,[50,51] as well as different risks to public, historic, and cultural assets.[52,53] Many model building codes have incorporated some hazard mitigation and climate adaptation elements; however, there remains insufficient progress in incorporating these standards at the state and local levels and in developing comprehensive architectural, design, and engineering codes and standards that enable adaptation to a wide variety of climate impacts.[48,54,55,56,57,58]

Long-term climate uncertainties will also affect future construction and maintenance of dams, levees, bridges, stormwater systems, electrical distribution systems, and building enclosures, as well as the protection of historic assets.[59,60,61,62,63] Impairment, damage, and failure across infrastructure systems are often not monitored, evaluated, or publicly disclosed within the context of climate change.[64] New stressors such as human migration (KMs 20.3, 28.4, 30.3),[65] supply chain disruptions (Focus on Risks to Supply Chains),[66,67,68] and the COVID-19 pandemic (Focus on COVID-19 and Climate Change) all highlight the interdependent vulnerabilities of infrastructure.

Observed and anticipated climate changes disproportionately burden low-wealth communities, groups that are historically excluded from decision-making, and individuals with lower educational access (Ch. 20; KM 9.2).[69,70,71] Low-wealth neighborhoods are more exposed to heat extremes (Figure 12.6; Ch. 15),[72,73,74] where hot weather leads not only to physical discomfort for many people but also higher rates of illness and death.[75,76,77] Flood risk across the country is expected to increase disproportionately for census tracts with higher Black and Hispanic populations.[78,79] These disproportionate impacts are in part a consequence of exclusionary development practices such as redlining. Exclusionary housing practices—which persist today—leave overburdened communities with lower access to heat-reduction strategies such as urban trees and green space, as well as to broader economic and social resources.[73,80]

Another example of the uneven impact of climate change on the built environment is the deteriorating indoor air quality experienced by people living in neighborhoods with substandard housing. This includes exposure to allergens such as mold and dust [81] and pollutants such as carbon dioxide [82] and nitrogen dioxide.[83] In wildfire-prone regions, indoor air quality is additionally compromised by smoke (Ch. 28; Focus on Western Wildfires). There are also potential negative mental health outcomes from decreases in social interaction and physical activity when people are confined indoors to avoid temperature extremes.[84]

Land Surface Temperature and Its Relationship to Median Household Income for Three Cities



Lower-income urban neighborhoods experience higher surface temperatures.

Figure 12.6. The figure shows the spatial distribution of maximum land surface temperature (LST) in 2020 for Atlanta (**a**), Houston (**b**), and Minneapolis (**c**). Graphs (**d**), (**e**), and (**f**) depict the relationship between maximum LST and median household income across census tracts in each city (see also Figure A4.4). A statistical trend analysis (the Theil-Sen estimator) returns negative values for all three cities, indicating that LST decreases as income increases (solid red line). Dashed red lines indicate the 95% confidence interval, meaning that the true slope of the trend is expected to fall within this range. Note that LST is measured at ground level and may differ from surface air temperature, which is measured at a height of 2 meters. Portions of this figure include intellectual property of Esri and its licensors and are used under license. Copyright © 2020 Esri and its licensors. All rights reserved. Figure credit: University of California, Davis; University of Texas at El Paso; Massachusetts Institute of Technology; City of Phoenix, Arizona; US Geological Survey.

Climate change impacts in urban areas are costly because of the density of infrastructure, people, and services (Ch. 19).[85,86,87] Estimates of projected annual losses vary widely based on data available and the full range of scenarios applied.[88,89,90] A more detailed assessment of the ways extreme events and climate impacts are attributed to human activities can be found in Key Messages 3.3 and 3.5. Consistent with federal guidance,[89] annual loss estimates are assessed ranging from a middle-of-the-road scenario, where GHG emissions trends do not shift markedly from historic development patterns, to a path of more rapid technical progress and increasing resource intensiveness. Quantifying annual losses according to this range can support decision-making at the local level.[90]

For urban drainage systems across the contiguous US, for example, projected average annual loss estimates range from $5 to $6.8 billion in 2090, while annual losses to electricity demand and supply systems are estimated to be $4.1–$11.2 billion in 2090 (in 2022 dollars, undiscounted).[86] For transportation infrastructure, average annual losses are estimated to range from $9.8 to $24.3 billion for roads and $620 million to $1.2 billion for bridges in 2090 (in 2022 dollars, undiscounted).[86] Costs are concentrated in the eastern half of the contiguous US due to a higher density of transportation infrastructure.[91] However, in one western state alone—Alaska—the projected annual costs of repairing, rehabilitating, or reconstructing the damage to built infrastructure from climate change could range from $100 to $207 million in 2090 (in 2022 dollars, undiscounted).[86]

Coastal counties and communities across the country are home to 123 million people (40% of total population; Ch. 9).[85,92] In the contiguous US, if no adaptation efforts are taken, estimates of average annual losses to coastal properties range from $112 to $146 billion in 2090 (in 2022 dollars, undiscounted).[86] Estimates of the value of coastal property at risk of inundation across the contiguous US range from $17 to $582 billion (in 2022 dollars, undiscounted).[85] Regions where risks to coastal properties are highest include the Southeast and Northeast Atlantic coast and Southeast Gulf coast.[85] Coastal property losses on the Southeast Atlantic coast are estimated to be nearly $692 billion per year by 2090 without adaptation (in 2022 dollars, undiscounted), with southeast Florida representing more than 80% of the total losses in the region.[91]

Homeowners, renters, stewards of cultural assets, investors, and actuaries now have greater access to information disclosing climate risks.[93,94,95] This information is critical for assessing, appraising, and managing climate risks to the built environment.[85] For example, real estate markets are responding to climate risk with adjustments to property values[96,97,98,99,100] and changes in mortgage lending practices.[94,101] Increasing awareness and belief in climate change can shape the degree to which land and property values account for climate risks.[98,102] Awareness of climate change is also associated with less housing construction in high-risk areas.[103]

Key Message 12.3

Urban Environments Create Opportunities for Climate Mitigation and Adaptation

Cities across the country are working to reduce greenhouse gas emissions and adapting to adverse climate impacts (*likely*, *high confidence*). Some states and cities are integrating climate considerations into relevant codes, standards, and policies. However, the pace, scale, and scope of action are not yet sufficient to avoid the worst impacts, given the magnitude of observed and projected climate changes (*virtually certain*, *very high confidence*).

The number of city-level GHG emissions-reduction and climate adaptation actions continues to grow (Figure 32.20),[104,105] although actions are concentrated among wealthier and more populous cities with resources to do more.[74,106,107,108] Federal initiatives to aid city-level efforts include the US Climate Resilience Toolkit, a guide for planning, funding, and implementing resilience efforts;[109] the National Integrated Heat Health Information System, an interagency portal for supporting communication, capacity building, and decision-making around heat;[110] funding opportunities such as FEMA's Building Resilient Infrastructure and Communities (BRIC) program; and community development block grants that consider climate risks in projects that affect low-wealth communities.

As of March 2023, 25,500 local governments and 246 Tribal governments had updated hazard mitigation and resilience plans,[111] although not all explicitly address climate risks.[112] Several hundred local jurisdictions have drafted climate action plans that specifically include GHG emissions inventories and reduction targets.[104]

City governments and residents have numerous options to lower GHG emissions and adapt to climate impacts (Table 12.1; Figures 31.1, 32.21). Urban temperature and energy demand can be reduced through physical changes in the built environment. For instance, cities can adopt or initiate certification programs to reduce building emissions, such as using the Phius standard for passive buildings[113] or the International Code Council's 2020 National Green Building Standard.[114] Cities are also using new technologies such as machine learning, remote sensing, social media, and crowdsourced initiatives to gather more climate information and reduce GHG emissions.[115,116,117,118,119,120,121]

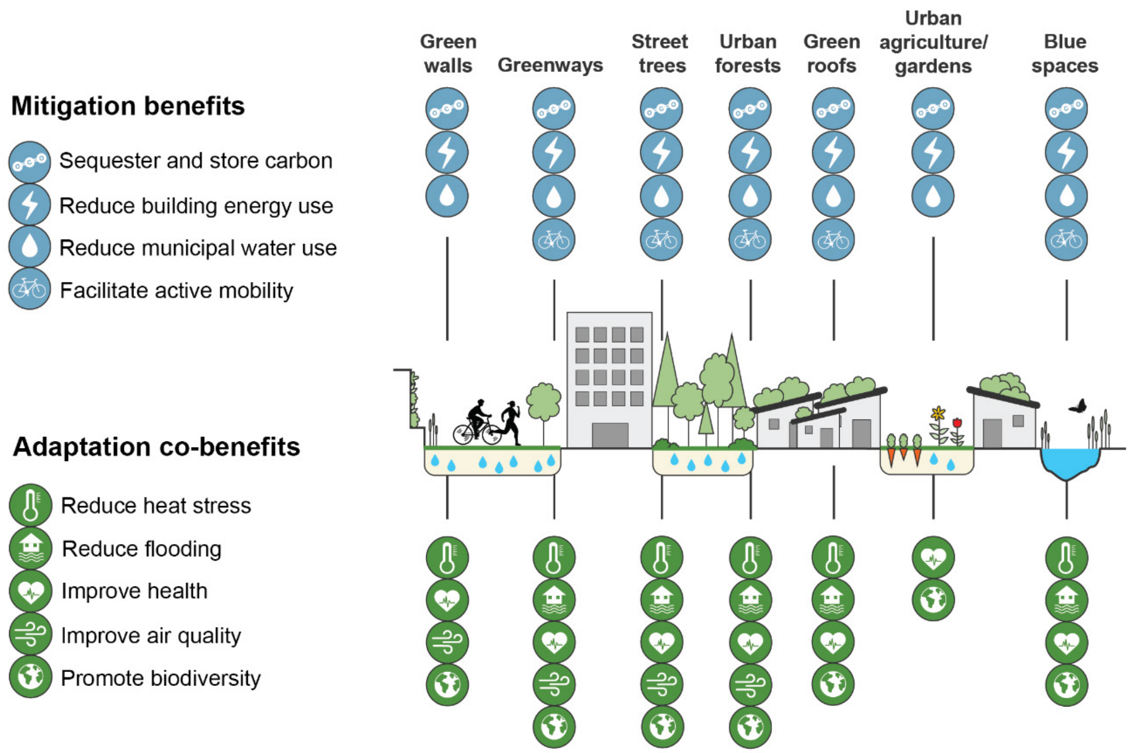
Table 12.1. Examples of Mitigation and Adaptation Options in Cities and Built Environments

These examples of mitigation and adaptation options are drawn from published sources or from other NCA5 chapters. Examples are illustrative and do not represent a comprehensive list. A longer discussion of potential greenhouse gas emissions reductions by mitigation actions can be found in Chapter 32 (see Figure 32.22). Option categories are adapted from Carmin et al. 2015; IPCC 2022, 2022; and Dodman et al. 2022.[122,123,124,125]

Societal Options	**Examples**
Programs and services	Climate action planning, disaster management and response, housing provision, public health services, environmental monitoring
Economics and finance	Social safety nets, insurance products, public finance mechanisms (such as bonds) (Box 12.1)
Communication and decision support	Early warning systems, hazard vulnerability assessments, health awareness training, risk assessments, civic partnerships, regional collaboratives
Building Options	**Examples**
Energy performance	Energy-efficient building retrofits, on- and off-site renewable energy production and use,[126] community/shared solar, energy-efficient lighting and appliances, monitoring and benchmarking,[127] grid-interactive buildings (see Ch. 5)
Codes and standards	Building ventilation;[71] cool and evaporative roofs;[128] vegetated roofs;[129] risk-reduction standards; resilient construction materials;[130,131] electrification, energy efficiency, and other GHG emissions reductions[132]
Land-Use and Ecosystem Options	**Examples**
Gray infrastructure	High albedo/reflective pavements, coastal protection (such as seawalls), dams, flood controls, drainage (see Ch. 9)
Natural, green, and blue infrastructure	Urban ecosystems and biodiversity, street trees, greenery, coastal wetlands and dune systems
Land management	Zoning to reduce impact exposure and support GHG emissions mitigation,[133] co-location of development with low-GHG transportation and technologies,[134] reduced encroachment on natural lands, fire management, land restoration
Migration and relocation	Managed retreat (see Chs. 9, 16, 29, 31)
Resource use	Improved water supply, reduced emissions from waste and wastewater
Urban Transport Options	**Examples**
Electric/fuel-efficient vehicles	Electric vehicle charging networks,[135] purchase and operation incentives,[136,137,138] GHG and air pollution emissions standards (Ch. 13)
Transit, active transport	Active transport infrastructure provision (see Ch. 13), safety and comfort measures

Many of the examples highlighted in Table 12.1 have mitigation and adaptation co-benefits.[139,140,141,142,143] Figure 12.7 illustrates select co-benefits associated with storing and sequestering carbon, preserving habitat and biodiversity, and improving water, air, and soil quality in urban areas (trade-offs are discussed in KM 12.4).

Natural Infrastructure in Cities



Natural infrastructure in cities provides climate mitigation and adaptation benefits.

Figure 12.7. The figure illustrates the potential benefits (in no particular order) of integrating natural infrastructure strategies—also termed green, blue, or nature-based solutions—within the built environment. Nature-based, green, and blue infrastructure options are strategically planned interconnected sets of natural and constructed ecosystems, spaces with vegetation or waterscapes, and other landscape features that provide important greenhouse gas mitigation and climate adaptation functions, as well as improve human well-being, biodiversity, and ecosystem health. This figure shows examples of how urban forests and street trees can sequester and store carbon while simultaneously reducing building energy demand. Reducing municipal water use can provide a mitigation benefit by decreasing energy use in wastewater treatment plants. Adapted with permission from Figure 8.18a of Lwasa et al. 2022.[144]

Natural and nature-based solutions—of both "green" terrestrial vegetation and "blue" marine or aquatic varieties—can have GHG mitigation and climate adaptation co-benefits (Ch. 8).[13,145,146] Many nature-based solutions target extreme heat and flood hazards. Notable examples include the use of urban forestry practices to promote mature-tree shading to reduce urban heat island impacts.[74,77,147] Green roofs and green walls can reduce heat stress, increase stormwater runoff retention,[148] and lower building energy demand.[149,150,151,152] City governments and communities can draw on different green and nature-based solutions—as well as traditional "gray" interventions—ranging from urban parks to green roofs and porous pavements (Figure 12.8).[153] All of these solutions require sufficient investment in design, construction, and long-term maintenance, as well as consideration of trade-offs (e.g., water consumption for tree planting), to realize their full GHG mitigation and/or climate adaptation potential.

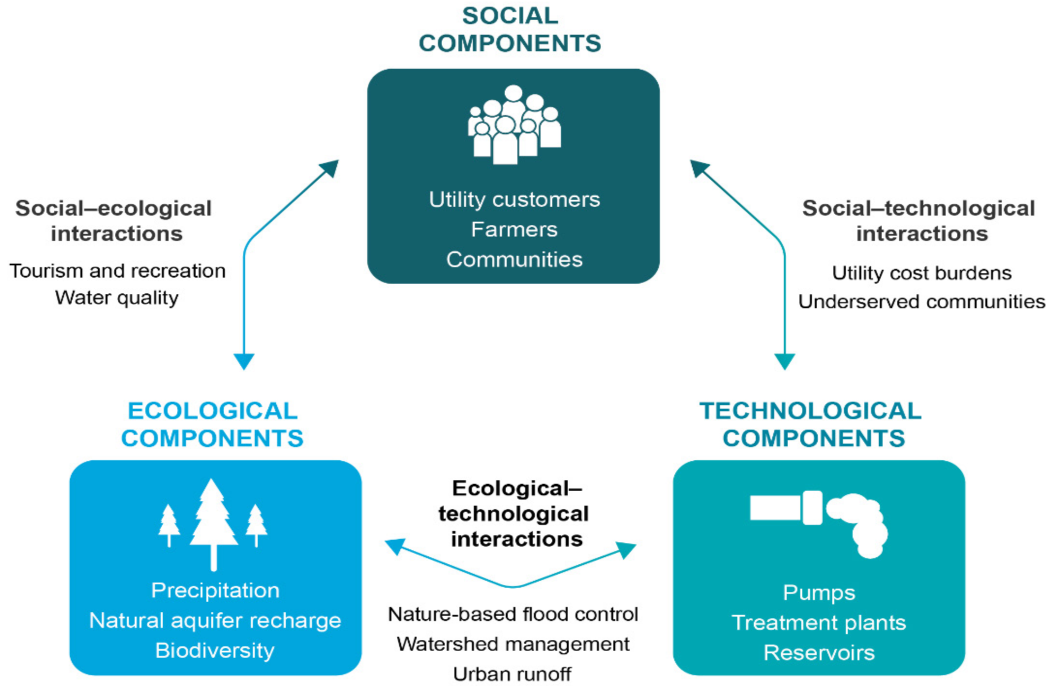
Green, Blue, and Nature-Based Solutions

Cities have diverse options for climate adaptation and mitigation.

Figure 12.8. The figure illustrates various built environment options that consist of green, blue, and nature-based components. Examples, which are for illustrative purposes only, highlight how city governments, communities, and residents can draw on diverse options to adapt to climate impacts, reduce greenhouse gas emissions, and sequester carbon in the built environment: (**a**) remnant forest in Forest Park, Portland, Oregon; (**b**) urban agriculture in Chicago; (**c**) bioswale in Portland, Oregon; (**d**) wetlands at Bayou Bienvenue Wetland Triangle, New Orleans; (**e**) urban park in Boston; (**f**) street trees in Miami; (**g**) green roof in Arlington, Virginia; (**h**) porous pavement in Milwaukee, Wisconsin. Photo credits: (a) Ari Weil via Flickr [CC BY 2.0]; (b) Linda N. via Flickr [CC BY 2.0]; (c, d) ©Annie Marissa Matsler; (e) Kelly Sikkema via Unsplash; (f) Faith Crabtree via Unsplash; (g) Arlington County via Flickr [CC BY-SA 2.0]; (h) Aaron Volkening via Flickr [CC BY 2.0].

Forward-looking designs and governance solutions that consider joint social, ecological, and technological systems (SETS) can better anticipate and respond to future climate change (Figure 12.9).[154,155,156,157,158] Such an approach assesses the vulnerability of urban infrastructure and standardizes design methods to account for future climate risks.[159,160] This approach also highlights the need to think across ecological, social, and technological components of the built environment to provide GHG mitigation or climate adaptation benefits, in addition to equitably protecting public health, safety, and welfare[57,62,154,157] for communities that have been overburdened and underserved based on a historical lack of infrastructure investment.[161] Forward-looking designs can also prevent cities from locking in building technologies, land uses, infrastructure plans, and transportation choices based on past GHG emissions levels (Chs. 13, 32).[60]

Social, Ecological, and Technological Components of Infrastructure



Urban infrastructure involves joint social, ecological, and technological systems. All face risks from climate change individually and in interconnected ways.

Figure 12.9. This figure is an example using water and wastewater systems to highlight the social, ecological, and technological interdependencies of infrastructure. Urban ecosystems (such as waterbodies), built infrastructure (such as pipelines and pumps), and social systems (such as residents) are impacted by climate change individually. Climate change also affects the interactions between these systems, such as when flooding overwhelms pipelines and disrupts service to utilities and/or increases utility costs for consumers. Forward-looking climate actions that consider these interactions—such as how improvements in water infrastructure affect the urban ecosystem and level of access by underserved communities—can lead to more effective and equitable outcomes. Adapted with permission from Markolf et al. 2018.[156]

Despite a growing number of actions, city governments remain slow to mitigate GHG emissions, adapt to climate impacts, and reduce the negative effects of urbanization on the local and regional climate.[74,103,104,162,163,164,165,166] Actions can be hampered by the long duration of planning and decision-making processes,[167,168] ambiguity around what counts as climate action,[165,166] financial constraints (Box 12.1), government staff turnover, difficulties with public buy-in, and gaps in knowledge and awareness.[163,169,170] These barriers constrain the ability of cities to plan for long-term and complex climate challenges (Ch. 18), such as extreme heat and drought,[171] or to effectively evaluate planning progress.[61] Smaller cities and communities generally have fewer resources and less capacity to deal with these challenges.[74,106,107,108]

To bridge these barriers, cities can pursue partnerships with governments at all levels, sectors, Tribal communities, utilities, and local residents (Table 12.2).[106,170,172] One example is the National Building Performance Standards Coalition, a nationwide group that promotes GHG emissions reduction, electrification, and social equity goals in building performance programs.[173] Some cities have appointed chief resilience officers[163] and chief heat officers.[171] Cities also develop relationships with university researchers and city-to-city networks.[107,174,175,176,177] There is growing evidence of policy diffusion and learning across cities, metropolitan regions, and states.[105,178,179,180,181,182,183]

Box 12.1. Financing Climate Action in Local Governments

Local governments can both fund and finance climate actions.[184] Climate change also poses new fiscal risks such as declining revenues and taxes from properties and businesses located in high-risk areas.[79,162,185,186,187] While the number of financial programs, tools, and incentives has grown, structural barriers and lack of capacity remain obstacles for many cities and communities (Ch. 19).[184] External funding options are limited since most states allocate less than 1% of their operating budgets to climate actions, although some notable exceptions include New Hampshire (4.9% in 2015), Delaware (3.3% in 2015–2016), and Missouri (3.1% in 2016).[185] Some cities—such as those that are part of the Southeast Florida Regional Climate Change Compact[188]—are pooling their resources with neighboring jurisdictions, but managing these funds is challenging.[106] Many infrastructure providers also have limited ability to pass on additional costs of climate change through user fees and assessments.[189]

Cities are increasingly utilizing public and private financing models to invest in climate action.[190] Because climate investments are seen to reduce physical and policy risks, they benefit cities by improving their creditworthiness.[191,192] At the same time, a shift toward private financing models results in competing infrastructure obligations and credit constraints, which limit city governments' planning capacities.[193] For instance, overburdened and underinvested communities face increased risk exposure when markets are unwilling to finance local risk-reduction infrastructure.[194] Despite these limitations, financial markets are moving forward with mitigation and adaptation investment strategies and products across diverse asset classes, including green bonds.[195,196,197]

Key Message 12.4

Community-Led Actions Signal a Shift Toward Equitable Climate Governance

There is varying progress in considering who benefits from, or bears the burden of, local climate actions (*very likely*, *high confidence*). The emergence of local and community-led approaches—coupled with increasing collaboration among city, Tribal, state, and federal governments—indicates a movement toward more inclusive planning and implementation of climate actions (*likely, high confidence*).

Urban planning has made progress on including overburdened and underinvested communities, including those that have been historically excluded from decision-making. However, progress on advancing social equity and inclusion has been slow, uneven, and lacking in scale.[166,198,199,200] Approaches for evaluating the social impact of climate actions are also generally lacking (KM 31.3).[201,202,203] These gaps raise questions about not only the efficiency and effectiveness of local planning and investments but also the distribution of the cost burdens associated with climate actions.[204]

Cities are confronting difficult decisions around how to fairly and equitably distribute the benefits and burdens of GHG mitigation and climate adaptation investments and actions. Social equity and justice are important considerations when evaluating potential trade-offs between GHG mitigation, climate adaptation, and urban development. For example, floodplain restoration can reduce property damage and promote development in adjacent areas,[140,205] but it can also shift flood risks from one location to another.[206,207] If risks are shifted to burden frontline communities, low-wealth populations sometimes relocate to equally high-risk areas.[208] Similarly, urban heat planning can reduce excess heat stress and promote physical comfort in indoor and outdoor spaces by retrofitting buildings and by designing active landscapes.[165,209,210,211,212] While high-quality building retrofits can improve comfort and indoor air quality, poor-quality building retrofits that simply seal off buildings to minimize infiltration can worsen indoor air quality by creating higher levels of trapped indoor air pollutants.[213] The health effects of indoor air pollution on building occupants pose additional risks to groups that have previously received poorer healthcare services and have lived in historically redlined neighborhoods.[214,215]

Just as with traditional gray infrastructure, the political, economic, and governance processes behind implementing green and blue infrastructure and nature-based solutions can result in social inequity and exclusion, although more research is needed to empirically measure how and how much these inequities and exclusions occur. For instance, efforts to cool streets by planting trees or creating flood barriers that also serve as parks can increase the amenity value of properties and lead to gentrification and displacement.[153,216] Climate gentrification may also arise from greater consumer demand for housing in lower-risk areas.[217] This highlights the need to address trade-offs between responding to climate change and social equity.

Pursuing inclusive and equitable climate governance can be a way to combat historic underinvestment and limited access to efficient, healthy, and affordable services and infrastructure in cities. Grassroots, community-led, and participatory actions are being documented across some cities, many of which draw on a city's civic and social infrastructure as well as residents' interest in pursuing zero-carbon, climate-resilient, and socially equitable development (Table 12.2). These actions tend to prioritize distributional strategies, such as sharing benefits and burdens more fairly, rather than inclusive efforts that recognize the needs, values, and knowledge of communities that have been historically excluded from decision-making or future generations more generally.[169,178,199,204,218,219]

Table 12.2. Examples of Local and Community-Led Actions

Examples of local and community-led actions are sourced from an assessment of published examples. Cities, local communities, and residents can draw on more community-led actions and forward-looking planning processes, as well as pursue collaborations with other city, Tribal, state, and federal governments. Examples are illustrative and do not represent a comprehensive list.

Category	Examples
Community-Led Planning and Implementation	• Neighborhood heat action plans co-created with the community[220] • Neighborhood resilience hubs that support community development and resources for emergency response[221] • Virtual platforms to connect overburdened communities across the country
Inclusive and Forward-Looking Urban Planning	• Equity training for city staff and decision-makers, e.g., the US Department of Housing and Urban Development Citizen Participation and Equitable Engagement Toolkit[222] • Plans with focus on youth, gender, and racial inclusion[169] • Reallocation of funds to support community engagement • Scenario planning,[112,223] games,[175,224] and future visioning[225]
Multilevel Collaboration	• Cross-Tribal networks[226] • Collaboration with nongovernmental organizations[227] • Creation of new leadership and coordinating roles[171] • Expansion of public participation opportunities[169,218]

Competing resource, capacity, and policy demands from across other local, Tribal, state, and federal entities can constrain the scope, scale, and pace of efforts to further fair and equitable GHG mitigation and climate adaptation. Such challenges could be addressed through future actions that prioritize long-term planning, new technologies, and radically different infrastructure designs, as well as through better understanding of how shifts in society and culture can help create a more socially just, inclusive, and equitable built environment.

Traceable Accounts

Process Description

Chapter 12 authors were selected according to three criteria. The first criterion was necessary disciplinary expertise as identified through the public call for comment on the Fifth National Climate Assessment (NCA5) draft prospectus—which called for social scientists, engineers, economists, architects, and urban ecologists/climate scientists—together with an initial visioning exercise by the chapter lead author based on reflections of key gaps and opportunities highlighted in NCA4. The second criterion was representation of diverse institutional affiliations, including those from the Federal Government and academia, as well as those with practitioner experience. A final criterion was recognition of diverse life and career stages, personal histories and backgrounds, and regional and geographic representation. The application of all three criteria led chapter leadership to select 11 individuals (three federal and eight academic) who encompassed early-career and senior professional stages and represented diverse disciplinary, personal, and geographical backgrounds.

The authors collected references through extensive searches on web platforms, including Scopus, Web of Science, and Google Scholar. The search focused on peer-reviewed scientific literature, working papers, and technical reports published since NCA4 to identify core areas of knowledge advancement since 2018. The literature search focused on eight topical areas: 1) urban and regional climate models and scenarios; 2) physical impacts and risks to the built environment; 3) sector-specific economic and human costs in the built environment; 4) social, ecological, and spatial vulnerabilities in the urban environment; 5) urban mitigation and adaptation options; 6) urban social equity and justice; 7) urban governance and decision-making; and 8) metrics and indicators. This led to a literature database of more than 600 sources. The author team then evaluated the sources to generate key themes and messages, which were then used to compile the four Key Message sections.

The public engagement process for Chapter 12 occurred in two phases. First, the chapter Zero Order Draft (ZOD) was publicly released through a Federal Register announcement in January 2022. The ZOD then proceeded through a six-week public commenting period. Detailed responses to these public comments were completed by the deadline of May 27, 2022. Second, the chapter ZOD went through one public engagement workshop on January 14, 2022. The workshop was attended by approximately 160 participants representing community groups, private-sector stakeholders, interested individuals, academic institutions, and nonprofits, as well as government scientists across local, state, and federal levels. The objective of the workshop was to provide participants an opportunity to exchange ideas with the author team on chapter key topics, share resources, and give feedback on issues of importance to the chapter topics.

Efforts to synthesize and assess literature were conducted in a collaborative and iterative manner, with extensive redrafting and revision efforts by all chapter authors. The approach was guided by the extensive literature database as well as chapter authors' own disciplinary expertise. The chapter team held weekly meetings throughout the drafting phase, with specific Key Message teams separately meeting nearly as frequently to discuss, draft, and revise specific sections of the chapter text. Additionally, extensive dialogues with other NCA5 chapter authors and 17 technical contributors held throughout 2022 and the spring of 2023 helped to ensure the comprehensiveness and representativeness of topics covered in the chapter.

Finally, the chapter Fourth Order Draft (4OD) went through a 12-week public review and commenting period between November 2022 and January 2023. This was accompanied by an extensive peer review conducted by the National Academies of Sciences, Engineering, and Medicine (NASEM). Detailed responses to both public and NASEM comments on the chapter 4OD were completed and approved by the chapter's review editor by April 28, 2023.

Key Message 12.1

Urban Areas Are Major Drivers of Climate Change

Description of Evidence Base

The evidence base for Key Message 12.1 draws on an extensive literature—based on diverse quantitative, geospatial, remote sensing, and different modeling methodologies—assessing how land-use, economic development, and human settlement patterns have affected and will continue to affect local and regional climate processes. Recent research highlights how the consumption of food, energy, and materials in urban areas is a driver of global climate change.[1,2,3] Key Message 12.1 builds on established assessments produced in the *Second State of the Carbon Cycle Report* (SOCCR2), published in 2018. It specifically builds on Chapter 4, "Understanding Urban Carbon Fluxes," in SOCCR2[5] by highlighting the science behind the role of urban areas as primary sources (i.e., responsible for a large proportion) of greenhouse gas (GHG) emissions across North America.[6]

Key Message 12.1 draws on scientific evidence behind cities as drivers of climate change. A significant amount of research across the fields of urban ecology, energy studies, climate modeling, physical geography, and engineering shows that urban and suburban areas contribute approximately 75% of total global GHG emissions,[1] although this is distributed unequally, as the 100 largest cities account for 18% of global GHG emissions.[3] As in the literature, Key Message 12.1 categorizes GHG emissions into Scope 1, 2, or 3 emissions. Scope 1 and 2 emissions refer to direct GHG emissions associated with fuel combustion in industrial or transportation sectors and direct emissions attributed to the energy for heating and cooling, respectively.[4,5] The scientific evidence additionally illustrates various approaches to accounting for indirect emissions—that is, Scope 3 emissions—which are incurred through the purchase of goods and services, distribution of goods and services through supply chains, and waste generated in operations of built environment assets. Studies note that across all these different forms of emissions, it is necessary to think beyond the physical boundaries of urban areas.[3]

Major Uncertainties and Research Gaps

There are uncertainties pertaining to the calculation of different sources of GHG emissions within the built environment, as well as difficulties in geographically bounding the "urban" area.[4,5] Comprehensive accounting of GHG emissions from cities and urban systems includes Scope 1, 2, and 3 emissions, but the data challenges of consistent attribution of emissions to individual cities are very high.[3,9] For example, there is evidence that cities are underreporting their own GHG emissions due to incomplete or missing data.[2] Attributing GHG emissions to cities and suburban areas requires apportioning emissions across multiple systems with multiple conceptual boundaries, including, but not limited to, spatial and territorial boundaries; useful lifetime and utilization of particular built environment systems; fixed and variable costs; ownership and decision-making; embodied emissions in material consumption and flows; and additional indirect effects and interactions between stages of use.

As in all forecasting, projecting future carbon emissions from cities and urban systems is inherently challenging because of considerable uncertainty about future trends and their interactions. Research into where and how the urban population will grow; what technologies will be available and put into use; and how people decide to build, maintain, and live within cities all depend on the interaction of future economic, social, technological, policy, and climate trends that cannot be known with complete certainty.

Description of Confidence and Likelihood

The available recent scientific evidence documenting the role of built environment systems and urban areas as drivers of climate change is extensive (e.g., Gurney et al. 2018[5]), hence the attribution of *very high confidence*. The scientific evidence attributing GHG emissions to land-use change, economic and industrial development, and human settlement patterns[1,2,3,12,13,14,15,16,17] is *virtually certain*. This likelihood assessment reflects a near scientific consensus that urban and suburban areas—through fossil fuel–driven industrial production, economic growth, transportation, and human consumption—contribute a majority of total global GHG emissions.

Key Message 12.2

Attributes of the Built Environment Exacerbate Climate Impacts, Risks, and Vulnerabilities

Description of Evidence Base

The evidence base for Key Message 12.2 draws on the extensive scientific literature documenting both observed and projected future natural, physical, and atmospheric trends associated with the effects of climate change on the built environment. There is broad scientific consensus that local and regional climate change in and near urban areas across the country will be affected by changes in land use, development, and human settlement patterns.[5,31,32,33] The Key Message assesses the extensive literature on impacts to surface and ambient air temperature,[12,13,14,15,16,17] local and regional humidity,[18,19] wind patterns,[20] precipitation,[21,22,23] flooding,[24,25,26] dispersion of air pollutants,[22,27] and intensity of storm surges and sea level rise.[28]

Literature from the fields of urban planning, geography, ecology, architecture, and engineering all note that the design, form, and mass of buildings and the configuration of streets and open spaces, together with their interaction, have a profound influence on urban climates.[5,31,32,33] In particular, urban systems directly add sensible heat to the environment via radiant heat and heat conductance from buildings,[35] and this is illustrated in Figures 12.4 and 12.5. There is significant research noting how extreme weather events such as landfalling hurricanes, heatwaves, and storm surges attributed to climate change have increasingly affected densely populated urban communities and their built infrastructure, as well as the ecosystems on which they depend.[20]

Key Message 12.2 assesses the scientific evidence on how climate change is posing risks to built environment systems and urban communities. Extensive evidence documents the increasing number of disasters as well as their increasing damage costs (Figure A4.5)[87] Recent scientific efforts—such as Martinich and Crimmins (2019), CBO (2019), and EPA (2021)[85,86,228]—seek to quantify the potential damages across diverse built environments, including the property and housing sectors, for projections based on multiple scenarios (e.g., RCP4.5 and RCP8.5 in the examples noted above) to the end of the 21st century. Sea level rise and increases in the frequency of hot days and extreme temperatures are key climate risks for cities documented extensively in the literature.

Key Message 12.2 also assesses US dollar estimates of projected annual damages in 2090 to different built environment sectors. Such quantitative estimates vary widely depending on the scenario applied to calculate future costs. As consistent with recent IPCC Assessment Reports and federal guidance, this chapter applies commonly used scenarios, including SSP2-4.5, which corresponds to a mid-range path of GHG emissions, and SSP5-8.5, which represents a high-end resource-intensive development path (KM 3.3).[89,229] Although there continues to be debate on the likelihood of a high-end GHG emissions scenario,[88] it is still common practice to quantify the full range of potential damages to infrastructure to support decision-making, especially for those tasked with making more near-term decisions (2050 or sooner).[90]

The Key Message assesses scientific research into the amplification of risks across built environment systems through compounding and cascading events.[37,38,39,40] As most infrastructure systems are designed for current climate conditions and are not built to withstand future climate projections, extensive evidence documents how the additional loads and stressors on infrastructure systems attributed to climate change—

especially when combined with the operational constraints of infrastructure—lead to cascading impacts across the built environment and connected systems.[39] The extensive evidence assessed in Key Message 12.2 also shows how cities and urban systems will spatially concentrate risks due to current levels of infrastructure deficits, unequal exposure of people and assets, and high levels of socioeconomic inequalities.[85,87] There is clear evidence that climate change also poses substantial financial risks to real estate assets,[230] while low-wealth communities are often less able to respond to climate change impacts or recover from exposure to extreme temperatures and natural disasters.[69,70] This Key Message responds to a larger (and growing) literature assessing climate vulnerability of urban residents,[70,215,219] particularly noting that frontline, overburdened, and low-wealth communities are often disproportionately affected by climate extremes.

Multiple emerging stressors highlight additional intersecting vulnerabilities in the urban built environment. Research has documented an increasing general awareness of climate risks by infrastructure managers, property developers, stewards of heritage sites, and urban residents.[93,94,95,100,103] This increasing awareness about climate risks is associated with less housing construction in high-risk areas. Key Message 12.2 therefore draws on the expansion in professional training, certification, guidance, assessment of existing land use, building codes and standards, risk communication, and efforts to define climate temporal and spatial resolution information needs.

Major Uncertainties and Research Gaps

The speed, geographic distribution, and extent to which key climate stressors will change over the intended service life of the built environment is uncertain, as is the burden of these impacts on urban communities. Changes in stressors and levels of burden are already observed and documented,[37,38,39,40] but uncertainties depend on the rate of global climate change as well as regional and many local and site-specific factors, such as changes in urban population, social inequalities, and the broader economy.

It is also unknown how extensive changes in engineering design practices and management of infrastructure systems will change in response to—and in efforts to adapt to—changing climate stressors. Engineering and architectural design professionals typically focus on weather extremes,[48,54,55,56,57,58] which are projected with more uncertainty compared to changes in average conditions. Actions to account for future climate impacts depend on the ways decision-makers evaluate the costs and benefits of implementing different infrastructure designs. It is unknown how different infrastructure systems will function under changing climate conditions and what the anticipated effects on urban systems and cities will be. Another gap in understanding is whether the pace and scale of changes in architectural and engineering design practice associated with the built environment and infrastructure systems are sufficient to address the pace and scale of expected climate change impacts.

Finally, there remain gaps in understanding of the market response in locations currently exposed and sensitive to climate shocks and stressors. The extent to which US financial markets can pursue innovations that provide anticipatory investment and appraisal services within the global market is unknown. Similarly, the way in which the design and construction market can innovate to provide these services to the global market is unknown.

Description of Confidence and Likelihood

There is scientific consensus that the increased rates of urbanization have significantly transformed the land use and land cover of cities across the US, contributing to the general degradation of the urban and regional climates.[31,32] The extensive scientific evidence evaluates how, for many urban areas, these processes will be significant and potentially dominant drivers of changes of urban climate over the remainder of this century.[34] The evidence therefore points to *very high confidence* in the role of climate change in exacerbating and amplifying loads on the built environment as well as imposing additional burdens on urban communities and infrastructure systems. There is also scientific consensus on how climate change poses additional risks to infrastructure systems. The literature describes, in *virtually certain* terms, that cities concentrate risks given current levels of infrastructure deficits, unequal exposure of people and assets, and high levels of socioeconomic inequalities.[37,38,39,40] Climate impacts are *virtually certain* to disproportionately burden low-wealth communities, groups that have been historically excluded from decision-making, and individuals with lower educational access.[69,70,71] The extensiveness of scientific evidence supporting these observations therefore gives the third statement of this Key Message an assessment of *very high confidence*.

Key Message 12.3

Urban Environments Create Opportunities for Climate Mitigation and Adaptation

Description of Evidence Base

Key Message 12.3 assesses scientific evidence of observed progress in mitigating GHG emissions and adapting to adverse climate impacts among cities across the country. Research shows that the technology or changes necessary for carbon neutrality are generally available and known to cities. Research has highlighted the growing number of cities that recognize the need to establish GHG-reduction targets; however, this research also shows that many lag behind these targets in implementation[104,105] or have broad efforts to reduce GHG emissions that tend to be similar. Since NCA4, more scientific evidence has pointed to cities planning to build resilience and adapt to climate change.[111,112] Research continues to note that efforts to enable GHG mitigation and climate adaptation, as well as efforts to realize their co-benefits remain difficult to implement.[162]

Recent scientific evidence documents how an increasing number of states and cities are considering climate risks in their relevant codes, standards, and policies, although such progress is not yet sufficient. For instance, there are emerging building standards, codes, and designs to enable forward-looking and anticipatory approaches to planning and designing for climate change across different built environment and infrastructure types.[62,154,157] Many city governments are also exploring strategies to protect infrastructure against sea level rise in the near and long term.

Example actions that are rapidly gaining popularity are nature-based solutions,[13,145,146,153] including those illustrated in Figures 12.7 and 12.8. Since NCA4, there has been a marked increase in the scientific literature documenting climate actions that utilize natural materials and processes to help protect infrastructure against different kinds of extreme risk.[146] An increasing number of quantitative, qualitative, and case study–based research has focused on nature-based solutions such as marshes, mangroves, dunes, beach nourishment, and several other types of natural structures (see Figure 12.8). Table 12.1 synthesizes some examples of GHG mitigation and climate adaptation actions in cities and the built environment that are sourced from published examples or from other NCA5 chapters.

Key Message 12.3 assesses the scientific evidence in quantifying a range of economic, health, and environmental co-benefits from mitigation and adaptation actions in cities and built environment systems.[139,141] Since NCA4, there is now a better understanding of how climate co-benefits are distributed across a community—in particular among overburdened and underserved communities—and how they can help to reduce gaps in uptake by increasing adaptive capacity while addressing historical disparities.[142,143]

Major Uncertainties and Research Gaps

Despite recent advances in scientific research on the different ways climate change efforts are integrated into planning processes, land-use controls, building designs, and financing mechanisms, there is still a lot to learn about how people modify their activity patterns in response to weather and climate. The scientific evidence on attributing individual and collective behavior change to specific experiences of climate change is still uncertain. Research gaps also exist in understanding specific policy changes in response to climate priorities, including the role of leadership, learning, and diffusion of ideas. Much of this research is based on single-case studies that are difficult to scale up and generalize. Of the larger-scale quantitative analyses that are available, many continue to show varying explanations. This research highlights different challenges. For example, one challenge is the definitional ambiguity regarding what counts as climate action.[163,165,166] Meerow and Keith (2022)[74] also document barriers related to human and financial resources and political will, while Barrage and Furst (2019)[103] note the prevalence of climate denialism.

Description of Confidence and Likelihood

Extensive scientific research representing diverse disciplines reflects *high confidence* in the continued growth in the number of city-level GHG emissions mitigation and climate adaptation plans found across the country. There has also been a large increase in scientific research documenting the drivers of climate action uptake in cities, with many quantitative and qualitative studies representing diverse regions and geographies.[105,179,180,181,182,183]

Despite the growth in number of plans in recent years, the empirical evidence also shows that the implementation of mitigation and adaptation actions in cities and local governments remains behind. As such, even though there is near certainty that city-level climate plans are being drafted and released, the data show that it is only *likely* that city governments and urban residents are employing an increasing variety of tools and strategies to enable implementation on the ground. Research notes how this difference can be attributed to the reality that planning processes and implementation of efforts are context-dependent, meaning the drivers and incentives of action are tied to local political, social, economic, and ecological fac tors.[74,103,104,162,163,164,165,166] Therefore, given the assessment of this emerging literature, it is *virtually certain* and there is *very high confidence* that the scope, scale, and pace of actions are not enough given the magnitude of observed and projected climate impacts of built environments and urban systems.[74,103,104,162,163,164,165,166]

Key Message 12.4

Community-Led Actions Signal a Shift Toward Equitable Climate Governance

Description of Evidence Base

The scientific evidence on urban climate change efforts highlights a growing concern over how their potential benefits and burdens will be borne by society.[169,178,199,204,219] In response, Key Message 12.4 assesses scientific evidence on the social equity implications of climate change planning efforts. Recently there have been increasing efforts to document the inherent inequalities in how climate actions are planned, designed, and implemented in local contexts, especially where cities across the country already see high levels of social and economic inequality.[166,169,198,199,200] More research on community-based, community-led, and bottom-up strategies has also emerged to better recognize the needs of urban frontline and overburdened communities,[178] including Black, Hispanic/Latino/Latinx, Pacific Islander, Alaska Native, and Indigenous communities,[226] as well as low-wealth groups.

Key Message 12.4 documents moderate but growing scientific evidence of inclusive planning and implementation approaches.[220,221] For some overburdened communities, the pursuit of equitable climate action can be a strategy to address historic underinvestments and to mobilize access to more healthcare and affordable urban services and infrastructure. Fiack et al. (2021)[204] find that social equity climate adaptation is present on the local level, based on 22 of 100 largest cities in the country. Many local governments are also actively collaborating with local stakeholders[106,107] for a wide variety of climate impacts, from extreme heat to sea level rise.

Table 12.2 illustrates several examples of shifts in urban climate governance toward local and community-led planning and implementation. Local governments that embed equity into their GHG mitigation and climate adaptation plans can focus on transforming process and shifting power and capacities to communities. Much scientific evidence shows that climate action plans are created and implemented when cities experience greater climate vulnerability and have active resident support and where governments have other related plans in place.[107,181] Still, a lot of scientific evidence suggests that participatory approaches remain challenging. For example, Sarzynski (2018)[218] showed how, in Baltimore, resilience has been limited to government actions and the city has had difficulty getting the community buy into their responsibility. Stults and Larsen (2020),[112] in analyzing 44 US local climate adaptation plans, found that none used local scenario planning or robust strategies.

Major Uncertainties and Research Gaps

For Key Message 12.4, the major sources of uncertainty pertain to the specific drivers of inequality (especially in urban communities that experience housing insecurity, lower pay, and lower socioeconomic indicators) associated with the implementation of specific GHG emissions mitigation and climate adaptation actions, as well as the uncertainties surrounding the long-term social impacts of climate-driven inequalities. Although there is ample empirical research documenting how climate change decision-making processes often do not consider frontline populations, overburdened communities, Indigenous Peoples, and groups historically excluded from decision-making,[166,169,198,199,200] the literature disagrees on whether specific climate change actions directly contribute to producing more burden on particular groups, such as through displacement. There is also considerable uncertainty around whether and how growing considerations of inclusion and fairness actually lead to more just and equitable outcomes on the ground.

Description of Confidence and Likelihood

Despite a notable shift in scientific research toward socially equitable and fair climate change actions, Key Message 12.4 notes with *high confidence* that actual progress in inclusive planning and implementation on the ground remains variable.[166,198,199,200] This assessment is based on scientific research published since NCA4 showing the increasing uptake of social equity and justice ideas in climate change plans and policies across cities and regions. Many of these plans and policies identify socioeconomic vulnerabilities and heightened risks experienced by frontline communities, but research shows that they fall short in incorporating social equity and justice priorities into the design and implementation of mitigation and adaptation efforts.[169,178,199,204,219] Some notable exceptions include larger cities or cities that have recent experience with extreme impacts, hence the assessment that implementation remains variable across the US.

Over the past several years, research in social sciences has broadly critiqued the way city-level plans have approached social equity and inclusion in climate plans. Research shows progress in documenting how climate change decision-making processes *very likely* do not include historically excluded populations, overburdened communities, and Indigenous Peoples. This research also notes the roles of civil society, nongovernmental organizations, social movements, and others in enabling more inclusive climate actions. Similarly, the literature documents an increasing number of partnerships across levels of government and between sectors to support decision-making and implementation.[106,107,169,170,171,172,174,175,176,177,218,227] With this growing body of literature, the Key Message notes with *high confidence* the growing number of participatory, community-led, and broadly inclusive decision-making arrangements found across the US, as well as how these arrangements are *likely* being considered in conjunction with traditional planning processes.

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